Emerging-Economy State and International Policy Studies

Jonna P. Estudillo
Yoko Kijima
Tetsushi Sonobe *Editors*

Agricultural Development in Asia and Africa

Essays in Honor of Keijiro Otsuka

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Emerging-Economy State and International Policy Studies

This is the first series to highlight research into the processes and impacts of the state building and economic development of developing countries in the non-Western World that have recently come to influence global economy and governance. It offers a broad and interactive forum for discussions about the challenges of these countries and the responses of other countries to their rise. The term 'emerging-economy state,' a part of the series title, or its shorthand 'emerging states,' is intended to promote dialogues between economists who have discussed policy problems faced by 'emerging-market economies' and scholars in political science and international relations who have discussed 'modern state formation.' Many emerging states are still in the middle-income status and not immune from the risk of falling into the middle-income trap. The manner of their external engagement is different from that of the high-income countries. Their rise has increased the uncertainty surrounding the world. To reduce the uncertainty, good understanding of their purpose of politics and state capacity as well as their economies and societies would be required. Although the emerging states are far from homogenous, viewing them as a type of countries would force us into understand better the similarity and differences among the emerging states and those between them and the high-income countries, which would in turn to help countries to ensure peace and prosperity. The series welcomes policy studies of empirical, historical, or theoretical nature from a micro, macro, or global point of view. It accepts, but does not call for, interdisciplinary studies. Instead, it aims to promote transdisciplinary dialogues among a variety of disciplines, including but not limited to area studies, economics, history, international relations, and political science. Relevant topics include emerging states' economic policies, social policies, and politics, their external engagement, ensuing policy reactions of other countries, ensuing social changes in different parts of the world, and cooperation between the emerging states and other countries to achieve the Sustainable Development Goals (SDGs). The series welcomes both monographs and edited volumes that are accessible to academics and interested general readers.

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Editors

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Dedicated to Professor Keijiro Otsuka

Foreword

After several major famines in the 1950s and 1960s, the main focus of food and agricultural development during the next two decades was to achieve food security and prevent hunger in developing countries. These challenges spurred the Green Revolution, characterized by the adoption of high-yielding wheat and rice varieties, which doubled or even tripled crop yields in a matter of 20 years, prevented large-scale famine, and laid down a solid foundation for the whole economy to take off.

The Green Revolution and its impact on income, poverty, and malnutrition in Asia and Africa are the main focus of this Festschrift book designed to honor Prof. Keijiro Otsuka's retirement.

This volume is authored by several accomplished scholars. The book chapters cover a wide range of issues, including the Green Revolution, land tenure and sustainable management of natural resources, the transformation of rural economies, and emerging issues, such as high-value agriculture and women's inclusion in agricultural sector growth. Although the book covers mostly Asia and Africa, it has global implications. Professor Otsuka is a pioneer of research on many issues related to agricultural development. Thus, the issues covered in the book are inspired by Prof. Otsuka's past work.

Looking toward the future, escalating and new challenges are expected, for example, climate change, regional conflict (including the current Russian-Ukraine crisis), degrading natural resource bases, persistent hunger, micronutrient deficiency, and rising overweight and obesity. These require agriculture and food systems to be transformed to tackle these challenges. The current volume will inspire many to continue looking for solutions like what this volume and Prof. Otsuka have done with regard to the Green Revolution.

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Preface

This volume is a compilation of essays written by top researchers on the topics that Prof. Keijiro Otsuka has been working on in his career. The authors have had either a chance to work with him on a research project or are simply his good friends in the profession. The essays were written in a way easily understandable by people in many different disciplines.

The aim of the volume is to identify the pathways of agricultural development in Asia and Africa. It evaluates whether Africa is following in Asia's footprints. This volume has a resounding message that Africa is becoming the next Asia as it benefits from the earlier experience of Asia in agricultural and overall development. Africa has followed the Asian pathways: borrowed technology from abroad; did adaptive research in rice farming (modern seeds, fertilizer, and mechanical technologies); secured property rights on natural resources; adopted information and communication technologies (ICTs); invested in human capital, including training; and spread high-value revolution. Borrowed technology from abroad and adaptive research have jump-started the Asian-style Green Revolution in rice farming in favorable production environments in Africa and are expected to spread to other areas.

In Asia, the Green Revolution resulted in higher food production and lower food prices that led to deterioration in terms of trade of agriculture (i.e., the decline in the price of farm goods relative to nonfarm goods), leading to rapid structural transformation. The most striking feature of structural transformation is the secular decline in the share of agriculture and the corresponding increase in the combined share of industry and services, whether measured in terms of output or employment. Structural transformation in Asia has been the primary driver of the region's rising income and geographic movement of capital and labor.

Asia was successful because it used agriculture as the engine of growth. Since the Green Revolution has started in Africa, we expect dynamic agriculture to follow soon, driving structural transformation and overall development in Africa. Borrowed technology and adaptive research serve as important keys to a modern agriculture. Professor Otsuka has been helping in this endeavor when he served on the Board of Trustees of the International Rice Research Institute (IRRI) as a member and subsequently as Chair and Senior Adviser to the Director General between 2002 and 2010. His first agenda was to send IRRI scientists to rice research institutes in Africa and allow African scientists to visit IRRI. Scientific exchanges of this kind are not new. It served as an important process in the whole gamut of strategic processes in Asia in the early stage of agricultural development. Professor Otsuka's dream is to have "a new Asia in Africa." Empirical evidence in this volume shows that it is not an impossible dream at all.

The volume editors would like to thank the chapter writers for their valuable contribution to this volume. Avril Adrianne D. Madrid provided excellent services in copyediting, helping from the book proposal to publishing. Laarni Revilla, Katrina Miradora, Jan Chael Pon-An, and Camille Garcia Dumalaog helped compile data, make descriptive tables, and draw graphs.

Above all, we dedicate this volume to Prof. Keijiro Otsuka, who continues to guide our journey in development economics.

Quezon City, Philippines — Jonna P. Estudillo
Tokyo, Japan — Yoko Kijima
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The Making of a Development Economist: Professor Keijiro Otsuka

Born in 1948 and raised in Nerima Ward, Tokyo, Prof. Keijiro Otsuka (fondly called by many as Kei) was never the typical metropolitan boy. Aside from being a respected development economist, he is also a horticulturist and a forester. On the 12th floor of the National Graduate Institute for Policy Studies (GRIPS) campus in Roppongi, Tokyo, where Kei taught for 15 years, he propagated orchids and basil, and in his home in Nerima, he has plenty of bonsai, cherry blossoms, and fruit trees. As a forester, even with the strict quarantine control in Narita Airport, he successfully brought the titan baobab tree from Africa and banana and mango trees from tropical Asia into Japan. When he was still at GRIPS, the meeting room on the 12th floor looked like a "mini forest," to the delight of students and faculty members. When he left GRIPS, the university administration decided to adopt the banana trees as members of the GRIPS family, planted them in classic Japanese-style pots, and placed them on the ground floor right in front of the student office. A few months later, the banana tree bore its first fruit. Kei left GRIPS with the baobab and mango trees which grow as majestically as in Africa. Surprisingly, all the trees are able to withstand the cold Japanese winters. According to him, three mango fruits are almost ripe, his first harvest.

At the time of the writing of this Festschrift, Kei is a professor of Development Economics at the Graduate School of Economics, Kobe University, and a chief senior researcher at the Institute of Developing Economies in Tokyo. He received a PhD in economics from the University of Chicago in 1979. His dissertation adviser was Prof. Theodore W. Schultz, who was awarded the Nobel Prize in Economics in 1979 for his pioneering research on the problems of developing countries. When Kei entered the Department of Economics at the University of Chicago, he had received an admission letter but had no financial support. Professor Schultz decided to donate USD 5,200 from his personal funds to the department as scholarship funds for Kei through a request from Prof. Yujiro Hayami. Kei's wife, Michiko Otsuka (known to many as "Kari"), typed her dissertation on an old battered typewriter.

Kei finished his MA in Economics at the Tokyo Metropolitan University, where he worked under the supervision of his lifetime mentor, Prof. Yujiro Hayami. The Hayami-Otsuka tandem had gained prominence in development economics internationally and in Japan because of their extensive works on rural economies in tropical Asia. Kei finished his BA in Agricultural Sciences at Hokkaido University, where he developed his "team player" attitude, which enabled him to work with a large number of researchers, both Japanese and foreign. He joined the Hokkaido University rowing club and remained active in the club even after finishing his undergraduate schooling. He occasionally meets the rowing club members for a "bottle of beer" to remember the good old days in the deep blue sea.

Before joining Kobe University, he was a Professor at GRIPS from 2001 to 2016. Formerly, he was a Chairman of the International Rice Research Institute Board of Trustees from 2004 to 2007 and President of the International Association of Agricultural Economists (IAAE) from 2009 to 2012. He is an honorary life member of IAAE, a fellow of the Agricultural and Applied Economics Association, and a distinguished fellow of the African Association of Agricultural Economists. To date, he has authored or coedited 27 books, 5 special volumes, 146 journal papers, 86 book chapters, 26 comments and reports, and 12 book reviews. He served in nine editorial positions in various international journals and received 15 awards; the most important ones are the Order of the Sacred Treasure, Gold and Silver Star in 2021 conferred by Emperor Naruhito; the Medal of Honor with Purple Ribbon bestowed by Emperor Akihito in 2010; and the 14th President Award of the Japan International Cooperation Agency (JICA). He was elected a member of the prestigious Japan Academy in 2018.

His works center on agricultural and industrial development in Asia and Africa. His focus is on the transferability of the Asian rice Green Revolution to Sub-Saharan Africa, how contract farming could be utilized to expand high-value agriculture, and the dynamic roles of the industrial cluster and foreign direct investment in the development of local industries.

Above all of these, his most valuable gems are his students. He is often quoted as saying that the most brilliant strategies in conducting good empirical research in development economics are to study microeconomics and econometrics seriously and to have a good grasp of reality by conducting field surveys. He practices "pedestrian economics," which is the art of observing rural communities and gathering information by walking around the villages and towns. Through pedestrian economics, Kei was able to produce a huge number of scientific works, many of them cutting-edge in his field. Undoubtedly, many scholars have benefited from his wit and deep knowledge of rural economies. The editors and contributors to this Festschrift extend their deepest gratitude for his mentorship, friendship, and encouragement. Long live Kei Otsuka!

You've Come a Long Way Since

It was a clear day in the autumn of 1969 when a sophomore undergraduate visited me at a study room for graduate students in the Agricultural Economics Department of Hokkaido University in Sapporo, Japan, where I was studying development economics. He said he was Keijiro Otsuka and wanted to study development economics. He looked like he had guts, if not anything else. We studied together at the department. After finishing the undergraduate course there, he proceeded to an MA course at Tokyo Metropolitan University, studying under Yujiro Hayami, then, further on to the University of Chicago studying under Theodore W. Schultz, and got a PhD in 1979.

Development economics in that decade was like fairy tales, though very fascinating ones. The dual-sector model of economic development, set forth by W. A. Lewis in *Economic Development with Unlimited Supplies of Labour* (1954), was still very popular and pervasive. Serious efforts were being made by many development economists and economic historians to test whether the marginal productivity of labor in the agricultural sector of developing countries was null or less than the market wage rate and to identify whether or when a developing economy passed the "turning point." Implicit in this model was an assumption that peasants in the agriculture sector of developing countries were not rational economic agents, therefore not responding to market signals. This model was challenged by T. W. Schultz in *Investment in Human Capital* (1961) and in *Transforming Traditional Agriculture* (1964). In the former, Schultz argued that the capital that developing countries lacked was human capital, not physical capital as assumed widely at the time. In the latter, he claimed that peasants in traditional agriculture were efficient but poor by presenting micro-level evidence that there could not be such incidences of zero marginal labor productivity and fixed subsistence wage in the peasant sector. Thus, it was kind of ironic that the 1979 Nobel Prize in Economics was awarded to T. W. Schultz and W. A. Lewis.

An epochal change in development economics happened in the 1970s, fired up largely by Schultz's provocative, path-breaking studies. This was when empirical research based on micro-level data collected by conducting field studies/field surveys became a common method of study. Development economists of our generation spent their student-hood and young researcher-hood during this transition period, and so did Keijiro Otsuka. His third journal paper, "Community and Market in Contract Choice: Jeepney in the Philippines" (1986; with M. Kikuchi and Y. Hayami), was written based on the data collected from his first field survey conducted in rural and semi-urban areas in the Philippines in 1982. The heavy reliance on the data and observations obtained from field surveys was, and is, a distinct feature of his studies in development economics: An overwhelming majority of his papers and monographs, about 300 in number, are based on field surveys of various kinds. This feature reveals his decisive preference to take reality-based, evidence-based approaches to tackle development economics issues to avoid falling into groundless speculation. It is my pleasure that I was able to help him establish his research style.

As empirical studies based on micro-level data analyzed within the framework of neoclassical economics became widespread, revealing that the conventional markets in traditional agriculture (e.g., markets for crop outputs and labor) did work, albeit not perfectly, development economics updated to a new version. Setting aside the development economics of the classical school (e.g., David Ricardo), Version 1 of (contemporary) development economics, which may also be called the structuralist model, prevailed during the pre-war to early years post World War II, during which time the target countries used to be called "backward" countries. The dual-sector model may be said to have belonged in Version 2. Following these was Version 3, which emerged in the late 1970s and extended into the 1980s and the 1990s, including the phases of the structural adjustment policies adopted by the International Monetary Fund (IMF) and the World Bank, with the popular keyword "getting prices right." By then, the modifier attached to the target countries had been changed from "backward" or "underdeveloped" to "less developed" and then to "developing." Keijiro Otsuka began his research career as a young development economist at this stage. As a student of Y. Hayami and T. W. Schultz, it was natural for him to select such research issues as agricultural policy and technological advances in agriculture, both of which were the research fronts pioneered by Hayami and Schultz.

Of the studies he engaged in this period, most noteworthy was a series of studies on land tenancy and labor contracts, integrated comprehensively into the final paper of the series, "Land and Labor Contracts in Agrarian Economies: Theories and Facts" (1992, with H. Chuma and Y. Hayami). This paper was interesting in two respects, among many others. First, his enduring efforts of ten years, since his first field survey on jeepney contracts in 1982, solved the long-standing mystery of sharecropping contracts, which had attracted, in the two decades from the 1960s to the 1980s, the attention of a large number of talented development economists at the time. The final paper mentioned above, published in the *Journal of Economic Literature*, was highly critical, criticizing most, if not all, of the existing studies. The paper was finally accepted for publication two years after it was first submitted and reviewed by as many as six reviewers, most of whom were criticized in this paper. Good evidence, he had strong guts.

Second, studies on sharecropping and other contracts in rural areas in developing countries in this period (not limited to his studies) contributed to upgrading the version of development economics to Version 4. Although development economics Version 3 recognized that the markets for crop outputs and labor in traditional agriculture were reasonably well-functioning, field-based studies on the markets and contracts in rural areas in developing countries during the last two decades of the twentieth century found that there were occasions that the markets sometimes failed because of information asymmetry, transaction costs, and agency problems. These market failures might be rectified by setting up appropriate institutions or by appropriate policy interventions by the public sector. Following Version 3, "getting institutions right" became a popular keyword for Version 4 around the turn of the century. Thirty years after aspiring to, and 20 years after starting research on, development economics, Keijiro Otsuka's research began to contribute to upgrading development economics considerably.

Another salient feature of his studies has been that he conducts his research in teams. Of his numerous research publications, only a few are single-authored. The total number of his coauthors thus far is nearly 400 as a simple summation and more than 100 if counting the number of researchers who coauthored with him. This implies that he has excellent leadership in research, which has attracted many excellent research collaborators. This mode of research has made it possible for him to expand the research themes he addresses. In the first 15 years of his research career, the major research themes were the Green Revolution in Asia, agricultural technology adoption, land tenancy and tenure systems, land reform, management of natural resources, and gender issues in rural communities. The list of themes expanded dramatically to the Green Revolution in Sub-Saharan Africa, contract farming of high-value agricultural products, and further beyond the boundary of agriculture and primary industries, to the development of small- and medium-scale industries, industrial clusters, agro-based clusters, and as far as foreign direct investment.

This "explosive" expansion of research themes has been accompanied by a rapid increase in the developing regions and developing countries where he conducts his research projects, from the Philippines to other countries in Southeast Asia, to countries in South and East Asia, and to countries in Sub-Saharan Africa. This has been the prima facie outcome of the third salient feature of his studies, that is, the international comparative case study. When testing a hypothesis in development economics, it is always desirable, for the test to be robust, to use data obtained from different countries with different initial conditions and different cultural heritages. For nearly all the themes in his research, research projects have been implemented as international comparative case studies.

The last feature of his studies, to be mentioned here, is that empirical analyses in his research have always been done by adopting the latest analytical methods at the time of research. Examples are the use of panel data in econometric analyses and the randomized controlled trial (RCT) in quantitative impact evaluation of policy and technology adoption, among others. The adoption of the latest method may seem a matter of course. However, analytical methods progress day by day, and generally, a new method consumes more time, human, and financial resources. While it is not easy for researchers with long research experience to catch up with the rapid progress, his efforts and that of his colleagues in the last 40 years are worth commending. Of various new methods, the RCT, introduced into economics research around 2010, is so innovative and essential that the development studies that adopt this method might be considered development economics Version 5. His recent studies have adopted this method since the early 2010s. Yet, his RCT-based studies are different from others; while many researchers tend to look for topics in which RCT can be applied without considering the big picture, Keijiro Otsuka applies RCT to the critical topics within his broad view of economic development processes.

Now, he is trying to integrate all his past studies into a book, with the tentative title of *Transforming the Poor Economy*, which translates T. W. Schultz's basic propositions (i.e., the driving force of economic development is innovation and what makes it possible is the investment in human capital), into a concrete development strategy applicable to all industries, from traditional grain agriculture to the most advanced manufacturing industry. It is a development strategy that only Keijiro Otsuka can recount.

Keijiro, more than 50 years have passed since you first envisaged being a development economist, and you have reached this height everyone admires. It is my great pleasure to express my deepest respect for what you have achieved. Don't call me too greedy, however, even if I tell you, "Aim at heights still higher."

Masao Kikuchi
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Abbreviations

ADB	Asian Development Bank
ARIMA	Autoregressive integrated moving average
ASEAN	Association of Southeast Asian Nations
CA	Conservation agriculture
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
COVID-19	Coronavirus disease
CSA	Climate-smart agriculture
DNA	Deoxyribonucleic acid
DR Congo	The Democratic Republic of the Congo
DS	Dry season
ESR	Endogenous switching regression
FAO	Food and Agriculture Organization
FDI	Foreign direct investment
FTF	Feed the Future Initiative
GAAP2	Gender, Agriculture, and Asset Project Phase 2
GGIA	Green Growth Index in Agriculture
GRIPS	Graduate Institute for Policy Studies
ICT	Information and communication technology
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IRRI	International Rice Research Institute
ISFM	Integrated soil fertility management
IV	Instrumental variable
JICA	Japan International Cooperation Agency
LSMS-ISA	Living Standard Measurement Study-Integrated Surveys on Agriculture
MLN	Maize lethal necrosis
MRGM	Mwea Rice Growers Multipurpose Co-operative Society
MSRI	Modified system of rice intensification
MV	Modern variety

NRM	Natural resource management
OECD	Organisation for Economic Co-operation and Development
PRO-WEAI	Project-level Women's Empowerment in Agriculture Index
PSM	Propensity score matching
QTL	Quantitative trait locus
RCT	Randomized controlled trial
RePEAT	Research on Poverty, Environment, and Agricultural Technology
SI	Sustainable intensification
SRI	System of rice intensification
SSA	Sub-Saharan Africa
StEA	South-through-East Asian
TTSA	Thai Tapioca Starch Association
UFO	Unconfirmed field observation
UN	United Nations
US	United States
USD	United States dollar
WEAI	Women's Empowerment in Agriculture Index
WS	Wet season

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Chapter 1
Introduction: Agricultural Development in Asia and Africa

Jonna P. Estudillo, Yoko Kijima, and Tetsushi Sonobe

1.1 Overview of This Book

Agriculture plays an important role in an economy. It supplies food, labor, and capital; serves as a domestic market for industrial commodities; and is a source of foreign exchange through exports. Many believe that Asia's take-off to rapid growth and development was propelled by productive agriculture and a dynamic rural economy. This book explores the multifaceted aspects of agricultural development and rural transformation in Asia and discusses the similarity of the Asian experience with that of contemporary Africa. In this book, Asia means tropical Asia, and Africa means Sub-Saharan Africa. Tropical Asia includes Southeast Asia and South Asia.

The most important finding presented in this book is that African agricultural development has evolved following the pathways of Asian agricultural development. The common pathways are borrowed technology from abroad and adaptive research exemplified by modern seeds, fertilizer, and mechanical technologies in rice farming; secured property rights on natural resources; adoption of ICTs; investments in human capital, including training; and launching of the high-value revolution (or high-value agriculture). In both continents, agricultural development started in the crop sector, which had a strong tendency to induce the dynamic development of other sectors in rural areas.

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This book is divided into four thematic parts: (1) the Green Revolution in Asia and Africa, (2) Land Tenure and Sustainable Natural Resource Management, (3) Transformation of the Rural Economy, and (4) Emerging Issues in Agriculture. In the following sections, we briefly present the findings in each part.

The term Green Revolution is intended to express an epochal change in which "Third World agriculture was embraced in the process of modern economic growth" (Hayami and Otsuka 1994, p. 15). The Asian Green Revolution was launched amid fear of famine due to high population growth, declining availability of farmland, and stagnant rice yield. It started with land-saving technology and improved seeds-inorganic fertilizer tandem intended to save land as a scarce factor. Later, the Asian Green Revolution moved to labor-saving mode as the nonfarm sector expanded, siphoning off labor away from agriculture. When Asian agriculture started experiencing labor scarcity and higher wages, mechanization started to accelerate. Land preparation and threshing were the first to get mechanized as these were the most labor-intensive activities in rice farming. Interestingly, Africa started to embark on the land-saving phase like the Asian Green Revolution, when the continent started experiencing population pressure on the closed land frontier. While the land-saving mode continues, there is evidence that Africa is now in the early stage of the labor-saving mode, as farm labor has started to become scarce and wages have started to go up.

Like Asia, Africa has also started embarking on management- and knowledge-intensive farm practices to increase input efficiency and save the environment. This volume shows that there has been technology transfer from Asia to Africa, as many of the technologies used in Africa are fairly similar to those in Asia. Current levels of rice yield in Africa are comparable to that in Asia. Overall, it is clear the Green Revolution in Asia is now being replicated in Africa, at least for the major rice-producing areas that are irrigated and favorably rainfed, suitable for rice production. Borrowed technology from abroad and adaptive research served as the main pillars of both the Asian and African Green Revolution.

Evidence in this volume shows that secured property right is the most important factor in increasing cropland productivity and enhancing the uptake of sustainable natural resource management (NRM) practices on both continents. Some policies, such as the household responsibility system in China, the land titling program in Thailand and Kenya, and low-cost registration certification in India and Vietnam, strengthened tenure security and enabled land rental market participation. Institution matters in forestland management. Communal property is far more superior to open access, but a mixed property system, which grants individualized property rights on timber on community forestlands, appears more superior to communal property in Ethiopia. To combat global climate change, cooperation among Asian countries could increase agriculture emission management efficiency to as high as 45%.

One aspect of rural development and transformation is the phenomenal spread of information and communication technologies (ICTs). Asia has quickly adopted ICTs, particularly computers, the internet, and mobile phones, and Africa is catching up rapidly. ICTs have a wide variety of uses, including electronic payment services or 'mobile money' in Africa and technology-assisted instruction in China. ICTs, however, have created a digital divide as their adoption is affected by human capital, resource endowments, and ICT infrastructure.

Nonetheless, ICTs have a clear transformative impact on urban and rural people's lives and livelihood, with positive distributional and welfare impacts. Rural transformation is also evident in the change in household strategies to earn a living away from the farm and into nonfarm, with an accompanying reduction in poverty. Farm mechanization facilitates the sectoral shift of labor from the farm to the nonfarm sector.

On emerging issues, high-value revolution is a developing component of 'new agriculture' on both continents. Evidence in this volume shows that this revolution is driven by rising income and global trade integration on the demand side and new technology, government and private sector assistance, and infrastructure on the supply side. Vietnam has become the largest exporter of shrimp, Thailand the largest exporter of cassava products, and Anding Province has emerged as one of the largest potato clusters in China because of improved seeds (in the case of cassava and potato) and improved farm practices (in the case of Vietnam). Government assistance played a significant role in China and Thailand in overcoming bottlenecks, such as developing new seeds, attracting buyers, and improving market access. In Nigeria, solar-powered cold storage that can overcome the lack of sustainable power supply can increase the consumption of perishable micronutrient-rich horticultural products, increase the incomes of market agents, and create employment.

1.2 Green Revolution in Asia and Africa

The Green Revolution in Asia started in the mid-1960s with increased investments in irrigation; the development of improved seed varieties; and the use of modern inputs, such as fertilizers and pesticides (Barker et al. 1985). This package was a land-saving technology that aimed to save on land as a scarce factor. Land has become scarce because of rapid population growth and closed land frontier. There were widespread fears of food shortages in the region; thus, the Green Revolution was focused on rice, wheat, and maize, which are the basic staples. The use of high-yielding seeds and modern inputs helped farmers increase yields. The per capita production of rice, wheat, and maize rose, and their prices declined leading to the deterioration of agricultural terms of trade (i.e., the decline in price of farm goods relative to nonfarm goods), which stimulates structural transformation.

In the mid-1980s, Asia started its structural transformation. Labor started to move out of agriculture and into industry and services. With farm labor scarcity, mechanization, such as the use of tractors and threshers, accelerated. Mechanization further contributed to agricultural modernization and productivity. Mechanization was partly triggered by rising wages as a result of the development of the nonfarm sector that siphoned off labor from agriculture, partly because of government subsidies to farmers in the purchase of machines and low oil prices before the 1972 oil crisis.

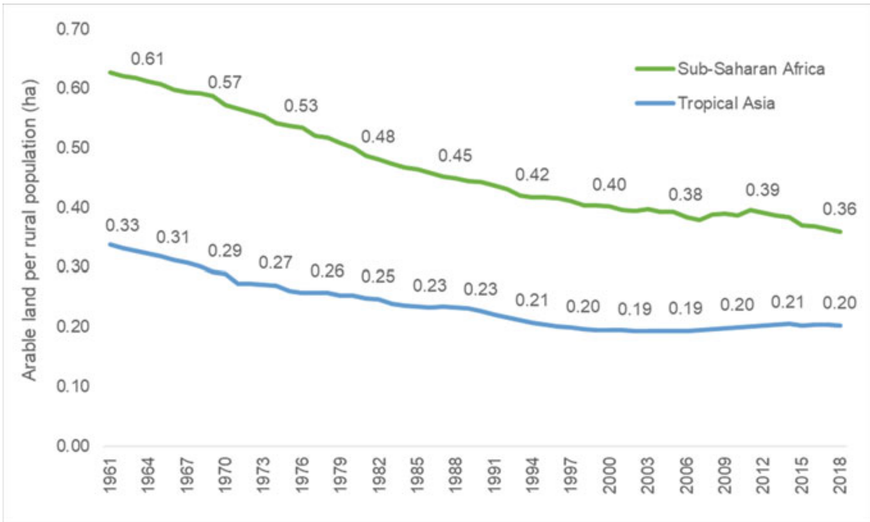

Fig. 1.1 Arable land per rural population in Asia and Africa, 1961–2018. *Note* The figure was drawn using data from FAOSTAT

1.2.1 Population Pressure

Malthus predicted that food shortages will be inevitable because the population grows exponentially while food production grows only arithmetically. In this scenario, food production will not be able to catch up with population growth. However, serious famine has never taken place in Asia in the past 50 years because of rapid growth in food production. Malthus failed to predict the emergence of technological change induced by population pressure (Hayami and Ruttan 1985).

Two conditions propelled the Green Revolution in Asia: severe population pressure on limited farmland and technology transfer from abroad. Figure 1.1 shows arable land per rural population in Asia and Africa from 1961 to 2018. Arable land was 0.33 hectares (ha) per rural population on the verge of the Asian Green Revolution in 1961. In 2018, arable land was 0.36 ha per rural population in Africa, which is fairly the same as Asia's in 1961 before the Green Revolution took off. Before the Green Revolution, there were widespread fears of food shortages because of a burgeoning population, stagnant yield, and increasing scarcity of farmland.

Rice is the most important crop in Asia in terms of harvested area.[1] Here we focus on rice because Asia has accumulated mature technologies that could be easily transferred to Africa. Such technologies are suitable for smallholder farms common in both Asia and Africa. Figure 1.2 shows the yield trends of six important grains in Asia and Africa. The wheat yield in the two continents has been rising and has been fairly the same since the 1980s, which means the Green Revolution in wheat

[1] Maize is the most important grain in Africa.

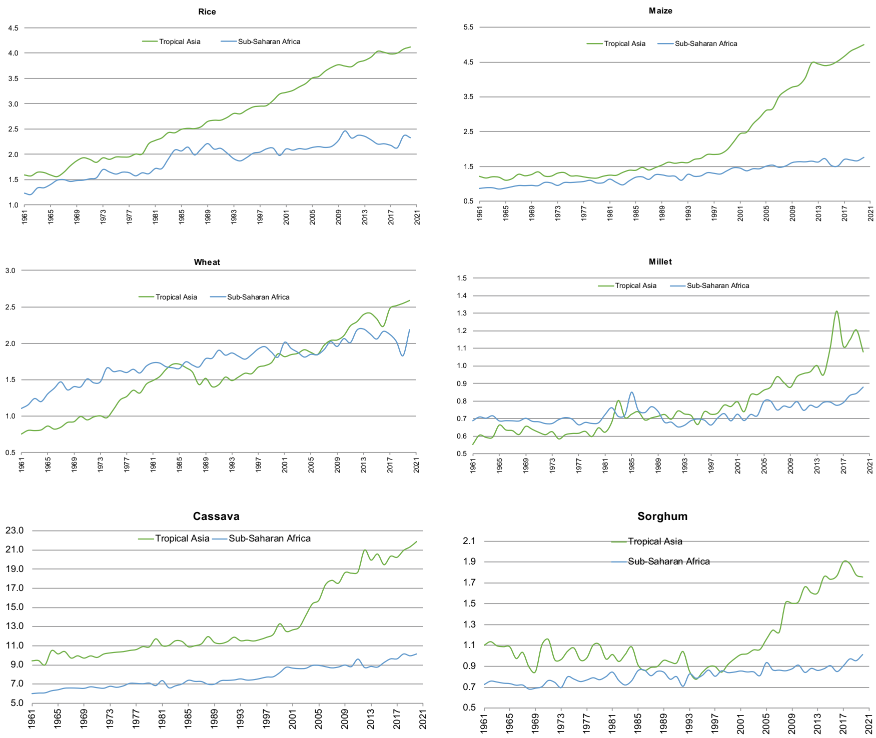

Fig. 1.2 Yields of selected crops in tropical Asia and Sub-Saharan Africa, 1961–2020. *Note* The figures were drawn using data from FAOStat

had already taken place in both continents. The yields of maize, millet, cassava, and sorghum are rising rapidly in Asia, but Africa is lagging, and yield is rising slowly. As a result, the yield gaps in these four crops have risen over time, indicating a widening technology gap between the two continents. In the case of rice, the yield has been rising rapidly in Asia, and the yield in Africa is also rising at a fairly moderate rate, which has led to a decline in the yield gap between the two continents. This means that the Green Revolution in rice could have started to evolve in Africa. While the rice area in Africa remains small, it is steadily increasing primarily due to the conversion of uncultivated marshy land to lowland paddy fields, indicating the rising importance of rice in African agriculture.

1.2.2 Technology Transfer from Abroad

Professor Keijiro Otsuka argues that technology transfer from abroad is the most decisive propelling force in the Asian Green Revolution. The Green Revolution in rice and wheat took place in Asia in the late 1960s when there was a huge technology gap in agriculture between the temperate and tropical countries. The essence of the Asian Green Revolution in rice was the transfer of intensive rice farming systems from Japan to Taiwan and Korea and from Taiwan and Korea to tropical Asia. This new technology was characterized by the adoption of semidwarf fertilizer-responsive high-yielding rice varieties, intensified use of chemical fertilizer, and application of improved management practices.

The Asian Green Revolution started in 1966 when the International Rice Research Institute (IRRI) introduced IR8 (the first high-yielding variety of rice). IR8 had a yield potential five times that of traditional varieties. IR8 was a crossbreed between Peta, a tall variety from Indonesia, and Dee-Geowoo-Gen, a semidwarf variety from Taiwan. IR8 was modeled after the high-yielding Japanese varieties. After IR8, many rice varieties with better characteristics were released. Adaptive crop breeding research played the most important role in developing varieties that thrive in different environmental conditions, incorporate qualities that satisfy consumers' preferences, and are environment- and climate-friendly.

The Green Revolution has three technological pillars: (1) land-saving technology (modern seeds, inorganic fertilizer, and irrigation); (2) labor-saving technology (mechanical technologies); and (3) knowledge-intensive practices. Modern varieties (MVs) of rice could be broadly categorized into two: (1) first-generation MVs (MV1) are more high-yielding than the traditional varieties (TVs) but are susceptible to pests and diseases; and (2) second-generation MVs (MV2) are designed for yield stability because they incorporated improved resistance against multiple pests and diseases, have better grain quality, and shorter cropping period. Hybrid and genetically modified rices have been released more recently.

Knowledge-intensive crop management practices, such as timely fertilizer application and intensive-pest management, have replaced chemical inputs. The Green Revolution was initially focused on irrigated rice land, as it produces 70% of the world's rice supply. New rice technology is now spreading in unfavorable areas because later MVs were designed to withstand extreme weather, such as floods and drought.

1.2.3 Transferability of the Asian Green Revolution to Africa

Here we argue that the Asian Green Revolution is transferable to Africa. First, through its long rice farming tradition, Asia has accumulated a huge stock of mature technology that can be transferred to Africa. Second, there is a huge technology gap in rice farming and in agriculture in general between Asia and Africa. This gap is similar to that between the temperate and tropical countries in the 1960s, which induced the establishment of national research centers for adaptive research and extension services to disseminate available new technologies to farmers. Third, in more recent years, population pressure has become so severe in Africa, fairly similar to Asia's on the eve of its Green Revolution. As shown in Fig. 1.1, Asia had 0.36 ha of arable land per rural population in 1961, while Africa had 0.33 in 2018. Fourth, agroclimatic and soil conditions in some areas in Africa, such as those in Uganda and Tanzania, are favorable for lowland rice cultivation. While it cannot be generalized to all of Africa, the literature review by Balasubramanian et al. (2007) concludes that the rice yield potential in Africa is high. Professor Otsuka observed that many rainfed paddy fields are located in valley bottoms in Africa, which are moist and fertile, and hence, favorable for rice production.

In Asia, input and output markets were already in place when the Green Revolution took off. The Green Revolution was based on the high input and big harvest principle, and, for it to proceed in Africa, markets should be working. Otsuka and Larson (2016) note that markets for inputs and outputs have started to develop in Africa. For example, in Uganda, access to rice millers was greatly improved due to the rapid increase in the number of millers. Seeds have become increasingly available from seed suppliers and purchased from neighboring farmers, indicating the development of seed markets. Importantly, rice traders have emerged in Kenya offering tied-in-credit, a contract where rice traders advance credit to farmers for fertilizer purchases, with the farmer paying the trader in paddy after harvest (Njagi and Mano, in this volume). Overall, the conditions in Asia when the Green Revolution was launched were fairly similar to contemporary Africa, so there is great hope that it could also succeed in the latter.

1.2.4 Trends in Rice Production and Prices

The Asian Green Revolution was a phenomenal success in increasing rice production and decreasing world rice prices (Fig. 1.3). Rice prices declined in the late 1970s after reaching an all-time high in the early to mid-1970s due to political conflict between the US and the Soviet Union that led to chaos in the grain market. Except for another one-time hike in 1980/1981, this time due to oil price increase, rice prices were generally lower from 1980 to 2005 (hovering around USD 400 per ton in 2010 USD PPP) compared to the 1960s and 1970s. The world food crisis in 2006–2008 made rice prices rise again, but at a level that is substantially less than the highest peak in 1974 at USD 1,374 per ton. The sharp reduction in rice prices would mean that the sure ‘winners’ of the Green Revolution are rice consumers, most importantly, urban consumers, while rice farmers who failed to adopt new rice technology were clearly the ‘losers’ because of lower rice prices. Farmers who adopted new technology gained from yield increases but suffered from low rice prices, so the net benefits to them are unclear.

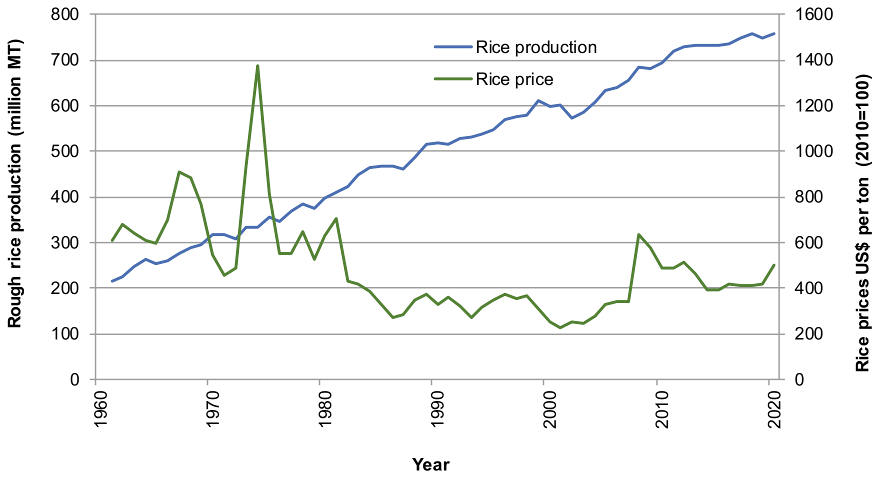

Fig. 1.3 World rice production and rice prices, 1960–2020. *Note* Figure was drawn using data from FAOStat and World Bank Commodity Price Sheets

1.3 Land Tenure and Sustainable Natural Resource Management

Well-defined property rights strengthen the incentives of agents to sustainably manage natural resources, such as croplands and forestlands. With respect to cropland, land tenure defines individual rights over a piece of land. Holden (in this volume) reviews the impacts of contemporary land tenure policies in Asia and Africa. In China, establishing the household responsibility system created many benefits for family farms that were not present under the collective and state farms. Land-to-the-tiller reforms that aimed to enhance land access to land-poor and landless households but infringed on the workings of the land market, on the contrary, failed to achieve their objectives in Bangladesh, India, Nepal, Pakistan, and the Philippines. Landowners tried to evict tenants, and tenants were often converted to permanent laborers. This is not a land contract but a labor contract (Hayami and Otsuka 1993).[2] Land titling programs, such as those in Thailand and Kenya, provided documented land rights and enhanced the functioning of the credit markets by facilitating the use of land as collateral (Feder and Onchan 1987). In Ethiopia, land registration has strengthened land tenure, promoting investment in conservation and encouraging land market participation (Holden et al. 2009).

Secured land tenure enables households to deepen their engagement in the nonfarm economy. In the Philippines, for example, beneficiaries of land reform used their increased farm income to send their children to school, who, upon completing school, decide to work in the rural nonfarm economy or migrate to local towns, big

[2] In the Philippines, this is called the *porcientuhan* contract where the laborer receives 10% of the gross output at harvest time.

cities, and overseas, sending remittances back home (Estudillo and Otsuka 2016). In some cases, land reform beneficiaries pawn out their lands and use the pawning revenues as school funds for their children or as fixed costs for overseas work (Estudillo et al. 2009). Pawning is an arrangement whereby a creditor advances a loan to the farmer in return for cultivating the land until the loan is paid.[3] Pawning emerged because land market sales have been constrained by law for lands obtained through land reform.

Unlike croplands, in which tenure is largely under individual rights, forestlands may be open access or owned/rented/managed by the community or an individual. Stronger tenure rights in croplands could be why degradation in Africa is much less pervasive on croplands than in other land uses, including forestlands (Place, in this volume). Institutions in managing forestlands may prove important in preserving and rehabilitating forestlands. One such institution is the mixed management system (Takahashi, in this volume), whereby forestlands are owned by the community, but the trees are owned by individual members. Since decision-makers in this scheme are individuals, women and men may develop the same degree of propensity to adopt NRM practices since men have an interest in conserving forests for their commercial values, while women have interests in food, water, firewood, and medicinal products, which may be among their tasks to collect. While tenure is important, there could be other factors in the uptake of sustainable NRM practices, such as information and technical advantage, discount rate, low economic returns, and gender differences in constraints and benefits.

1.4 Transformation of the Rural Economy

There has been a phenomenal rise in the usage of ICTs in Asia. Africa is following suit more visibly in internet and mobile phones, but not so much in broadband and fixed phone subscriptions (Fig. 1.4). The spread of the internet and mobile phones started on both continents around the mid-1990s. The percentage of the population using the internet in Africa has been very close to Asia since the early 2000s. The number of fixed telephone subscriptions rose spectacularly in Asia in the mid-1980s. Its peak was in the mid-'00s, followed by a sharp drop when mobile phone subscriptions rose substantially.

The transformation of the rural economy is the shift of the locus of rural economic activity away from the farm to the nonfarm sector. The most important propelling force in rural transformation is the decline in the price of farm goods relative to

[3] Pawning during the Hispanic colonial period was known as the *pacto de retrovenda*, in which a moneylender, usually a local Chinese trader (Chinese mestizo), secured the protection of his loan to a peasant by taking immediate control of the land. In the *pacto de retrovenda*, the indebted peasant remains in possession of the land but in the role of sharecropper to the Chinese trader. Land acquisition by the Chinese trader was inspired by the booming domestic trade in rice, corn, indigo, and fruits and vegetables.

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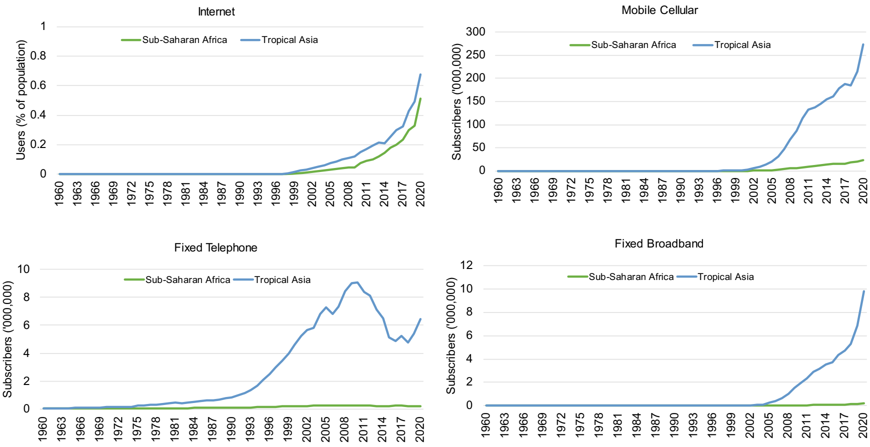

Fig. 1.4 Adoption of ICTs in Asia and Africa, 1960–2020. *Note* The figures were drawn using data from World Development Indicators

nonfarm goods (i.e., deterioration in agricultural terms of trade) that stimulates the movement of resources away from the farm to nonfarm sectors. Rural transformation is often accompanied by (1) increasing productivity of agriculture (i.e., crop farming and high-value agricultural products); (2) more lucrative employment opportunities in rural nonfarm sectors; and (3) migration. The agricultural growth linkage hypothesis postulates that modern agricultural technology propels the development of the nonfarm economy through several production and consumption linkages (Haggblade et al. 2007). Production linkages come through backward linkages (e.g., the production of implements, agricultural machinery, and retail stores for fertilizer). It could also come through forward linkages (e.g., processing and agro-based industries). Consumption linkages come through increases in rural household income that stimulates consumer demand for locally-produced nonfarm goods and services. Consumption linkages are the more dominant.

There is no doubt that nonfarm income has been increasingly the major source of household income growth because of the decline in farm prices and increased profitability of nonfarm activities. Nonfarm income comes from wage income and remittances. The rise in nonfarm income is pro-poor as the landless and near landless households are engaged in nonfarm work. Remittances of migrant workers have transformative impacts on the rural economy. First, remittances can help increase the level of household consumption and reduce its volatility. Second, remittances can be used for productive investments, such as microenterprises, children's education, and housing. Finally, migration facilitates land consolidation and mechanization in rural areas. With the land rental market, migrants with land can rent or sell their land. Migration and rural wages going up induce farmers to mechanize to save on labor.

Economic transformation is the key driver of growth and development in Asia at the macro-level, accompanied by rapid income growth and poverty reduction (ADB 2020). Many believe that Asia's investments in primary and secondary education are the main propelling force for economic transformation and rapid, sustained growth. Figure 1.5 shows that Asia's gross enrollment in primary school has steadily increased since the 1960s, reaching more than 100% in the 1990s. It is higher than 100% because the gross enrollment rate includes overaged and underaged pupils and repeaters. The gross enrollment rate in secondary schooling is lower than in primary school but has risen fast since 1981. The tertiary enrollment rate in Asia is much lower than the secondary level, but there was a sharp rise beginning in 2001. From 2011 to 2020, the gross enrollment rate in tertiary schooling was nearly 25%. Africa has caught up with Asia at the primary level and is slowly catching up at the secondary and tertiary levels. If Africa were to follow the Asian path toward growth and development, investments in secondary and tertiary schools appear to be the right direction to go.

Fig. 1.5 Gross enrollment in primary, secondary, and tertiary schooling in tropical Asia and Sub-Saharan Africa. *Note* The figures were drawn using data from the World Development Indicators

Sawada (this volume) argues that Asia's economic success was attributed to its rapid human capital accumulation that increased its capacity to absorb and adapt new technology from abroad, enabling rapid economic transformation. Because of investments in education, Asia improved to catalyze technological advances from abroad that drive sustained long-term growth ('innovation') in the nonfarm sector. Indeed, the major ingredient in the 'East Asian Miracle' was human capital investments in education and health, serving as the flagship in Asia's long-term rapid growth.

1.5 Emerging Issues in Agriculture

In the 'new agriculture,' high-value products tend to dominate, driven by supply and demand factors. On the supply side, the factors are new technology and improved farm management, support from trade guilds, and local government and infrastructure. On the demand side, higher income stimulates the demand for a more diversified diet and global trade integration. Case studies presented in this volume are the shrimp industry in Vietnam; cassava/tapioca in Thailand; fresh fruits and vegetables in Nigeria; and agricultural clusters in China (potato), Egypt (medicinal aromatic plants), and Tunisia (dates).

Emerging issues in agriculture go beyond the farm and into the social sphere. On women, a new metric, the Women's Empowerment in Agriculture Index (WEAI), was launched in 2012 and is being continuously upgraded to monitor women's inclusion in agricultural sector growth. The WEIA can help governments and civil society organizations design and implement gender-sensitive agricultural development programs in line with the adoption of SDG 5 on women's empowerment and gender equality. On governance, public choice considerations in Asia tend to exempt agriculture from competition law prohibitions, such as those involving exercise of market power by farmers' associations. Such a move serves as a countervailing force for the farmers' comparatively weak political influence in agricultural policy and their relative market power vis-à-vis the more concentrated wholesale-retail segments of the agri-food value chain.

1.6 Contributions of This Volume

This volume provides a comprehensive exploration of recent agricultural and rural development issues in Asia and Africa. This volume compiles the works of top scholars who provided analyses and evidence from household-level surveys collected over many years and, more recently, randomized controlled trials (RCT) in the two continents. The four themes in the volume represent the main research interests of Professor Keijiro Otsuka, with almost all authors having worked with him on a research project along these themes. This work will be of great value to development economists, students, and researchers interested in rural economies and policymakers engaged in rural and agricultural development in Asia and Africa.

1.7 A Road Map to the Book

There are 27 chapters in this volume, including the Introduction and Summary and Conclusions. The remaining 25 chapters are divided into four thematic parts.

The first theme—*Green Revolution in Asia and Africa*—documents the evolution of the Green Revolution in Asia for more than six decades and evaluates to what extent the Asian Green Revolution has been replicated in contemporary Africa. We focus on the expansion of irrigation, development of high-yielding seeds, increased use of modern inputs, acceleration in mechanization, and improved farm management practices.

Part 1 has eight chapters. Chapter 2 (Pingali) synthesizes the lessons learned and spells out the policy redirections needed for a new version of the Green Revolution that addresses unresolved issues, such as food and nutrition security and economic development, while minimizing social, environmental, and health trade-offs. Chapter 3 (Kajisa et al.) reviews how rice farming practices in the lowland rainfed and irrigated ecosystems in Central Luzon have evolved for over half a century in terms of the adoption of new technology and rice yield. Chapter 4 (Yamano) reviews recent studies on the adoption and impacts of submergence-tolerant rice varieties in South Asia and found, in a study using DNA fingerprinting, that many farmers in Bangladesh wrongly identified varietal names, indicating that adoption studies may not accurately reflect farm-level adoption rates. Chapter 5 (Njagi and Mano) identifies factors and constraints in the spread of mechanization in the Mwea Irrigation Scheme in Kenya. Chapter 6 (Nakano and Magezi) summarizes four of their own studies in Tanzania that evaluate the effectiveness of irrigation, agricultural training, and microcredit in enhancing rice productivity. Chapter 7 (K. Takahashi) uncovers the impacts of the system of rice intensification (SRI) on enhancing rice productivity in Africa, with a particular focus on careful field management practices. Finally, Chapter 8 (Kijima and Tabetando) summarizes the findings and achievements of the Research on Poverty, Environment, and Agricultural Technology (RePEAT) conducted in East Africa for over 20 years.

The second theme—*Land Tenure and Natural Resource Management*—deals with the dynamics of land tenure, land market, property rights in agriculture, and the sustainability of current farming systems. Here we uncover the constraints and drivers of the uptake of sustainable NRM practices and identify which existing farming practices are sustainable. This section also assesses to what extent transboundary crop diseases affect global and African food security and spells out the prospective role of regional cooperation in attaining sustainable green growth by increasing emission-management efficiency.

Part 2 has six chapters. Chapter 9 (Holden) reviews the extant literature on land and tenure contracts in developing countries and presents an analysis of major land tenure reforms in the twentieth century. Chapter 10 (R. Takahashi) presents the results of a randomized experiment in Ethiopia on the property rights regime and forest resource management. Chapter 11 (Place) reviews recent studies on the constraints and drivers of the degradation of agricultural resources in smallholder farms in Africa and spells out action agenda to redirect Africa's agricultural development pathways toward sustainability. Chapter 12 (Muraoka) investigates the possibilities and limitations of sustainable agricultural intensification and draws policy agenda on how to make it possible in the context of Africa. Chapter 13 (Mottaleb) quantifies the production loss caused by the spread of maize lethal necrosis in Kenya, DR Congo, and Tanzania. Finally, Chap. 14 (Zaman and Kalirajan) discusses the important role of regional cooperation in sustaining green growth in agriculture by increasing emission-management efficiency.

The third theme—*Transformation of the Rural Economy*—describes the strategic processes that underlie economic transformation, which is the shift of economic activities away from agriculture and into industry and services. One emerging aspect of rural development is the increasing use of ICTs, most importantly, the internet and mobile phones. If Asia is fast in this aspect, Africa is following suit. Evidence from long-term datasets at the macro- and household-level in Asia shows a fast sectoral movement away from agriculture and into services, putting into question whether there is an escalator leading directly to services without going through industrialization.

Part 3 includes six chapters. Chapter 15 (Huang et al.) documents the overall trends in the use of the internet, computers, and mobile phones in rural China and examines the enabling and constraining factors in farmers' adoption of major ICTs. Chapter 16 (Abbey et al.) assesses the potential of using educational technology to improve teaching quality in rural China. Chapter 17 (Matsumoto and Munyegera) summarizes the findings from research on the impact of the mobile revolution, focusing on the impacts of 'mobile money' on the lives and livelihood of rural residents in developing countries. Chapter 18 (Estudillo) describes the drivers of economic transformation in four villages in the Philippines, the so-called Kei's villages, and describes the strategic processes that accompany such transformation. Chapter 19 (Sawada) presents a case study of two pathways of economic transformation using long household panel data in Laguna in the Philippines. The first one followed the agricultural-manufacturing-services historical pathway (i.e., 'canonical industrialization') while the second skipped industrialization, moving straight to services (i.e., 'premature deindustrialization'). Finally, Chap. 20 (Larson) explores the relationships between sectoral migration, gaps in sectoral incomes, and mechanization using a cross-country panel spanning five decades.

The fourth theme—*Emerging Issues in Agriculture*—which are evolving in Asia and Africa, include the spread of high-value revolution and issues beyond the farm, such as the evolution of metrics to measure women's empowerment in agriculture and governance issues that exempt agriculture in competition laws. These themes show a high degree of commonality between Asia and Africa in their agricultural and rural development journeys.

Part 4 contains six chapters. Chapter 21 (Suzuki and Nam) illustrates how the shrimp culture industry has evolved in Vietnam by spelling out the factors that led to its evolution. Chapter 22 (Aida) describes the evolution of the cassava/tapioca industry in Thailand by identifying the motors of evolution. Chapter 23 (Zhang) compares agricultural clusters' performances in China and Africa using case studies on the potato cluster in China, the dates cluster in Tunisia, and the medicinal and aromatic cluster in Egypt, focusing on the important role of local government in providing the necessary public goods. Chapter 24 (Yamauchi and Takeshima) investigates the impacts on food loss, perishable horticultural commodities consumption, and livelihood outcomes of solar-powered cold storage systems in Nigeria. Chapter 25 (Quisumbing et al.) describes the development of new metrics that measure women's empowerment in agriculture. Chapter 26 (Balisacan) explores how exemption of agriculture from the competition laws has become beneficial to smallholder farmers in Asia in terms of the balance of political influence in agricultural policymaking and market power over the more concentrated wholesale-retail sector.

Recollections of Professor Keijiro Otsuka

Among the non-Japanese researchers, I believe I have the longest association with Professor Otsuka, which spans well over two decades. I first met him at the International Rice Research Institute in 1988 when I was a masteral student. He then recommended me to the University of Hawaii, where I finished my Ph.D. in Economics. Our long research work started when I worked at the Tokyo Metropolitan University as a postdoc under his supervision. I then joined him at the Foundation for Advanced Studies on International Development and the National Graduate Institute for Policy Studies in Tokyo. We have produced three books (two written, one edited), 18 journal articles, and ten chapters on our joint research on poverty, economic mobility, gender and development, the nonfarm sector, agricultural productivity, and inclusive growth. It is my great pleasure and honor to be the chief editor of his Festschrift.—*Jonna P. Estudillo.*

I first met Professor Otsuka in 1995 when I decided to enter the master's program at Tokyo Metropolitan University. He was a visiting research fellow of IFPRI and traveled to Africa and Asia on projects related to land tenure and natural resource management. Luckily, he made me a part of the project, and we conducted research on tree management in community forests in Japan. This taught me the value of research and made me decide to be a researcher. After I obtained my Ph.D., he gave me an opportunity to work with him on the New Rice for Africa (NERICA) project in Uganda in 2004. Since then, I have been collaborating with him on studying the African rice Green Revolution. I am grateful to be his student and later colleague and collaborator and have learned from him how to conduct research in the development economics field. Curiosity, hard work, positive thinking, leadership, teamwork, and a warm and strong heart are what I learned from Professor Otsuka.—*Yoko Kijima.*

My Ph.D. dissertation supervisor, Professor TN Srinivasan, asked me, "Is this the university where Yujiro Hayami and Kei Otsuka work?" He encouraged me to accept the job offer I had just received from Tokyo Metropolitan University in 1992. Since then, I have followed Kei and learned many important things from him. He and I were born in the Year of the Rat and raised in the same town. We are Taurus and share the same blood type. Our names share similar stroke-counts of Chinese characters. Do these coincidences mean that we resemble? Of course, no! But we share the same general values because we have discussed numerous things over thousands of beer and wine bottles.—*Tetsushi Sonobe.*

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Part I
Green Revolution in Asia and Africa

Chapter 2
Are the Lessons from the Green Revolution Relevant for Agricultural Growth and Food Security in the Twenty-First Century?

Prabhu Pingali

Abstract The Green Revolution had profound positive impacts on human welfare and economic development across the developing world. However, its global reach was limited by agroclimatic, infrastructural, social, and political constraints. Regional disparities in poverty reduction, intra-societal inequities, and gender differences in the distribution of benefits persist even in countries that witnessed positive Green Revolution outcomes. This essay synthesizes the lessons learned and the policy redirections needed for a 'redux' version of the Green Revolution that enhances food and nutrition security and economic development while minimizing social, environmental, and health tradeoffs.

2.1 Introduction

The Green Revolution was an epochal event that had an enormous impact on global hunger and agricultural development. It had a significant influence on the development trajectory of numerous countries, particularly those in Asia. Countries that were desperately food insecure in the 1960s have become middle-income emerging economies today, some rising rapidly toward high-income status. It is hard to imagine what the developing world would have looked like had the Green Revolution not happened. Despite the success, food insecurity continues to daunt the global community. The number of hungry and malnourished continue to be stubbornly high. A large share of the rural population across the developing world, particularly in Sub-Saharan Africa and South Asia, continues to subsist on low productive agricultural systems and live in poverty. There are incessant calls for donor and national government investments to emulate the Green Revolution experience.

As we look toward future investments in agricultural productivity growth in the developing world, it is important to consider the lessons from the Green Revolution.

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The Green Revolution led to rapid productivity growth, but only for a small set of crops and for favorable agroclimatic environments. Its productivity impacts on the marginal environments were limited. Small farm productivity growth transformed Asian economies, but Sub-Saharan Africa did not see similar benefits. Even in countries that were considered Green Revolution successes, inter-regional differences in productivity and rural poverty persisted. We saw significant progress in hunger reduction, but micronutrient malnutrition persists across the developing world. Productivity growth in the big three staples—rice, wheat, and maize—led to the crowding out of traditional staples, such as millets, and other micronutrient-rich crops. The environmental consequences of the Green Revolution are well known, but corrective action has been limited. The persistence of Green Revolution-era agricultural policies has dampened farm-level incentives for adopting sustainable intensification practices.

This essay presents a brief synthesis of the lessons learned from the Green Revolution, both positive and negative, and explores options for the way forward. I draw on my numerous papers on the Green Revolution, with my 2012 *Proceedings of the National Academy of Sciences* (PNAS) paper as a starting point. Interested readers can get further details on the arguments presented from the papers listed in the references. This chapter starts with a presentation of the positive impacts of the Green Revolution, followed by the limits to its success, and ends with a discussion on the way forward that incorporates the lessons learned.

2.2 Positive Impacts of the Green Revolution

2.2.1 Impact on Productivity and Food Prices

The rapid increase in agricultural output resulting from the Green Revolution came from an impressive increase in yields per hectare. Between 1960 and 2000, yields for all developing countries rose 208% for wheat, 109% for rice, 157% for maize, 78% for potatoes, and 36% for cassava. Developing countries in Southeast Asia and India were the first to show the impact of the Green Revolution varieties on rice yields, with China and other Asian regions experiencing stronger yield growth in the subsequent decades. Similar yield trends were observed for wheat and maize in Asia. Analysis of agricultural total factor productivity (TFP)[1] finds similar trends to the partial productivity trends captured by yield per hectare. For the period 1970–1989, the change in global TFP for agriculture was 0.87%, which nearly doubled to 1.56% in 1990–2006 (Pingali 2012). Widespread adoption of Green Revolution technologies led to a significant shift in the food supply function, contributing to a fall in real food prices.

[1] TFP is defined as the ratio of total output to total inputs in a production process.

The transformation of Asia from a desperately food-deficit continent to one that is food self-sufficient and, in the case of some countries, achieving a food exporter status, is a well-known story. However, it is also important to remember that a monumental change the Green Revolution ushered in was eradicating famine in Asia. Famines had taken a toll of 80.3 million lives between 1900 and 1969. Between 1970 and 2016, the widespread mortality owing to food shortages declined to 9.2 million (Pingali and Abraham 2022). Asia saw the highest fall in mortality, where the last famine due to non-political reasons was the 1974 Bangladesh famine. The fact that the Green Revolution made famine history in Asia is not appreciated as much as it ought to be.

The Green Revolution-led technological change and investments led to smallholder productivity boosts, significant income growth, and massive poverty reduction in most Asian countries, kick-starting a structural transformation process. Along with the declining share of agriculture in economic output and employment, structural transformation also ushered in rising urbanization; increasing urban economic activity, driven by the industry and services sectors; income growth; and a drop in fertility rates. Many of the emerging economies of Asia today were low-income agrarian economies during the 1960s and used agriculture as an engine of growth and poverty reduction. Current divergence in the levels of economic development across Asian countries can be largely explained by their initial investments in their agricultural sectors, long-term sustained investments in agriculture and rural development, employment generation outside of agriculture, and massive investments in human capital and labor force development at all levels.

2.3 Where Did the Green Revolution Work?

The success of the Green Revolution was most visible in areas with high population densities and good market infrastructure. The demand for productivity growth through land intensification was highest in these areas. It is therefore not surprising that the earliest adopters of Green Revolution technologies were the densely-populated countries of Asia, such as India, China, and Indonesia. Even within these countries, there was significant intra-regional variation in the adoption of Green Revolution technologies. The irrigated and high rainfall environments quickly assumed the role of the 'food baskets' of the country. While the less favorable production environments, such as those with low rainfall, drought-prone areas, and poorer soils, lagged behind and continue to be food-deficit today.

In retrospect, it is not surprising that the focus of the Green Revolution was restricted to three crops—rice, wheat, and maize. These crops had a head start in research and technology investments building on the knowledge stock obtained from the US, Europe, and Japan. Green Revolution innovations, such as short stature and stiff stems, made these crops responsive to intensification inputs, such as irrigation and fertilizer application, and hence, had higher yield potential. Traditional staples, such as millets, sorghum, and tropical tubers, did not have the benefit of drawing on a similar research backlog and were not prioritized during the early phases of the Green Revolution. Although investments during the subsequent decades tried to bridge the research gap between these crops and the big three staples, their productivity and societal welfare impacts were limited.

Additionally, the strength of a country's national agricultural research system (NARS) was crucial in Green Revolution-led productivity growth. Strong NARS, such as those in China and India, were important conduits for accessing and adapting CGIAR (Consultative Group on International Agricultural Research) technologies and disseminating them to farmers' fields. NARS capacity focused on the big three staples, and even the strong NARS had weaker capacity in other crops. Sustaining funding support for the NARS during the post-Green Revolution period has been a challenge, and countries that managed to provide continued high-level support saw sustained productivity gains.

Political economy imperatives, especially the management of urban food supplies and food prices, played a major role in enhancing food crop productivity in Asia. Output price supports, input and credit subsidies, and controls on the international food trade played significant roles in providing farmers the incentives for investing in modern high-yielding technologies and management practices.

2.4 What Were the Limits to the Green Revolution Strategy?

2.4.1 Technology Was Important But Only with Enabling Policies, Institutions, and Infrastructure Investments

Technological innovation played a pivotal role in the Green Revolution, but technology by itself was not sufficient to ensure success. Infrastructure investments, institutional reforms, and price incentives, all working together, were essential for the rapid adoption of modern technologies and the ensuing growth in productivity and food supplies. Numerous country case studies across Asia have documented the positive food security outcomes of government policies that brought the above four components (innovations, infrastructure, institutions, incentives) into a coherent agricultural policy. The case of Vietnam is particularly illustrative. The country transformed itself from chronic food-deficit status to a major rice exporter by completely overhauling the structure of its production system. Moving away from collective agriculture to freely operating small farms, investments in market infrastructure, and liberalization of food and agricultural commodity trade resulted in an immediate and dramatic transformation of the agricultural sector and kick-started overall economic growth. Vietnam's agricultural liberalization policies followed closely the earlier and very successful experience of China.

2.4.2 The Focus on a Limited Set of Crops Crowded Out Diversity in the Food System

A significant unintended consequence of the Green Revolution has been the crowding out of nutrition-rich coarse grains, such as millets, sorghum, and pulses in Asia. Expansion of cultivated area under cereals came at the cost of coarse grains and pulses in many countries. Policies that promoted staple crop production, such as fertilizer and credit subsidies, price supports, and irrigation infrastructure (particularly for rice), tended to crowd out the production of traditional non-staple crops, such as pulses and legumes in India. Coarse grains and pulses are a significant source of critical micronutrients and proteins for the poor in Asia, which has had implications for their nutritional status, as discussed below. By the early 1990s, there was a growing recognition that food security meant more than staple grain self-sufficiency—the need for a balanced diet that included protein, vitamins, and other micronutrients, in addition to calories, was increasingly recognized. At the same time, rising incomes and urbanization led to a rise in demand for diet diversity. Yet, the diversification of production systems away from staple cereals was slow, despite the rising relative prices of non-staples. Policy and structural impediments and a weak private sector limited the supply responsiveness for vegetables and other non-staples.

2.4.3 Successfully Addressed Calorie Hunger, But Micronutrient Malnutrition Persisted

Nutritional gains of the Green Revolution have been uneven; while overall calorie consumption increased, and there has been a dramatic decline in the incidence of hunger, micronutrient malnutrition persisted, especially among the poor. As discussed above, the narrowing of the food system, making it more concentrated in staples cereals, had an adverse effect on micronutrient supply. Traditional crops that were important sources of critical micronutrients (such as iron, vitamin A, and zinc) were displaced in favor of the higher-value staple crops. Biodiversity loss led to the further narrowing of food diversity (Pingali 2019). For example, intensive rice monoculture systems led to the loss of wild leafy vegetables and fish that the poor had previously harvested from rice paddies in the Philippines. Price effects of such supply shifts further limited access to micronutrients as prices of micronutrient-dense foods rose relative to staples in many places. In India, the increasing price of legumes has been associated with a consequent decline in pulse consumption across all income groups. The calorie-dense nature of the food system has increased the risk of micronutrient malnutrition and contributed to the rise in obesity trends observed across the region today.

2.4.4 Inter-regional Inequalities in Poverty and Food Insecurity Persisted Despite the Green Revolution Success

The adoption of Green Revolution technologies was also limited to irrigated tracts or regions with high rainfall and low agroclimatic risks, thus leaving out marginal environments and semi-arid areas, creating regional disparities in productivity and income growth. The initial focus on the high-potential environments was undoubtedly the right strategy, given the urgent need to address hunger and food insecurity and the high probability of success building on the scientific progress made in the advanced countries. However, the strategy of replicating the success in the favorable environments by adapting the big three staples to the marginal environments did not provide the intended boost in productivity. A more balanced approach to the marginal environments would have been to focus on the crops that are naturally adapted to those environments, millets, for example. Such a strategy would have required a decentralized approach and relatively more resources but could have resulted in more inclusive growth and enhanced the overall breadth and quality of the food system. People in marginal environments have benefited from the productivity growth in the more favorable environments through lower food prices, migrant labor opportunities, and, to an extent, a reduction in the inter-regional wage gap. However, the welfare gains would have been larger if concurrent efforts were made in investments in human capital and job creation for populations migrating out of the low productive environments.

2.4.5 Unintended Consequences Undermined the Gains Made

While the Green Revolution was instrumental in averting hunger for millions of people, reducing poverty, and restricting the conversion of additional land for agriculture, it also had other unintended consequences. Environmental degradation resulting from injudicious use of inputs, such as pesticides, fertilizers, and water, and the rise in greenhouse gas (GHG) emissions are well documented. Human health impacts from exposure to pesticides and water contamination due to chemical runoff are also well documented. Negative externalities associated with the Green Revolution were not because of the technology per se but rather its inefficient or improper use. High levels of subsidies for chemical inputs, energy, and water, reduced incentives for being more discriminate in their use. The incentives for learning to be smarter and safer in input use were limited because of distorted input and output prices. True cost accounting of the externalities associated with intensive agricultural production systems is essential for understanding the human welfare costs associated with Green Revolution-era policies and practices.

2.4.6 Stickiness of Green Revolution-Era Policies Prevented Food System Transformation and Sustainability

The persistence of staple grain fundamentalism in agricultural policy hampers farmer incentives to diversify their production systems and adopt sustainable practices. During the Green Revolution, policies that promoted staple crop productivity growth prioritized rapid increases in the 'pile of grains,' with minimal regard for the nutritional tradeoffs and environmental externalities. These policies have been hard to get rid of even after a country has achieved staple crop self-sufficiency and shifted toward diet diversification. The political economy constraints to dismantling antiquated policies that do not address the current demand for food diversity and sustainable food systems have become a major challenge for agriculture and rural development across the developing world.

2.5 The Way Forward—Policy Agenda for Sustainable Food Systems[2]

The challenges for agricultural development and food security improvement are as great today as they were at the start of the Green Revolution in the 1960s. We have been largely successful in addressing calorie hunger through increased supplies and access to food grains, particularly rice, wheat, and maize. However, we made limited progress in addressing 'hidden hunger' caused by inadequate access to micronutrient-rich foods. Transforming food systems to enhance the supply of diversity and nutrient quality is the dominant challenge for developing-country agricultural systems today. Food systems face multiple and concurrent threats, from unabated growth in food demand to intensification pressures on the agricultural resource base and the growing threat of climate-related risks; the complexity of the task ahead is significantly greater than what we faced in the past. Agricultural policy needs to evolve from its traditional focus on productivity improvement for the big three staples toward promoting sustainable food systems that meet the food and nutrition needs of the populations while also driving rural growth.

Unlike in the 1960s, developing countries are on divergent growth trajectories in the twenty-first century, from the least developed countries in parts of Sub-Saharan Africa to the middle-income emerging economies of Asia and Latin America. The pathways to agricultural growth and food security will differ by a country's economic development stage (Pingali 2010). A 'one-size-fits-all' approach used in the past is no longer appropriate in designing agricultural development programs. While the least developed countries face chronic conditions of low productivity and high levels of food insecurity, the emerging economies are rapidly moving toward market

[2] This section draws on material presented in Pingali (2018).

integration and agricultural commercialization. Feeding the cities with a diverse food basket provides new growth opportunities for these economies.

A policy agenda for sustainable food systems strives for simultaneous improvements in rural ecosystems' economic, human health, social, and environmental welfare. Agricultural intensification without increasing negative externalities of agricultural production, such as diminishing biodiversity, increased GHG emissions, and land and water degradation, is important here. In addition, sustainable food systems policies explicitly address the welfare of producers, especially smallholders and the rural poor, and consumers, including considerations of nutrition and food safety. The broad elements of the food and agricultural policy agenda are presented in the following sections.

2.5.1 Looking Beyond Staple Crop Intensification for the Emerging Economies

Emerging economies face a myriad of challenges that have implications for food system transformation and sustainability. First, rapid growth in incomes, urbanization, and the rise of the middle class lead to the rapid diversification of diets and boost demand for higher-value crops and livestock products. Second, despite significant gains in food supply and food access, inter-regional inequalities in income and nutritional status continue to persist at high levels, especially in the more marginal agroclimatic zones bypassed by the Green Revolution. Third, reversing the negative consequences of the productivity-environment tradeoffs made during the Green Revolution is a major challenge emerging economies face as they try to transition to a more sustainable food system. There is a common thread through all the above issues, and that is a need to reexamine the emphasis given to staple crop production systems in developing countries. Also, there is a need to promote diversity across agro-ecologies and across the food system and enhance resource-conserving technical change.

2.5.2 Continued Relevance of the Agriculture-Led Growth Strategy for Sub-Saharan Africa

For the low productivity agricultural systems in Sub-Saharan Africa, the Green Revolution strategy of using agriculture as an engine of economic growth and poverty reduction continues to be the 'best bet' option. However, unlike in the past, agricultural productivity growth cannot be restricted to the big three staples. It should be inclusive of traditional staples, such as millets, sorghum, and cassava; these crops tend to have higher nutrient content and are better adapted to the agroclimates of the region. Unlike in the case of rice and wheat, the opportunities for technology transfer of these crops to Sub-Saharan Africa from Asia are limited. Africa-based research and development programs are essential and need to be strengthened. Building food system resilience is also a necessary part of the strategy through investments in irrigation infrastructure, promotion of drought-tolerant crop varieties and animal breeds, information services to empower farmers to anticipate and manage crises, and innovations in agricultural insurance. Low-income countries are becoming increasingly integrated into the global food economy, and hence, the sustainability of small farm systems would require them to be competitive and integrated into markets rather than be focused primarily on subsistence production systems.

2.5.3 R&D for Enhancing Food and Nutrition Security

Agricultural research is often cited as the single-best investment in increasing productivity and reducing poverty in the developing world. Among many investments made in agricultural research during the past five decades, South Asia's Green Revolution—the doubling of the yields and output of South Asia's major food staples between 1965 and 1985—is one of the most-cited examples of this high payoff. Continued high levels of investments are needed to enhance the productivity of the major staple grains—rice, wheat, and maize—to meet their rising demand due to population and income growth.

Additionally, productivity gains in traditional staples, such as cassava, millets, barley, and sorghum, that were not the initial focus of the Green Revolution, need to be focused on to improve the diversity of diets and essential micronutrient availability. Such investments could provide new opportunities for growth in the marginal production environments and enhance the supply and accessibility of micronutrient-rich food to the rural poor. There is also an urgent need for R&D investments in making food crops climate-sensitive, especially in marginal production environments.

Biofortification of staple and non-staple food can be a sustainable means of reducing immediate concerns of micronutrient deficiency. Essential micronutrients, such as iron, zinc, and vitamin A, can be accessed through biofortified foods cost-effectively. Biofortification may be an effective approach to remedy deficiencies and ought to be seen as a complement to the promotion of non-staple micronutrient-rich crops.

Research and technology development are also essential for enhancing input use efficiency, focusing on soil fertility, water use efficiency, and pest resistance. Modern information and communication technology (ICT) tools, such as geographic information system (GIS) and remote sensing, could contribute significantly to the sustainable use of inputs. Research on delivery systems for these intrinsically knowledge-intensive technologies is crucial, especially in developing-country smallholder systems. Policy research for effective means of reducing incentive distortions in adopting and using efficiency-enhancing technologies is also essential.

2.5.4 Promoting Food System Diversity

Despite rising demand, the persistence of Green Revolution-era policies and structural impediments, as well as a weak private sector, limited the supply responsiveness for vegetables, non-staple food, and other sources of food, including livestock and aquaculture. Creating a 'level policy playing field' that corrects the historical bias in favor of staple crops would help improve the incentives for diversification of production into non-staple foods. An agricultural policy that is 'crop-neutral' (i.e., one that does not favor a particular set of commodities) removes distortions and allows farmers to respond to market signals in making crop production choices (Pingali 2015).

In addition to leveling the playing field, investments in road and transport infrastructure and cold storage systems are required for developing markets for perishable products. Investments in market information systems and farmer connectivity, especially through mobile phones, could significantly cut transaction costs for market participation. Policies promoting food safety should be a priority for upgrading traditional markets and ensuring that human health is safeguarded (Pingali et al. 2015). In addition to reducing foodborne illness and disease, food safety policies can make traditional markets viable places for procurement by modern retail value chains.

Investments in general literacy and specialized training for farmers in meeting quality and safety standards for high-value crops would help integrate smallholders into market value chains. Finally, institutional investments in establishing clear property rights to land and other assets, formalized contractual arrangements that depersonalize market transactions, and access to finance (that is not tied to particular commodities) are essential for diversifying production systems.

2.5.5 Growth that is Inclusive of Rural Women

Despite having an important role in production, women face high costs in accessing capital, engaging in entrepreneurial activities, and adopting technological inputs and mechanization. Therefore, in many developing countries, women-headed households have lower yields and incomes due to poor access to markets and productive resources, affecting their contributions to agricultural productivity. Closing the gender gap and addressing gender-specific transaction costs and agricultural production constraints is crucial to increasing agricultural productivity and women's empowerment.

The two major interventions needed to address gender-specific challenges in agriculture are improved access to product markets and labor savings for rural women. Policy initiatives to promote women's organizations and build capacity to make them self-sustaining are important to tackle gender-specific challenges in production and marketing. Gender-sensitive value chains that make women's participation in high-value markets easier are essential. As women are often involved in agricultural labor and non-marketed household labor, measures to improve labor efficiency and productivity of women will enable cost savings and free up time. Labor-saving technology through mechanization in agriculture is needed to reduce drudgery.

2.5.6 Managing Climate Change Impacts

Mitigating the effects of climate change and the need to increase yield simultaneously will pose a major challenge to the growth and development of the agricultural sector. This challenge could be particularly important for crops that are important to the poor, such as millets and cassava. Little is known about the long-term climate impacts on crops beyond the major staples. To offset the current impact of climate change, investment in R&D to promote heat- and drought-resistant crop technologies and infrastructure investment, like micro-irrigation systems, are necessary. Making these technologies easily accessible to smallholders is also crucial. Policy interventions to promote sustainable agricultural intensification are essential to managing the dual challenge of climate change and productivity growth.

Recollections of Professor Keijiro Otsuka

I first met Professor Kejiro Otsuka in 1987 when I joined the International Rice Research Institute (IRRI) in the Philippines. We have been colleagues and close friends since then. Kei Otsuka's research on technical change in small farm agricultural systems in Asia has had a profound impact on our understanding of the Green Revolution. Kei's research on technology transfer from Asia to Africa has been extremely influential in African agricultural development policy. Kei is a true economist; he always reaches back into his learnings of economic theory and principles to provide explanations and solutions for real-world problems in developing countries. I am honored and delighted to be part of the Festschrift celebrating his enormous lifetime achievements.

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Chapter 3
The Central Luzon Loop Survey: Rice Farming in the Philippines from 1966 to 2021

Kei Kajisa, Piedad Moya, and Fe Gascon

Abstract The Central Luzon Loop Survey in the Philippines is one of the longest-running and ongoing household-level farm surveys in tropical Asia. This chapter reviews the changes in rice farming from 1966 to 2021, with a particular focus on the past decade. The data show that rice yields have stagnated and become more variable despite a prompt and continuous switch to newer modern varieties with an appropriate nitrogen application level since the Green Revolution. This implies that the Green Revolution-type agricultural development is at a crossroads. As background factors, this chapter reviews how the adoption of labor-saving technologies, mechanization, and farm size have changed over time under increasing rural labor scarcity. A subjective assessment of the impact of COVID-19 on rice farming is also discussed.

3.1 Introduction

The Central Luzon Loop Survey in the Philippines (the Loop Survey) is one of the longest-running and still ongoing household-level farm surveys in tropical Asia.[1] The International Rice Research Institute (IRRI) started the survey on the eve of

[1] Other distinguished long-term farm household surveys covering multiple villages include the Village Dynamics in South Asia (VDSA) by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and the Bangladesh Panel initiated by IRRI and succeeded by the Bangladesh Institute of Development Studies (BIDS) and BRAC. Single village, fixed-point long-term surveys include the East Laguna village survey in the Philippines (Hayami and Kikuchi 2000) and Palanpur in India (Bliss and Stern 1982; Lanjow and Stern 1998; Himanshu et al. 2018).

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the Green Revolution in 1966, the year of the official release of the miracle rice, IR8. Since then, the survey has been conducted every four to five years until 2021, generating 14 rounds of datasets, covering a period of more than half a century.[2] The datasets of this feature enable us to explore the situation of rice farming and rice farm families before the Green Revolution, how the situation changed through the progress of the Green Revolution, and the emerging issues in the post-Green Revolution era in the Philippines.

The Loop Survey revealed Green Revolution's substantial impact on the country's food production and poverty alleviation. Among the 34 major publications (books, reports, and journal articles) produced from the Loop Survey, comprehensive documentation from 1966 (first round) to 2012 (12th round) was found in a study by Moya et al. (2015).[3] It shows that the paddy (unmilled rice) yield per hectare had increased from 2.3 tons per hectare (t/ha) in 1966 to 3.9 t/ha in 2011 in the wet (rainy) season and from 1.8 t/ha in 1967 to 5.8 t/ha in 2012 in the dry season, thereby increasing the farmers' rice income. Accordingly, the first-generation Green Revolution farmers increased schooling investment in their children, resulting in an increase in the proportion of secondary- or tertiary-level graduates from 18 to 65% in the same period. These educated children moved to the non-agricultural sector. Hence, although the proportion of rice income increased from 68% in the 1960s to 86% in the 1970s, it decreased successively since then to the level of 17% in the first decade of the twenty-first century ('00s), whereas the proportion of off-farm income and remittances accounted for 34% and 28%, respectively. In general, countries benefiting from the Green Revolution show a similar pattern of agricultural development and income change (Otsuka et al. 2008).

However, Green Revolution-style agricultural development is now at a crossroads. It is ironic that the Green Revolution, which has achieved success through the advancement of seed-fertilizer technology and the adoption of labor-intensive crop care, is now challenged by increasing rural labor scarcity caused by its success. This is an inevitable historical pattern of agricultural transformation in the Philippines and other countries that have started economic 'take-offs' (Viswanathan et al. 2012; Briones and Felipe 2013; Timmer 1988). Furthermore, disasters and infectious disease pandemics are becoming increasingly rampant as contemporary phenomena. The achievement of sustainable rice farming is challenged by these contemporary issues.

This chapter aims to identify emerging issues on rice farming in the post-Green Revolution era in the Philippines using the last two rounds of the Loop Survey, namely the 2015–16 and 2020–21 rounds. This discussion includes the impact of the COVID-19 pandemic on rice farming.

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[2] See Appendix Table 3.4 for the researchers involved in each round. Keijiro Otsuka led the 6th round (1986–87).

[3] See Appendix B of Moya et al. (2015) for the 33 publications (other than Moya et al. 2015) released by 2009.

3.2 Survey Design and Survey Site

The use of ‘loop’ in the name stems from the survey’s sampling feature: selecting sample farm fields along the loop of the national highway passing through six provinces (Fig. 3.1). Randomization of the sample was achieved by specifying the fields to be observed at specific kilometer posts along the main highway (e.g., the 50th, 60th, 70th, etc.). The most important feature of the data is that they were collected from the same fields despite changing operators. Hence, this dataset provides long-term, plot-level panel data. The initial sample size was 95 farmers who cultivated 120 parcels in 1966, gradually decreasing mainly due to land conversion to non-agricultural purposes, thus supplemented in the 1979–80 round, for a total of 148 farmers with 338 parcels. Since then, no compensation has been made, resulting in a sample size of 81, with 126 parcels in the 2021 interview. The sample size for each round is presented in Table 3.1.

The area is known as the country’s rice bowl and has a distinct wet season (WS) and dry season (DS)—the WS begins in May or June and ends in October, and the DS begins in November and ends in March or April. The introduction of large-scale surface irrigation systems in the 1970s and the adoption of low-lift pumps and shallow

Fig. 3.1 Map of the Central Luzon Loop Survey

Table 3.1 Adoption (%) of new technologies, farm size, and area planted with rice (ha), 1966–2021 (The Loop Survey)

Wet season (WS)	1966	1970	1974	1979	1982	1986	1990	1994	1999	2003	2008	2011	2015	2020
Animal	96	90	98	72	67	90	89	75	74	56	59	52	63	39
Power tiller (2 W)			17	47	56	58	85	93	96	99	99	100	99	94
Big tractor (4 W)	11	42	36	30	24	14	18	16	28	26	31	30	31	35
Rotavator							2		2			4	16	52
Manual threshing	13	26	51	46	10	4								1
Small thresher	0	0	5	21	73	96	100	100	100	100	100	100	55	3
Big thresher	87	74	44	31	17									3
Combine harvester												0	45	96
Direct seeding				1	16	15	22	24	21	14	7	8	10	27
Transplanting	100	100	100	100	90	95	85	81	80	87	94	92	90	76

(continued)

Table 3.1 (continued)

Dry season (DS)	1967	1971	1975	1980		1987	1991	1995	1998	2004	2007	2012	2016	2021
Animal	100	100	79	53		69	98	77	67	58	65	65	78	40
Power tiller (2 W)	6	0	43	79		88	90	100	93	100	100	100	100	92
Big tractor (4 W)	47	62	43	9		6	2	9	17	17	18	8	28	42
Rotavator												15	2	49
Manual threshing	24	31		37		3								4
Small thresher			36	44		98	100	100	100	100	100	100	54	8
Big thresher	71	69	64	20										
Combine harvester												0	46	96
Direct seeding				9		48	71	63	54	63	57	30	43	45
Transplanting	100	100	100	91		59	33	41	48	41	44	73	57	61

(continued)

Table 3.1 (continued)

Years	1966–67	1970–71	1974–75	1979–80	1982	1986–87	1990–91	1994–95	1999–2000	2003–04	2008–09	2011–12	2015–16	2020–21
Farm size (annual) (ha)*	2.09	2.54	2.60	1.89	1.78	1.81	1.81	1.7	1.59	1.9	1.75	1.94	2.2	1.79
Area planted with rice in WS (ha)	1.91	2.12	1.86	1.23	1.05	1.40	1.12	1.21	1.17	1.22	1.16	1.22	1.20	1.18
Area planted with rice in DS (ha)	1.49	1.88	1.53	1.38		1.32	1.23	1.18	1.12	1.33	1.21	1.32	1.46	1.37
Sample size	95	62	59	148	135	120	108	100	85	116	107	95	85	81
Number of parcels	120	89	99	338	226	232	254	212	172	263	172	209	129	126
Number of farmers planting in WS	95	62	59	147	135	114	107	99	82	115	101	93	85	77
Number of farmers planting in DS	17	13	14	81	na	64	58	56	46	71	68	66	50	71

Note * Defined as operational landholdings including rented-in and excluding rented-out parcels tube wells in the 1990s have made DS rice farming possible.[4] Accordingly, the crop intensity (taking a value of 2 if fully double-cropped), which was 1.33 in 1966–67, jumped up to 1.55 in 1979–80 due to the availability of surface irrigation systems, and then further increased to 1.82 by 2011–12, mainly due to the expansion of pump irrigation.

The last feature of the survey site is land ownership and tenure distribution. Large rice and sugarcane *haciendas* (plantations) developed in this area during the Spanish colonial period in the nineteenth century. Given this historical background, the Central Luzon region was targeted as the first place for implementing the comprehensive land reform program.[5] From 1966 to 2012, the distribution of tenancy changed from 13 to 47% as owners, 13–29% as leaseholders, 75–5% as share tenants, and 0–19% as borrowers, indicating an increase in owner or leaseholder cultivators who used to be the share tenants. Usually, in other countries, land reforms are implemented at once in a short period, but it is unique in the Philippines that the program has been continuously extended, and the reform is continuing (as of 2021).

The last survey round was conducted under the COVID-19 pandemic using telephone interviews one year after the regular cycle. Hence, it covers the regular period of 2019–20 with recall data and the period of 2020–21. In the telephone interviews, questions were limited to key variables, but they also included questions about the impact of the COVID-19 pandemic. This chapter used only 2020–21 data as the data patterns in 2019–20 are quite similar.

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[4] The completion of the Pantabangan Dam in 1975 and the establishment of the Upper Pampanga Integrated Irrigation System represented the first major irrigation project in the region. The Casecnan Irrigation and Hydroelectric Plant, which commenced in 2002, diverts water from the Casecnan and Taan rivers of Nueva Vizcaya to the Pantabangan Reservoir, further enhancing the expansion of the irrigated area in the region. In the last two decades, the adoption of low-lift pumps and shallow tube wells has been the major source of irrigation expansion, particularly in the dry season.

[5] The Agricultural Land Reform Code (RA 3844), was a major advancement of land reform in the Philippines. It was enacted in 1963 to abolish tenancy and establish a leasehold system in which farmers paid fixed rentals to landlords, rather than a percentage of the harvest. In September 1972, the second presidential decree that Marcos issued under martial law declared the entire Philippines a land reform area. A month later, he issued Presidential Decree No. 27, which had the specifics of his land reform program. The reform attempted to convert share tenants to leaseholders when the landlord owned less than 7 hectares (ha) of land or to amortizing owners when the landlord owned more than 7 ha of land. The reform procedure involved two steps. The first, Operation Leasehold, converted share tenancy to leasehold tenancy with rent fixed at a rate of 25% of the average harvest for the three normal years preceding the operation. The second step, Operation Land Transfer, transferred land ownership to tenants. In the latter operation, the government expropriated the area in excess of the landlord retention limit, with compensation to the landlord being 10% of the land value in cash and the rest in interest-free redeemable Land Bank bonds. The land was resold to the tenants for annual mortgage payments over 25 years, and they were granted a Certificate of Land Transfer (CLT). Upon completion of the mortgage payments, the CLT holders were given Emancipation Patents (EP) on the land, that is, a land ownership title with the restricted right of land sale. In 1988, the Comprehensive Agrarian Reform Program (CARP), which covers non-rice and non-corn areas, was introduced and has been continuously extended (as of 2021). See Moya et al. (2015) for more details.

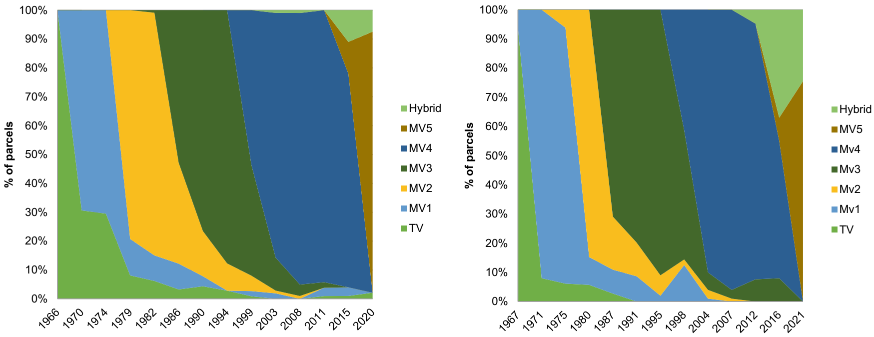

Fig. 3.2 Trends in the adoption of modern varieties in the Wet season (left) and the Dry season (right), 1966–2021 (The Loop Survey)

3.3 Recent Changes

The Asian rice Green Revolution has been led by farmers' vigorous adoption of seed-fertilizer technology under irrigated or favorable rainfed conditions. Figure 3.2 shows the seasonal diffusion of modern varieties (MVs) from 1966 to 2021. Following the analytical style of Estudillo and Otsuka (2001, 2006) and Laborte et al. (2015), the varieties are classified by generation based on their release dates and distinct characteristics, consisting of the traditional variety, the five modern variety generations (MV1 to MV5), and hybrid rice.[6] The figure indicates that the switch from old to new MVs has occurred promptly; more than 70–80% were replaced within four-year intervals. This implies that Loop farmers are active farm managers with strong enthusiasm for newer technologies. Recently, hybrid rice varieties have become popular, particularly in the DS when the risks of pests, diseases, and harsh weather shocks are low under irrigated conditions (Laborte et al. 2015). The hybrid varieties have a potential yield of approximately 10–14 t/ha compared with 6–10 t/ha of the latest inbred varieties. This has proceeded since 2011, and 7% of farmers in the 2020 WS and 24% in the 2021 DS cultivated the hybrid varieties.

In parallel with MV diffusion, farmers increased the application of inorganic fertilizers. The Loop data indicate that the amount of nitrogen applied to rice fields started at 9 kg per hectare (kg/ha) in 1966 (pre-Green Revolution), increased steadily since then, and in the 1987 DS and the 1994 WS reached close to the recommended 100

[6] The MV1 is the first generation of modern varieties released from the mid-1960s to the mid-1970s, including IR8, sharing the trait of being high-yielding without pest and disease resistance. MV2 varieties released from the mid-1970s to the mid-1980s, were characterized as having short maturity with multiple pest and disease resistance traits. MV3 varieties released from the mid-1980s to the mid-1990s, added better grain quality, and a stronger host plant resistance trait, and MV4 (from the mid-1990s to 2005) added tolerance to abiotic stresses and lower amylose content (for soft-cooked rice) but had lower resistance to pests and diseases. MV5 varieties were released after 2005 without taking into account the difference in characteristics with MV4.

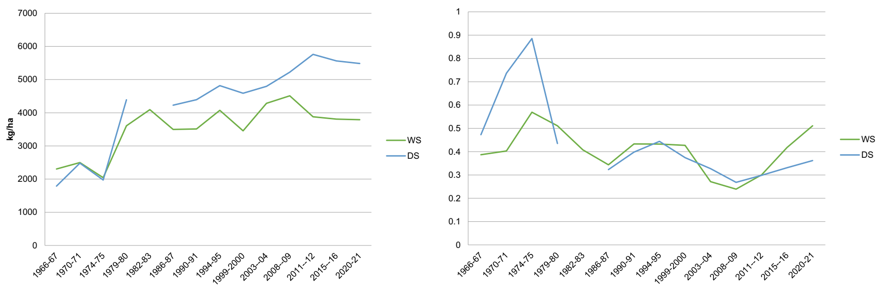

Fig. 3.3 Trends in the mean (left) and the coefficient of variation (right) of paddy yield, 1966–2021

kg/ha level (Moya et al. 2015). The nitrogen application level has been approximately 100 kg/ha since then.

What is the impact of the diffusion of seed-fertilizer technology on rice productivity? Figure 3.3 shows the long-term trend of the mean (Panel A) and coefficient of variation (CV) (Panel B) of the paddy yield (kg/ha). The yield increased sharply during the early phase of the Green Revolution (the 1970s and the 1980s). During this period, the CV increased initially in the 1970s but steadily declined until the early '00s, indicating that the Green Revolution technologies were much riskier than the traditional ones when they were introduced, but gradually standardized.

We can identify two features in the recent rounds: (1) stagnant yield growth in the WS since the late 1990s and in the DS since the 2010s, and (2) the increasing trend of the CV since the 2010s. As we have seen, the adoption of hybrid rice varieties has continued since 2011. However, the yield did not significantly increase. The recent trend indicates that the potential yield has not been fully realized in the fields and that the stability of rice production has been diminished.

This trend may be attributed to two major reasons. First, many sources indicate that natural disaster events, such as floods and insect outbreaks, are increasing in the Philippines, but the varieties commonly planted in recent years (i.e., MV4 and MV5) are characterized by lower resistance to pests and diseases compared to MV2 and MV3 (Laborte et al. 2015). In addition, floods have become more rampant in Central Luzon because newly-constructed factories and roads block water flow to the drainage. In this regard, natural and human-made disasters have hindered yield increases in this region. Second, increasing labor shortages require a structural transformation in rice farming, but this has not been fully achieved. The second point is discussed later in this section.

How has the increasing labor shortage affected rice farming in this area? Table 3.1 shows the trend in the adoption of labor-saving technologies, farm size (operational landholdings including rented-in parcels and excluding rented-out parcels), and the area planted with rice from 1966 to 2021, revealing four features. First, small-scale mechanization proceeded rapidly after the Green Revolution and was completed in the early 1990s. The adoption rate of power tillers (hand tractors) and small threshers reached approximately 100% by the early 1990s.

Second, the adoption of combine harvesters has jumped up in the last two rounds—the government promoted it as a replacement for manual harvesting. Its utilization increased in both seasons from 0% in 2011–12 to 96% in 2020–21. This was the reason for the sharp decline in the use of small threshers to the level of 3% in the 2020 WS and 8% in the 2021 DS.

Third, crop establishment still fully relies on manual labor—it can be done either through transplanting or direct seeding, with the latter—broadcasting seeds directly on a field—being a labor-saving method introduced in this area in the 1980s. However, it is appropriate only for plots with suitable water control because otherwise, the germination of seeds cannot be synchronized. Hence, as shown in Table 3.1, the boom in direct seeding's adoption during the introduction period notwithstanding, particularly in the WS when water control is more difficult; the adoption rate in the WS decreased to merely 7% in 2008. However, the last round survey shows it increased again to 27% in 2020, presumably reflecting increasing challenges in finding a sufficient number of laborers for transplanting. Simultaneously, transplanting machines have not been used in the 2020–21 round. Thus, crop establishment is still a relatively labor-intensive activity, although not as much as in the past when direct seeding technology was unavailable.

Fourth, farm size (shown in the lower part of the table) shows no dramatic change at approximately 2 hectares (ha). Given this farm size, the area planted with rice in the WS declined from approximately 2 ha in the 1970s to approximately 1 ha in the 1980s. It then remained almost unchanged at slightly more than 1 ha. In contrast, the area in the DS was slightly less than 1.5 ha throughout the survey period. To better understand this aspect, we need to consider the land reform issues of this country. The land reform program has continued to be extended, and there is concern that landlords are reluctant to rent out their land for fear of land expropriation, resulting in an inactive land rental market. This could be a hurdle for land consolidation and further progress in large-scale mechanization.

In summary, mechanization is still limited to land preparation, harvesting, and threshing, and enlargement of the farm size has not been realized at the study site. In other words, the agricultural transformation has reached only the halfway mark.

As explained above, crop establishment depends fully on manual labor as of 2020–21. Nevertheless, the labor employment for this activity is also affected by the increasing rural labor shortage. Table 3.2 shows the number and composition of hired labor for crop establishment by labor type from 2012 to 2016 using the recall data collected in the 2015–16 round. We classify hired labor into three categories based on the length of the working period: (1) regular workers who have worked for the interviewee farmer for more than five years in total; (2) occasional workers who have worked for 1–4 years in total; and (3) new workers who worked for the first time.[7]

[7] In our survey module, we also asked questions about where the laborers came from (for example, the same village, different village but still in the same municipality, and different municipality). Since we find that the location and the length of work period are highly correlated so that the workers from the distant locations are relatively newer than the others, we use only the length of work period for our analysis.

Table 3.2 Composition of hired labor for crop establishment, 2012–2016 (The Loop Survey)

Wet season	**2012**	**2013**	**2014**	**2015**
No. of hired labor/ha	23	22	21	26
Hired labor composition (%)				
Regular (≥5 years)	62	61	53	35
Occasional (1–4 years)	21	14	21	37
New	17	25	27	28
Dry season	**2013**	**2014**	**2015**	**2016**
No. of hired labor/ha	23	18	19	19
Hired labor composition (%)				
Regular (≥5 years)	51	54	43	39
Occasional (1–4 years)	36	30	39	39
New	14	16	19	22

Note 2012 WS–2015 DS is based on recall data

The table clearly indicates that it had become more challenging to recruit regular workers, and the farmers had to rely more on new workers in both the WS and the DS. The proportion of regular workers decreased from 62 to 35%, whereas that of new workers increased from 17 to 28% in the WS. A similar trend was observed for the DS. The stagnant and fluctuating yield in recent rounds may stem from the management challenges of new unknown laborers who might not only be unfamiliar with the agronomic characteristics of hiring farmers' particular plots (thus cannot do transplanting efficiently) but also be less reluctant to commit opportunistic behaviors, such as the delay or absence in the appointment and labor effort shirking.[8]

Therefore, Table 3.2 implies that although labor was becoming scarce within the Loop villages, it was still available from distant areas at least until the 2015–16 round. As the Ricardian trap model predicted, the labor wage rate would not rise if this were the case. Figure 3.4 shows the agricultural wage rate trend from 1966 to 2021. It clearly shows that although the nominal wage rate continued to increase sharply, particularly after the 1980s, the real wage rate (deflated by consumer price index [CPI] or paddy price) initially increased from the 1980s until the mid-1990s but was relatively stable in the '00s until the 2015–16 round. However, the real wage rate seems to have started to rise in the 2020–21 round. A sharp increase in the real wage rate in the 1980s is puzzling because economic growth was slow, and population growth was high during that period.

Last, we provide an overview of the impact of the COVID-19 pandemic on rice farming. In our survey period, the 2000 WS and the 2021 DS were the pandemic periods of the country, with a much higher number of cases in the 2021 DS. Anecdotal

[8] When farmers need many laborers for transplanting and manual harvesting, they usually call for a foreman, called a *kabisiliya*, who has his or her group of laborers. Hence, the control of opportunistic behavior is an issue that has to be handled by the kabisiliya. Anecdotal evidence during the interview tells that farmers are becoming more serious about finding a reliable kabisiliya.

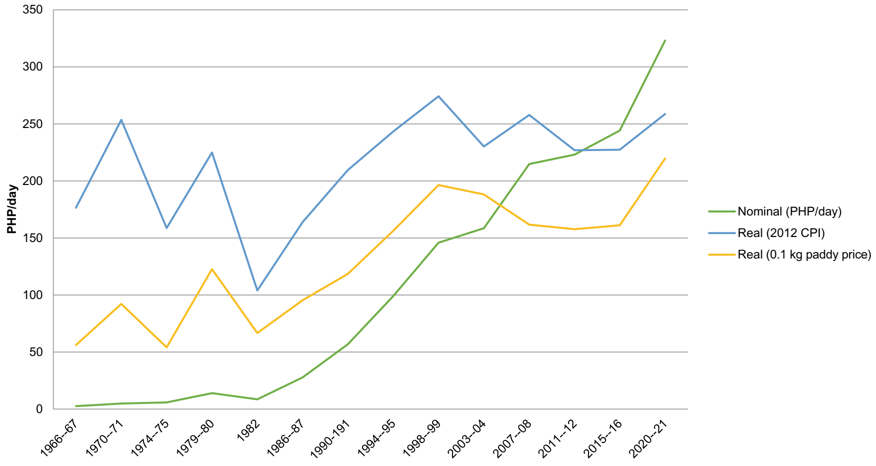

Fig. 3.4 Trends in agricultural labor wage rate, 1966–2021 (Loop Survey for wage and paddy price; Philippine Statistics Authority for CPI)

evidence indicates that, as possible negative effects, external labor activities were restricted, and input and output supply chains had limited activities. Meanwhile, many urban factory workers returned to their rural home villages because of the suspension of factory operations, which might have relaxed labor shortages.

Table 3.3 summarizes the subjective assessments of the aforementioned impacts. Contrary to our initial expectation, less than 15% of the farmers experienced challenges working outside and finding hired labor. Also, only approximately 20% claimed challenges in finding buyers for their harvest. Similarly, only 8% of farmers in the WS and 4% in the DS had challenges accessing chemicals and seeds, whereas 57% and 82% complained of increases in the prices of inputs in the WS and the DS, respectively. Regarding positive effects, approximately 10–20% of farmers recognized an increase in family or hired labor availability. These snapshots indicate that while the pandemic generated an enormous impact on the entire society, its effect on rice farming is limited, seemingly implying relatively stronger resilience of rural livelihoods.

3.4 Conclusion

Rice farming in Central Luzon is at a crossroads. Rice yields have stagnated and have become more variable in the last decade, despite a prompt and continuous switch to newer MVs. We discussed the adoption of labor-saving technologies and mechanization, stagnation of land consolidation and enlargement, increasing labor management challenges, and more rampant natural and human-made disasters. To choose the right direction moving forward from the crossroads, we need further

Table 3.3 Subjective assessment of COVID-19 impact on rice farming, 2020–2021 (The Loop Survey)

	Proportion of 'Yes' among rice farming families (%)	
	2020 WS	2021 DS
Negative effects		
Prohibited from working outside	13	7
Difficulty in finding labor for hire	14	15
Difficulty in finding buyers of harvest	21	21
Difficulty in accessing chemical inputs and seeds	8	4
Increased price of chemical inputs and seeds	57	82
Positive effects		
Increased availability of family labor	11	11
Increased availability of labor for hire	11	20

studies to make rice farming more resilient to rapid demographic changes, rampant disasters, and future pandemics. The Loop Survey can provide important information for this purpose and contribute to drawing useful lessons for Asian countries and show possible future paths for rice-producing Sub-Saharan African countries.

Recollections of Professor Keijiro Otsuka

It is a great asset to my research life that I served as a researcher at IRRI from 2006 to 2012, where Professor Otsuka also served in the 1980s. There I learned the importance of fieldwork and interaction with researchers in other fields. *–Kei Kajisa*

It was an honor for me to know and interact with Professor Kei Otsuka when he was then a Senior Staff and Chairman of the Board of Trustees of IRRI. I learned a lot from his insights and knowledge of IRRI's research and management and how he was instrumental in securing stable funding during his term. *–Piedad Moya*

Professor Otsuka joined IRRI in the mid-1980s, and I was then a research assistant involved in his projects on how technological changes in rice farming affected farmers' socioeconomic conditions in different areas in the Philippines. It was a great learning experience to pick up his approaches to collecting field information. I am greatly honored and privileged to have worked with a well-known economist and one who has a passion for sharing his research knowledge and experiences in his field of expertise. *–Fe Gascon*

Appendix

See Table 3.4.

Table 3.4 Researchers and funding sources of the surveys

Years	Persons responsible	Researchers/Enumerators who conducted the interviews	Funding source
1966–67	Randolph Barker, Stanley Johnson, Ben Hur Aguila	Violeta Cordova	IRRI
1970–71	Randolph Barker, Violeta Cordova	Fe Gascon, Geronimo Dozina, Jr.	IRRI
1974–75	Randolph Barker, Robert W. Herdt, Chandra Ranade	Ricardo Guino, Bonifacio Cayabyab	IRRI
1979–80	Robert W. Herdt, Ricardo Guino, Violeta Cordova	F. Gascon, Dolor Palis, Sylvia Sardido, Perla Pantoja, Aida Papag	IRRI
1982	Robert W. Herdt, Fe Gascon	Dolor Palis, Sylvia Sardido, Perla Pantoja, Leonida. Yambao	IRRI
1986–87	Keijiro Otsuka, Fe Gascon	Dolor Palis, Luisa Bambo, Esther Marciano	IRRI
1990–91	Cristina David, Fe Gascon	Joel Reaño, Alvaro Calara, Luisa Bambo, Milagros Obusan	IRRI
1994–95	Mahabub Hossain, Fe Gascon	Esther Marciano, Joel Reaño	IRRI
1998–99	Mahabub Hossain, Fe Gascon	Joel Reaño, Teodora Malabanan, Aida Papag, Nancy Palma	IRRI
2003–04	David Dawe, Kazushi Takahashi, Fe Gascon	Maria Shiela Valencia, Milagros Obusan, Violeta Cordova, Mary Rose San Valentin	FASID*
2007–08	Kei Kajisa, Pie Moya	Fe Gascon, Mary Rose San Valentin	FASID*
2011–12	Sam Mohanty, Pie Moya	Joel Reaño, Mary Rose San Valentin, Teodora Malabanan	IRRI
2015–16	Kei Kajisa, Pie Moya, Fe Gascon	Mary Rose San Valentin, Teodora Malabanan	JSPS**
2019–21	Kei Kajisa, Pie Moya, Fe Gascon	Mary Rose San Valentin, Teodora Malabanan	JSPS**

Notes * Foundation for Advanced Studies on International Development (FASID), Tokyo, Japan; ** Japan Society for the Promotion of Science (JSPS)

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Chapter 4
Diffusion of Submergence-Tolerant Rice in South Asia

Takashi Yamano

Abstract Climate change is expected to increase the incidence and magnitudes of extreme weather events. To help farmers mitigate the expected impacts of extreme weather events, abiotic stress-tolerant crop varieties have been developed. The diffusions of the stress-tolerant crop varieties, however, have been limited. This chapter reviews recent studies on the adoption and impacts of the submergence-tolerant rice varieties in South Asia. Studies have identified significant benefits of those rice varieties in South Asia using various survey and analytical methods. However, farmers have problems identifying submergence-tolerant rice varieties in informal seed markets. Using DNA fingerprinting, a study found that many farmers in Bangladesh could not identify varietal names correctly. Effective public interventions are needed to help farmers in flood-prone areas adopt submergence-tolerant rice varieties.

4.1 Introduction

Climate change studies predict that the frequency and intensity of extreme weather events will continue to increase (IPCC 2018; ADB 2021). In developing countries, agriculture absorbs more than 60% of the damage and loss caused by climate-related disasters across all economic sectors (FAO 2021). In Asia, flood-prone areas are also major rice-producing areas where farmers depend on rice to support their livelihoods, and flood risks are high in rainfed areas where resource-poor farmers tend to reside. To mitigate flood-related losses in rice production, the International Rice Research Institute (IRRI) and its collaborators have developed rice varieties tolerant to submergence.[1]

[1] IRRI and other international agricultural research institutes have been developing and disseminating stress-tolerant crop varieties and other climate-smart agricultural technologies. Yamano et al. (2016) and Mishra et al. (2022) present reviews of recent agricultural technologies and their impacts among farmers in developing countries.

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Despite the benefits of stress-tolerant rice varieties, the adoption of submergence-tolerant rice varieties has been limited. Although many adoption studies on agricultural technology in developing countries exist,[2] recent studies focus on social networks and farmer-to-farmer technology extension (Takahashi et al. 2019). Because the adoption of submergence-tolerant rice varieties requires seed costs and no additional rice production knowledge, studies found information access as a major adoption constraint (Yamano et al. 2018; Veettil et al. 2021; Bairagi et al. 2021). By conducting a randomized controlled trial (RCT), Emerick and Dar (2021) show that farmer field days effectively encourage farmers to adopt submergence-tolerant rice varieties in Eastern India.

Submergence-tolerant rice varieties, or other stress-tolerant crops, exhibit few stress-tolerance traits under normal conditions. Their benefits become visible only when the specific stresses they are tolerant of occur. Thus, the adoption process of farmers and diffusions of the varieties in target areas would be different from other agricultural technologies that exhibit technological advantages under normal conditions.[3] In addition, farmers have difficulties identifying seeds of stress-tolerant rice varieties in informal seeds markets. To better understand how farmers gather information about submergence-tolerant rice varieties and examine their ability to identify rice varieties they cultivate, this paper reviews (1) studies on the adoption of submergence-rice varieties and (2) studies that use DNA fingerprinting for rice variety identification in South Asia.

4.2 Background

Rice plants respond to flooding stress through two mechanisms: (1) their ability to elongate above rising floodwater levels, which allows them to avoid complete submergence,[4] and (2) submergence tolerance through which certain rice varieties survive submergence of ten days or more, particularly through metabolic adjustment in shallow water (Xu et al. 2006; Mackill et al. 2012). In the 1990s, rice scientists found that the second mechanism of the submergence tolerance of certain rice varieties is controlled by a single major quantitative trait locus (QTL),[5] named Sub1, which

[2] Doss (2006) and Foster and Rosenzweig (2010) provide reviews.

[3] For instance, during the Green Revolution, modern rice varieties were easy to identify because they were shorter and produced significantly more grains than traditional rice varieties (David and Otsuka 1994).

[4] They are called floating rice in some areas and their genetic mechanisms have been identified (Hattori et al. 2009).

[5] Single major quantitative trait locus (QTL) is a section of DNA that correlates with variation in a phenotype.

provides tolerance to complete submergence for up to 14 days. By using marker-assisted backcrossing (MAB),[6] rice scientists successfully introgressed[7] the Sub1 QTL into Swarna (Neeraja et al. 2007). Subsequently, many Sub1 varieties[8] have been developed using popular rice varieties in target areas. Studies in agronomy and agricultural economics found that submergence-tolerant rice experiences no significant yield penalty under normal conditions but performs better under submergence than other varieties (Sarkar et al. 2006).

To observe the performance of Swarna-Sub1 on farmers' fields, Dar et al. (2013) conducted an RCT in Odisha, India. Half of the 128 flood-prone villages across eight blocks in Balasore and Bhadrak districts were randomly assigned to treatment in 2011. Five farmers were randomly selected in each treatment village to receive 5 kg (kg) Swarna-Sub1 seeds, which can be cultivated on 0.1–0.2 ha. The authors found that Swarna-Sub1 had an estimated 45% increase in yields over other popular rice varieties when fields were submerged for ten days. Further, in a subsequent study based on the Odisha RCT, Emerick et al. (2016) found that submergence-tolerant rice induced farmers to apply more inputs, presumably because of the reduced risks from floods.

In the most recent study coming out from a series of RCT studies from Odisha, Emerick and Dar (2021) implemented three different ways to select seed recipient farmers/demonstrators for dissemination of Swarna-Sub1 in 100 villages.[9] Then, in randomly selected 50 treatment villages, they conducted field demonstration days promoting Swarna-Sub1. The results indicated that the field days increased adoption rates by 40%. This is an encouraging result supporting the effectiveness of dissemination efforts. Their results show no differences among the three different selections of recipient farmers.

4.3 Adoption Studies of Submergence-Tolerant Rice in Bangladesh and India

To better understand how submergence–tolerant rice varieties spread among farmers, a series of adoption studies were conducted in flood-prone areas in northern Bangladesh and Eastern India (Yamano et al. 2018; Bairagi et al. 2021; Raghu et al. 2022). The three studies took different sampling strategies.

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[6] After crossing two rice varieties, scientists examine DNA markers of new seeds and select ones with a set of desirable markers. After a few seasons of multiplications and selections, they complete a MAB process.

[7] Introgression is the gradual movement of genes from one species into the gene pool of another, when there is some opportunity for hybridization between them.

[8] For this reason, some studies call submergence-tolerant rice varieties with Sub1 QTL as Sub1 varieties. In this review, we use 'submergence-tolerant rice varieties' because it is a more general term, possibly including submergence-tolerant rice varieties without Sub1 QTL.

[9] The three selection processes of seed recipients included selection by village officials, by villagers in participatory selection, and by local women groups.

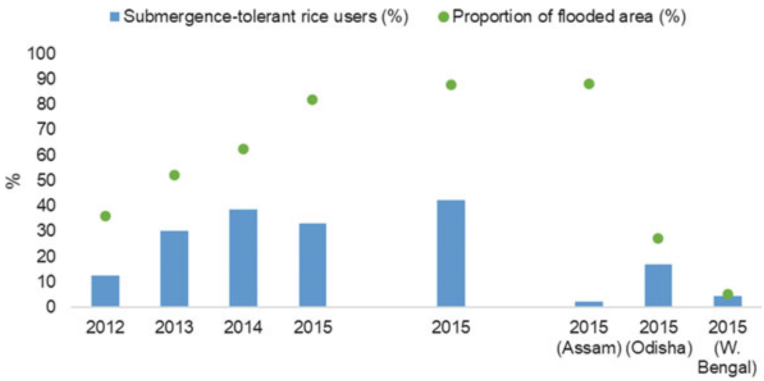

Fig. 4.1 Adoption of submergence–tolerant rice and flood experience in Bangladesh and India (Yamano et al. 2018; Bairagi et al. 2021; Raghu et al. 2022). *Notes* 465 farmers in Lalmonirhat, Kurigram, and Rangpur districts; 1,020 farmers in Gaibandha, Jamalpur, Kurigram, Lalmonirhat, Rangpur, and Sherpur districts; 1,544 farmers in Assam, 1,600 farmers in Odisha, and 1,600 farmers in West Bengal, India

Yamano et al. (2018) selected villages where submergence–tolerant varieties were distributed between 2009 and 2012. They obtained lists of villages and names of seed recipient farmers in three districts in northern Bangladesh. The authors conducted the first survey of 465 farm households in 2013, asking about the 2012 *aman* season (July–December growing season). In 2016, asking about the 2015 aman season, the authors conducted a follow-up survey, revisiting the same respondents. The results of the panel surveys are presented in Fig. 4.1.

In 2012, the adoption rate was only 12%, although 37% of the sample households experienced floods. In subsequent years, the adoption rate increased to 30% in 2013 and 39% in 2014 before declining to 32% in 2015. In 2013 and 2014, the proportions of farmers who experienced floods increased to 52 and 62%, respectively. In 2015, floods were severe. More than 80% of the sample farmers in this study reported floods in 2015.

To assess the impacts of the 2015 floods, another survey was conducted in 2016 in northern Bangladesh by Bairagi et al. (2021). They covered six districts where the 2015 floods occurred. Unlike Yamano et al. (2018), their sampling did not depend on prior distributions of submergence–tolerant rice varieties. Thus, their respondents should be considered as a representative sample of flood-prone areas in northern Bangladesh. Nevertheless, they found a higher adoption rate, at 42%, than Yamano et al. (2018) did in 2015. About 90% of the surveyed households experienced floods in the 2015 aman season.

In India, a survey was conducted in flood–prone districts of three states (i.e., Assam, Odisha, and West Bengal) in 2016 (Raghu et al. 2022). There were 160 randomly selected villages in flood-prone areas in each state. From the total of 480 villages in the three states, 4,750 farm households were randomly selected. The results found that only a small number of farmers (around 2%) adopted submergence-tolerant rice varieties in Assam, although heavy floods occurred during the 2015 *kharif* season. The adoption rate was relatively high in Odisha at 16.7%, where about 27% of areas were affected by floods in 2015. On the other hand, the adoption rate in West Bengal was only 4.2%, while the proportion of flooded area was only 5%. Based on the 2015 flood information alone, it seems farmers in Assam should have been targeted more in the promotion of submergence-tolerant rice varieties.

4.3.1 Yields and Profits

All three studies discussed found yield advantages of submergence-tolerant rice over other rice under normal and submergence conditions. According to Yamano et al. (2018), in the 2012 aman season, the average yields of the flood-tolerant rice varieties were higher than their parental varieties under normal and submergence conditions (Fig. 4.2). However, the observed yield differences should not be considered causal impacts of the submergence-tolerant rice varieties. First, farmers who adopt new varieties could be progressive farmers who are more capable than other farmers. Second, Emerick et al. (2016) observed that farmers may allocate more inputs to submergence–tolerant rice varieties because of reduced risks of flood damage. Third, submergence-tolerant rice varieties could have been adopted on flood–prone plots and had a low yield because of the location.

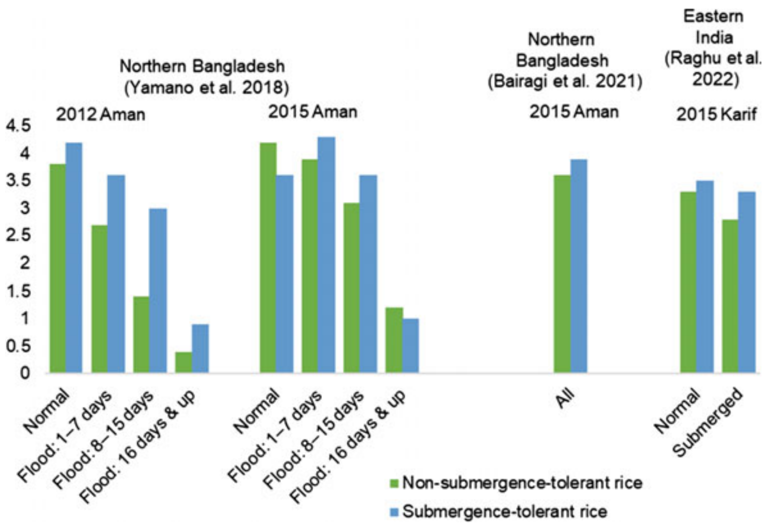

Fig. 4.2 Yields (t/ha) of submergence–tolerant varieties and other rice varieties (Yamano et al. 2018; Bairagi et al. 2021; and Raghu et al. 2022). *Note* See Fig. 4.1 for details on the study areas

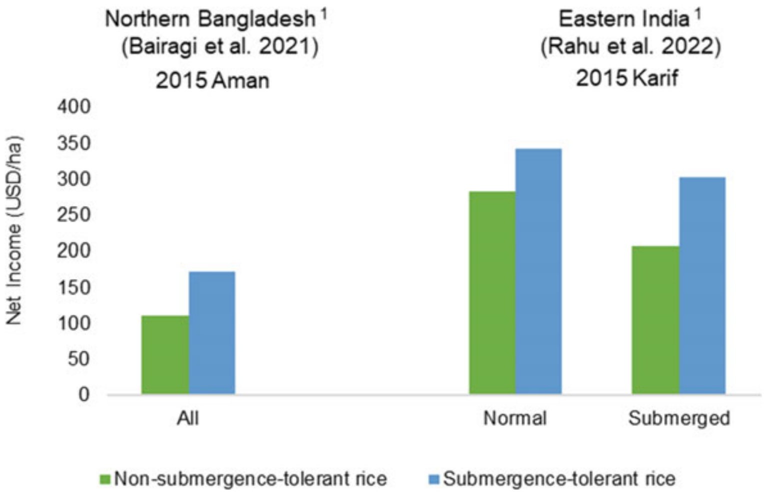

Fig. 4.3 Net income (USD/ha) from submergence-tolerant varieties and other rice (Yamano et al. 2018; Bairagi et al. 2021; and Raghu et al. 2022). *Notes* See Fig. 4.1 for details on the study areas. Exchange rates used: USD 1 = IDR 67.2; USD 1 = BDT 78.4

Both Bairagi et al. (2021) and Raghu et al. (2022) realized the selection problem and employed an endogenous switching regression (ESR) model to identify the impacts of the submergence–tolerant rice varieties on different outcomes. Both studies observed higher yields for the submergence–tolerant than other rice varieties. The results from the ESR model found yield impact as a 10.2% increase among the adopters and a 7.7% increase among the non–adopters (Bairagi et al. 2021). In India, Raghu et al. (2022) found the yield impact as a 29.6% increase among the adopters. Among non-adopters, the expected impact was 7.7%, as noted in Bairagi et al. (2021). The two studies identified larger causal impacts than the observed differences.

In addition to the production outputs, farmers consider profit or net income when they decide to adopt new agricultural technology.[10] The observed net incomes are presented in Fig. 4.3. Both studies found higher net incomes for the submergence–tolerant rice varieties than other rice varieties. The ESR model in Bairagi et al. (2021) suggested that the impact of submergence-tolerant rice varieties on net income would be 145% among adopters and 48% among non–adopters. Raghu et al. (2022) found that the average treatment effect (ATE) among adopters and non–adopters of the submergence-tolerant rice varieties on net income ranged from 31 to 60% under submergence, depending on estimation models. Under normal conditions, it would be in the range of 18–27%. These studies suggest that the expected gains in net income would be large for farmers in flood-prone areas in northern Bangladesh and India.

[10] In studies of agricultural economics, net income is usually calculated after subtracting paid-out costs from revenues, while profit is calculated by subtracting imputed own labor costs from net income.

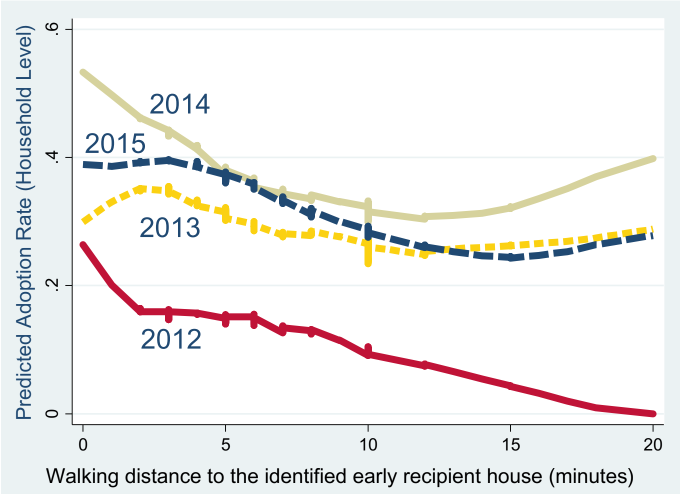

Fig. 4.4 Adoption rate of submergence-tolerant rice in terms of walking distance to the identified seed recipient's house (Yamano et al. 2018)

4.3.2 Farmer-To-Farmer Information Exchange and Adoption

To investigate how to disseminate submergence-tolerant rice varieties among farmers, Yamano et al. (2018) focused on the information and seed exchanges between seed recipient farmers and their neighbors. During the interviews, enumerators showed a list of the seed recipients in the village and asked respondents to identify one recipient that the respondent knew best. The recipient farmers tended to be recognized as progressive farmers in each village.[11] After identifying one recipient farmer, respondents were asked about the walking distance (in minutes) from the respondent's house to the identified seed recipient's house. Figure 4.4 shows the relationship between the distance to the identified recipient farmer and the adoption of the submergence-tolerant rice varieties. From the figure, the authors found that the adoption rate was higher among farmers who were located closer to the identified seed recipient.

[11] Yamano et al. (2015) conducted surveys in 50 villages in Uttar Pradesh and Odisha, India, where demonstrations of Swarna–Sub1 took place. They found that the seed recipient farmers had higher scores on self-perception toward adoption of new agricultural technologies than the representative farmers. Farmers from scheduled castes, female farmers, and less educated farmers had low scores on self–perception.

4.3.3 Seed Sources

In the survey region, government agencies and non-government organizations (NGOs) have promoted submergence-tolerant rice varieties since 2009. At the same time, private seed dealers are also involved in seed production multiplications and sales. Figure 4.5 shows the proportions of the main seed sources of submergence-tolerant rice seeds among the adopters in Yamano et al. (2018). In 2012, 56% of the users used their own seeds from the previous season. In the same year, about 25% of the users obtained seeds from other farmers, and another 16% obtained seeds from NGOs; no farmer obtained seeds from shops or dealers in 2012. In 2013, however, farmers bought the seeds at local shops and dealers. The proportion of users who bought the seeds increased to 26% in 2013 and 40% in 2015. In the same period, the proportion of users who obtained the seeds from the government and NGOs declined to 21% in 2015. In 2015, the private seed sector became the largest seed source of the submergence-tolerant rice varieties.

The seed information sources in Fig. 4.5 relied on farmers' identification of rice varieties. There are no mechanisms to verify seed identity in the informal seed markets and farmer-to-farmer seed exchanges. Thus, farmers' poor ability to identify rice variety names has been the main limitation of these adoption studies, and this has been addressed in studies using DNA fingerprinting, as discussed in Sect. 4.4.

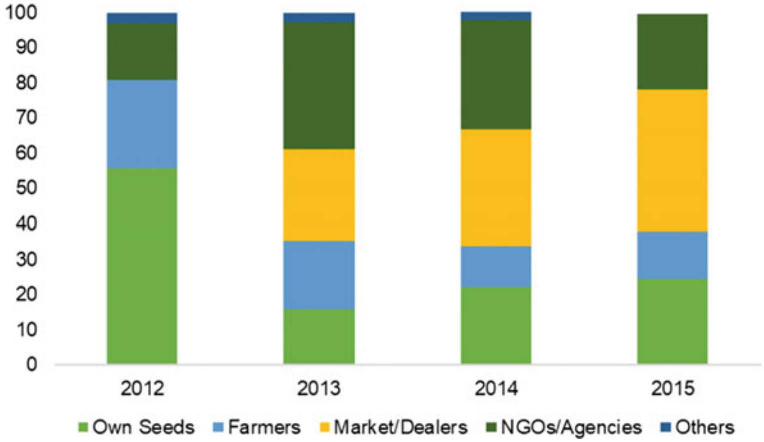

Fig. 4.5 Seed sources of submergence-tolerant rice varieties in 2012–2015 in northern Bangladesh (Yamano et al. 2018)

4.4 DNA Fingerprinting of Farmers' Seed Samples

Realizing farmers' poor ability to identify rice variety names, researchers often grouped rice varieties (Estudillo and Otsuka 2006). When detailed survey data on variety adoptions were absent, studies relied on experts (Tsusaka et al. 2015). Without reliable area estimates under different rice varieties, rice breeders and policymakers are left with little guidance in understanding farmers' preferred rice varieties.

To obtain accurate information on the varietal identification of crops produced by farmers, some studies have used DNA fingerprinting, which has become available and affordable. It has been applied to track the adoption of wheat (Gade et al. 2021) and rice (Kretzschmar et al. 2018) varieties. These studies collected seeds or leaves from farmers' fields. Then, genome-wide markers, such as single nucleotide polymorphisms (SNPs), were used to identify the sample varieties against a reference library of existing varieties.

In the case of submergence-tolerant rice varieties, varietal identification is even more difficult because they are designed to possess characteristics of one of their parent varieties. The only difference is the presence of the Sub1 QTL in Sub1 varieties. DNA fingerprinting was conducted on rice seeds collected from major rice-producing areas of Bangladesh to investigate the issue. The main results are summarized in Yamano et al. (2017) and Kretzschmar et al. (2018).

The authors conducted cross-section surveys of 3,000 households in Bangladesh, 1,500 households each in 2014 and 2015,[12] and collected seed samples from almost 20% of the sample households. In total, 1,380 seed samples were collected from 544 farmers in Bangladesh. Later, the seeds were planted in individual pots, and their leaves were collected in individual plastic bags. The plastic bags were sent from Bangladesh to the IRRI Headquarters located in Los Baños, Laguna, Philippines. Instead of rice seeds, leaves were used to extract DNA because it was considered easier and more accurate to extract DNA from leaves than seeds. The genotyping of the farmer and breeder seed samples was conducted using Illumina Infinium 6 K SNP chips. Out of over 6,000 DNA data points, about 4,000 data points were used to genotype farmers' seeds.

The results of the varietal identification are presented in Fig. 4.6. The most popular rice variety in Bangladesh was Swarna, developed in the 1980s in India. Interestingly, Swarna was never officially released in Bangladesh. Thus, farmers probably smuggled Swarna across the border between the two countries. Figure 4.6 also shows the levels of DNA matches between the samples from farmers and the ones in the reference library. Not all samples were identified as 100% matches of those in the reference library. In fact, old rice varieties tended to have low levels of DNA matches. This may be because rice may lose DNA purity over time.

Note that new varieties developed in or after 2007 tended to have 100% matches. About 5% of the sample were identified as BR11-Sub1, while just over 1% were

[12] The surveys covered all rice–producing areas, not only in northern Bangladesh, so that the surveys were representative of rice–producing areas in Bangladesh.

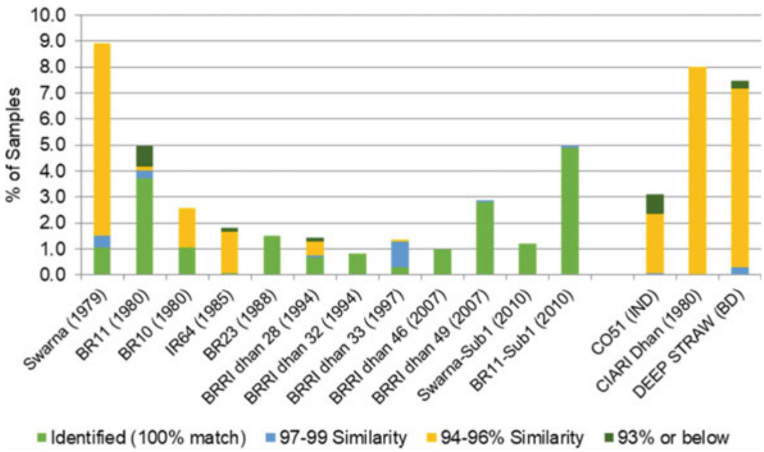

Fig. 4.6 DNA fingerprinting identification of rice varieties in Bangladesh (Yamano et al. 2017)

identified as Swarna-Sub1. Thus, DNA fingerprinting confirms that Sub1 varieties have been disseminated in Bangladesh.

Note that new varieties developed in or after 2007 tended to have 100% matches. About 5% of the sample were identified as BR11-Sub1, while just over 1% were identified as Swarna-Sub1. Thus, DNA fingerprinting confirms that Sub1 varieties have been disseminated in Bangladesh.

Regarding the farmers' ability to identify rice varieties to cultivate, Yamano et al. (2017) found that they identified newer varieties more accurately. Table 4.1 compares the identification of varieties by farmers and DNA fingerprinting. For this analysis, the authors used strict DNA identification (i.e., 99–100% accuracy with the best match in the reference library). Because old varieties were poorly identified by DNA fingerprinting, the proportions of correct identifications tend to be small.

For BR11–Sub1, farmers' identifications were 72% accurate. This means that 72% of the 50 seed samples they reported as BR11–Sub1 were actually BR11–Sub1, according to DNA fingerprinting. DNA fingerprinting found 64 samples as BR11–Sub1, suggesting that some farmers reported BR11–Sub1 under different names. The results indicated that farmer identifications would underestimate the adoption or area coverages of BR11-Sub1. For Swarna–Sub1, the results indicated that farmers tended to over–identify Swarn–Sub1, leading to overestimations of Swarna-Sub1 adoptions and area coverages.[13]

The DNA fingerprinting results are interesting and have implications for adoption studies of new varieties of rice and other crops. But DNA fingerprinting studies are few. As DNA fingerprinting becomes widely available at low costs, the technology is expected to be applied to adoption studies and to monitoring seed food supply chains, food safety, or nutrition studies.

[13] More results from the same samples are reported in Kretzschmar et al. (2018).

Table 4.1 Farmers' identifications of rice variety names in Bangladesh

Variety	Farmer identification	DNA identified 99–100%	Correctly identified by farmers	Direction of area estimate bias
	(A)	(B)	(C)	(D)
	Number	Number	%	
Swarna	177	14	5.6	Overestimation (A > B)
BR11	69	49	31.9	Overestimation (A > B)
BR10	30	14	13.3	Overestimation (A > B)
IR64	0	1	0	Small bias
BR23	22	20	0	Small bias
BRRI dhan 28	8	9	0	Small bias
BRRI dhan 32	8	11	0	Small bias
BRRI dhan 33	15	4	0	Overestimation (A > B)
BRRI dhan 46	4	13	100	Underestimation (A < B)
BRRI dhan 49	47	37	57.4	Overestimation (A > B)
BR11–Sub1	50	64	72.0	Underestimation (A < B)
Swarna–Sub1	49	16	14.3	Overestimation (A > B)

Source Yamano et al. (2017)

4.5 Conclusion

This chap reviewed recent studies on the adoption and impacts of submergence-tolerant rice varieties in South Asia. Rice scientists have identified a gene component that provides tolerance to complete submergence for up to 14 days in the 1990s. Since then, many submergence-tolerant rice varieties have been developed and disseminated in flood-prone areas in Asia. Yet, adoption studies found that the adoption levels of the submergence-tolerant rice varieties are lower than expected in flood-prone areas in Bangladesh and India, leaving potential gains from mitigated flood damage in these areas. There are several policy recommendations to realize the gains.

First, effective information campaigns may help farmers adopt submergence-tolerant rice varieties in flood-prone areas. One panel data study found that submergence experience in the previous year increased the adoption of submergence-tolerant rice varieties in the following year in northern Bangladesh. Other adoption studies have found that increased access to information about submergence-tolerant rice varieties would increase adoption among farmers. Thus, information campaigns should be better targeted to areas where floods frequently occur so that farmers can observe the benefits of the submergence-tolerant rice varieties.

Second, better seed quality monitoring systems need to be in place. It is difficult for farmers to monitor the quality and names of the varieties of rice seeds that they buy and grow. Without accurately knowing the characteristics of their rice varieties, they cannot benefit fully from their rice production. DNA fingerprinting technology is becoming available at low costs. Public monitoring may help seed supply chains maintain seed quality.

The review in this chap suggests large potential gains from submergence-tolerant rice varieties in flood-prone areas in South Asia. Frequent floods also occur in areas outside of South Asia, and submergence-tolerant rice varieties suitable for such areas have been developed. More studies should be conducted to examine the diffusion of such varieties outside of South Asia.

4.6 Recollections of Professor Keijiro Otsuka

Otsuka sensei and I graduated from the same department at Hokkaido University, Japan, although, of course, he did so several decades before me. Because my teacher was a friend of Otsuka sensei, we received a proofread version of his Oxford University book with Hayami sensei. After reading the book, I immediately decided to follow them. Some years later, I joined GRIPS and was fortunate enough to start the RePEAT project with Otsuka sensei. We spent many days traveling to rural villages in Ethiopia, Kenya, and Uganda, endlessly talking about farmers' problems, analyzing data, and publishing papers. Otsuka sensei's energy and sincere attitude toward work pushed me to work hard. I cannot say enough to express my gratitude for his mentorship.

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Chapter 5
Toward a Green Revolution in Sub-Saharan Africa: Farm Mechanization in the Mwea Irrigation Scheme

Timothy Njagi and Yukichi Mano

Abstract Governments in Sub-Saharan Africa (SSA) have made concerted efforts to improve farmers' adoption of modern technologies in their farm operations to realize a rice Green Revolution, improve food security, and alleviate poverty. However, smallholder farmers' access to farm mechanization in SSA remains constrained due to supply-side and demand-side challenges. On the supply side, the market for agricultural machinery services is often underdeveloped. On the demand side, the smallholders with inadequate knowledge of improved rice cultivation practices have limited demand for mechanized services despite increasing wage rates. This study analyzes the mechanization process of rice farmers in the Mwea Irrigation Scheme, Kenya. The Mwea Irrigation Scheme is the most advanced rice production area in SSA, with farmers familiar with improved rice cultivation practices, well-functioning input credit markets, and millers adopting modern milling technologies, enabling local rice to compete with imported Asian rice. Analyzing original data collected in 2011, 2016, and 2018, we found that most farmers in Mwea implemented rotavation using tractor services provided by farmers' cooperatives, while they implemented leveling using draft animals. Non-cooperative members reduced tractor use and adopted draft animals to implement both harrowing and leveling, implying the importance of a well-developed mechanization service market.

5.1 Introduction

Sub-Saharan African (SSA) countries and international organizations have been making concerted efforts to facilitate farmer adoption of modern farming technologies to realize the rice Green Revolution, improve food security, and alleviate

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poverty. These technologies include appropriate productivity-enhancing and labor-saving farm-level technologies, such as farm mechanization. In the case of Asia, population pressure on farmland has induced rice farming intensification since the 1960s (Hayami and Ruttan 1985). Farmers implemented intensive land preparation using draft animals, which facilitated the adoption of proper rice cultivation practices and seed-fertilizer technologies during the rice Green Revolution (David and Otsuka 1994). As the farm wage and cost of draft animals increased, farmers adopted farm machinery, like tractors (Binswanger 1978).

But farming intensification and the adoption of tractors have been slow in SSA. Farmers are less familiar with intensive land preparation because of the little use of draft animals in rice farming due to the prevalence of the tsetse fly-transmitted sleeping sickness (trypanosomiasis) (Alsan 2015), coupled with deteriorating animal health services and recurring droughts (Takeshima et al. 2015, 2013). In Cote d'Ivoire, farmers that intensively prepared land using two-wheel tractors more intensively applied fertilizer and used more labor to carefully implement proper agronomic practices, such as straight-row transplanting (Mano et al. 2020). However, few studies examine the use of tractors in the adoption of cultivation practices, productivity, and profitability from rice farming in SSA.

This study attempts to fill this gap in the literature by analyzing the adoption of tractors and other farm machinery in rice farming in the Mwea Irrigation Scheme in Kenya, using original data collected in 2011, 2016, and 2018. We studied rice farming in the Mwea Irrigation Scheme because it is a leading rice production area in terms of technology adoption and productivity in SSA (Njeru et al. 2016; Kikuchi et al. 2021; Mano et al. 2022). The Japan International Cooperation Agency (JICA) introduced small horsepower mechanized inputs coupled with other yield-enhancing technologies in 2014, and our data in 2011 and 2016 allows us to examine farm mechanization over the critical period. We explored which type of farmer was more likely to mechanize. This study also analyzed the possible complementarity between mechanization and other modern agricultural technologies. We draw vital policy implications to promote mechanization and improve food security in Kenya, in particular, and SSA in general.

The rest of this chapter is organized as follows. Section 5.2 explains the development of rice farming in the Mwea Irrigation Scheme in Kenya. We also briefly introduce the three studies we conducted in the Mwea Irrigation Scheme with Professor Keijiro Otsuka. Section 5.3 describes the original data used in this study, and Sect. 5.4 provides descriptive analyses. Section 5.5 concludes the paper.

5.2 Mwea Irrigation Scheme

This paper analyzes the development of rice farming and mechanization in the Mwea Irrigation Scheme, Kenya's leading rice production area, situated 90 km northeast of Nairobi. This scheme has 8,500 ha of irrigated paddy area and grows primarily improved Basmati rice[1] with two crop cycles (Njeru et al. 2016; Kikuchi et al. 2021). The Mwea Irrigation Scheme is the oldest[2] and largest among the four major gravity-based irrigation schemes and produces 80% of the paddy rice produced in Kenya. The scheme previously consisted of five sections (Mwea, Tebere, Thiba, Karaba, and Wamumu) and gradually expanded. The government retains land ownership in the irrigation scheme, with farmers being allocated land with transferable use rights. Farmers were initially given four 1-acre parcels (equivalent to 1.6 ha [ha]) per household, but some farmers have divided and bequeathed land (use rights) to their offspring. Currently, the average farm size is 1.2 ha.

The authors of this chapter are former students of Professor Keijiro Otsuka who are fortunate to have had opportunities to continue working with him and pursue the possibility of the rice Green Revolution in SSA by examining the development process of rice farming and related sectors in the Mwea Irrigation Scheme. We have investigated the effect of credit on input application and rice productivity (Njeru et al. 2016), the economic viability of the Mwea Irrigation Scheme (Kikuchi et al. 2021), and the technology improvement in the rice milling sector toward the development of rice value chains and the quality and price of local rice to compete with imported rice from Asia (Mano et al. 2022). Because the Mwea Irrigation Scheme is the leading rice production area in SSA, we have learned many important lessons that may contribute to realizing the rice Green Revolution in SSA.

More specifically, Njeru et al. (2016) examined the efficiency of the input credit market in Mwea by comparing the fertilizer application and rice production performance among farmers borrowing from different sources and non-borrowers. After the liberalization of the rice farming system in the Mwea Irrigation Scheme in 1999,[3] a farmers' cooperative, the Mwea Rice Growers Multipurpose Co-operative Society (MRGM), started providing farm inputs on credit. MRGM charged a monthly interest rate of 1% on the value of credit advanced to farmers. Farmers were only required to deliver paddy enough to cover their credit and allowed to sell the remaining harvest to any buyer.[4] To fill the credit demand of farmers who could not access credit from MRGM, many rice traders started to also provide credit to farmers in the early 2000s. The number of farmers receiving credit from traders has increased even though the interest rates were as high as 100% for three months. This is mainly because of the high perceived risks influenced by their history of defaulting on MRGM credit. The

[1] Improved Basmati is a cross-breed between Basmati and high-yielding modern varieties and is widely grown in India and Pakistan. It is of lower quality but is higher yielding than original Basmati rice. A small amount of other rice varieties are produced solely for farmers' domestic consumption.

[2] Mwea Irrigation Scheme was established in 1954.

[3] Similar to the inefficient state management usually seen in managing local commons, such as large-scale irrigation schemes in Asia (e.g., Ostrom 1990; Bardhan 2000; Bardhan and Dayton-Johnson 2002), the state management suffered several shortcomings, such as inefficient water distribution, and overexploitation of water by head users (Abdullahi et al. 2003). In addition, returns to rice farming for farmers were very low as the price of paddy offered by the state was far below the market price.

[4] This new system faced potential challenges (Njeru et al. 2016). First, farmers were not paid immediately after delivery. Second, farmers could receive prices far below the market price.

contract between farmers and traders is that the trader provides cash at the beginning of the season, while farmers will repay in kind (i.e., a predetermined amount of paddy at the market price) at the end of the season. Njeru et al. (2016) found that fertilizer application and rice yield are not significantly different among borrowers from MRGM, borrowers from rice traders, and non-borrowers. Although a potential disadvantage to farmers may arise from the strong monopoly power of traders over farmers (Bell et al. 1997), our finding suggests that the input credit market functions efficiently in Mwea. The contract between the farmers and traders is likely to be competitive as there are hundreds of traders and thousands of farmers. The market is liberalized, with the traders competing with larger institutional buyers, such as MRGM, to purchase paddy from farmers. The successful development of the rice input credit market is likely to reflect the complementarity between the seed-fertilizer technology and the well-managed irrigation scheme.

To see the economic viability of the Mwea Irrigation Scheme, Kikuchi et al. (2021) calculated the costs and benefits of establishing the irrigation scheme under the assumption that the Mwea Irrigation Scheme was constructed as a brand-new project. Unlike the high construction and management costs of many other large-scale irrigation schemes established in SSA during the twentieth century, the Mwea Irrigation Scheme's construction and management costs were modest and comparable to the successful cases in Asia.[5] Furthermore, farmers in the irrigation scheme are likely to be well-trained and adopt seed-fertilizer technologies and proper rice cultivation practices. Although the Mwea Irrigation Scheme can be considered a successful irrigation project, its investment returns were not high. This low investment return is likely due to the low global prices of Asia rice, suggesting the importance of efforts to improve the quality and price of local rice.

Mano et al. (2022) explored technology adoption in the Mwea Irrigation Scheme's rice milling sector and its associated rice value chain development toward improving the quality and price of local rice compared with imported rice from Asia. Liberalization of the Mwea Irrigation Scheme's irrigation management allowed the entry of input retailers, rice traders, and rice millers into the market. The millers in Mwea focused on milling services by operating traditional milling machines, and millers and traders used to hire casual workers to manually remove small stones and other impurities from milled rice. In the early 2010s, several entrepreneurial millers in Mwea visited China. They learned about modern milling technologies, such as the destoner module, which removed small stones and other impurities automatically and thoroughly. Although a limited number of millers initially adopted the large-scale modern milling machines, smaller modern milling machines were introduced and widely adopted in the late 2010s. The adoption of modern milling machines improved the quality and price of Mwea's milled rice and facilitated rice value chain transformation, in which Mwea's rice was sold to urban supermarkets and consumers.

[5] The construction and management cost of Mwea Irrigation Scheme per hectare is slightly higher than the average cost of successful irrigation schemes in the twentieth century (Kikuchi et al. 2021). Its size is relatively small among the category of large-scale irrigation schemes, which prevents it from exploiting the economies of scale.

The rice milled by these millers is of higher quality and successfully competes with imported rice from Asia in urban markets, including in Nairobi. In December 2018, we observed supermarkets in Nairobi selling improved Basmati rice from Mwea at KES 140–200 per kilogram (kg), compared with Pakistani long grain at KES 100–120 per kg.[6] These observations indicate that African rice can compete with Asian rice if improved milling machines are introduced to the SSA.

During the irrigation scheme development, the farmers received training on seed-fertilizer technologies and proper rice cultivation practices (Kikuchi et al. 2021). We will investigate their technology adoption and rice farming performance in the sections that follow. In particular, we analyze the adoption of tractors and other farm machinery for different activities as well as fertilizer application and rice productivity.

5.3 Data

The data used in this study comes from three rounds of original household surveys conducted by the authors in 2011, 2016, and 2018. For the baseline in 2011, stratified random sampling was employed, which followed the zoning of the Mwea Irrigation Scheme. The scheme used to consist of five sections in 2011. Scheme Area 1 (SA1) covers the Tebere section, and Scheme Area 2 (SA2) covers the Mwea, Thiba, Wamuru, and Karaba sections. The 2011 survey covered all the sections in both SA1 and SA2. From each section, seven (or eight) units were randomly selected for a total of 36 units (out of 59 units).[7] The next stage was to choose a feeder canal in each of the units selected. After randomly selecting a feeder canal in each unit, the list of registered farmers for the scheme was used to randomly select eight farmers along each feeder canal. If a feeder canal had fewer than eight farmers, all the farmers along that feeder canal were interviewed. In 2011, 259 farm households were interviewed.

In 2016, the scheme added two new sections for a total of seven sections. Outgrower Area 1 (OG1) covers one additional section, and Outgrower Area 2 (OG2) covers the other section. Because we wanted to compare farmers' situations outside the irrigation scheme to those cultivating rice within the irrigation scheme, the 2016 survey covered SA2, OG1, and OG2, but not SA1 due mainly to the budget constraint. In SA2, a subsample of farmers visited in 2011 were randomly selected and interviewed, maintaining the key sampling structure used in the 2011 survey. First, three units out of all the sample units in each of the four sections in SA2 (i.e., Mwea, Thiba, Wamuru, and Karaba) were randomly selected. All farmers in the selected units interviewed in 2011 were interviewed again in 2016. Furthermore, 25 farmers

[6] In 2019, Pakistan accounted for 67% of imported rice to Kenya, followed by Thailand with 25%, Republic of Korea with 3%, and India with 2% (KNBS 2021). The Pakistani rice is not Basmati, but a type of long-grain nonaromatic rice. According to our informal interviews with local rice traders, some sellers blend Mwea rice with imported rice from Pakistan, and they sell this as 'Mwea rice.' However, note that consumers prefer high-quality Asian rice. For example, Jasmine rice from Thailand retailed at KES 350 per kg while Mwea rice was sold at KES 140–200 per kg.

[7] We selected eight units in the Karaba section because two units shared the same feeder canal.

were randomly selected in each of the four units in OG1, and 15 farmers were selected in each of the seven units in OG2. In total, 314 farmers were interviewed across SA2, OG1, and OG2.

In 2018, all the 51 sample farmers in SA1 in 2011 were interviewed to complement the 2016 survey, in which the farmers in SA1 were excluded from the sample. In addition, using the sampling methodology used in 2011, seven units were randomly identified, and eight farmers in each unit were interviewed for the first time. In total, 107 farmers were interviewed in SA1 in the 2018 survey.

We interviewed these sample rice farmers using structured questionnaires about their rice farming practices for the cropping season. Other information collected included: (1) household demographics and nonfarm occupation, (2) characteristics of land holdings, (3) input and output for rice, (4) source and amount of credit, and (5) agricultural assets held.

5.4 Descriptive Analyses

Table 5.1 presents the sample farmers' basic characteristics in 2011. The average age of the household head is 56, with extensive rice farming experience. The average household consists of 4.5 members, including 1.7 men and 1.5 women of working age (15–64 years old), who are lowly educated. The average sample farmers cultivate 1.17 ha of rice fields and pay the rental value of USD 341 per hectare. Their rice field is located 0.63 km from the intake on average, and there are 16 plots of fellow farmers along the feeder canal. Most sample farmers belong to MRGM and borrow USD 371, while non-members of MRGM borrow USD 144 from rice traders per season.

Figure 5.1 shows the trends in agricultural wages in Kenya. Using data from the Tegemeo Institute panel survey and our original survey data, the average wage rate has more than doubled over the past two decades. A fundamental hypothesis in supporting the adoption of mechanization is that mechanization helps substitute for labor as it becomes more expensive (Binswanger 1978). The rising wage rate is an indicator of scarcity. During peak periods of crop development, the wage rate will likely be higher, and fewer workers face diminishing returns to their productivity.

Table 5.2 presents the use of four-wheel tractors and draft animals across the three survey rounds. Almost all farmers use a tractor and draft animals. The high proportion of farmers using tractors is due to the rice farming experience under the National Irrigation Authority (NIA) (formerly National Irrigation Board [NIB]) and MRGM, where these services were provided on credit. In 2011, tractor services were primarily used for plowing, while draft animals were used mainly for leveling, which equalizes the water level in the rice field and facilitates the even growth of rice plants. Almost all households had this combination, with 98% reporting using both a tractor and a draft animal. This finding contrasts with rice farmers' widespread use of two-wheel tractors for plowing and leveling in Cote d'Ivoire (Mano et al. 2020). According to the Cote d'Ivoire study, intensive land preparation facilitated

Table 5.1 Household characteristics of sample farmers in 2011

Characteristics	
Age of household (HH) head (years)	55.80 (14.73)
Female-headed HH (%)	18.9 (39.2)
% of HH heads who started rice farming after 2000	29.7 (45.8)
HH size (number of members)	4.5 (1.9)
Number of working-age men (15–64 years old)	1.67 (1.21)
Number of working-age women (15–64 years old)	1.46 (0.99)
Highest education attainment of non-head HH members	3.3 (1.2)
Cultivated farm size (ha)	1.17 (0.6)
The rental value of land (USD/ha)	341 (81)
The average distance from intake to plot (km)	0.63 (0.37)
Number of farmers along the feeder canal	16 (6)
Value of assets (USD)	263 (433)
Dropout from MRGM (%)	30.5 (46.1)
Credit from MRGM (USD) per season	371 (188)
Credit from traders (USD) per season	144 (176)
N	259

Notes Standard deviations are in parentheses. Dropouts are farmers who were members of MRGM in 2000 but were no longer members at the time of the survey. The rental value of land, assets, and credit are in USD (the exchange rate was USD 1 = KES 84.21). Assets include small livestock, such as goats, sheep, poultry, and light farm equipment

the adoption of labor-intensive rice cultivation practices, and it was also the case in the Mwea Irrigation Scheme, where almost all the farmers adopted transplanting in rows (not shown in the tables here). In 2011, rotary weeders were yet to be adopted, and no farmer interviewed reported the adoption of the rotary weeders. Similarly, there was no use of mechanized services for harvesting.

In 2016, there was a reduction in the proportion of farmers reporting the use of tractor services, which can be attributed to the newly-added sample farmers in OG1 and OG2. The farmers in these areas were initially not served by NIB and therefore had to access services from private sector suppliers. When they were formally recognized as sections, they joined MRGM and continued to receive mechanized services. Also, a much lower proportion of farmers reported using tractors in the first plow, but more reported using tractors to harrow after the first plow. Similar to 2011, draft animals were mainly used for leveling, although more farmers reported using draft animals to transport produce from the farm. In 2016, a small proportion of farmers had started using rotary weeders, reflecting the sharp rise in farm wages (Fig. 5.1). In

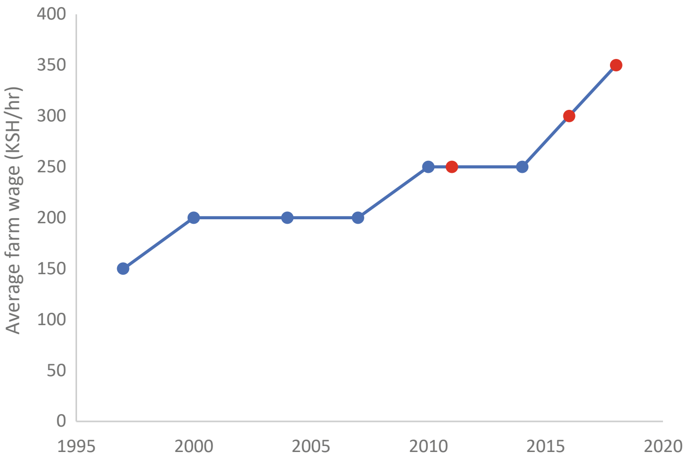

Fig. 5.1 Trends in agricultural wages in Kenya (Tegemeo Institute data in triangles [1997–2010, 2014] and survey data in round dots [2011, 2016, and 2018])

Table 5.2 Use of mechanized inputs and activities

	2011		2016		2018	
	Oxen	Tractor	Oxen	Tractor	Oxen	Tractor
% of farmers using activities (%)	99.6	98.0	97.3	82.2	98.8	41.5
Rotavation	0	98.0	0	16.3	0	32.9
Harrowing	2.4	0.4	8.1	65.5	97.6	1.2
Leveling	99.6	0	93.0	0	97.6	0
Transport	2.9	0	15.5	3.1	0	15.9
Harvesting	0	0	0	38.8	0	3.7
Used mechanical weeder (%)	0		8.1		19.5	
N	245		258		82	
Sample	SA1, SA2		SA2, OG1, OG2		SA1	

addition, more than one-third of the farmers reported using mechanized harvesting of rice.

In 2018, tractor use was further reduced and mainly used for plowing. A higher proportion of farmers reported using tractors for transporting produce from the farm. Draft animals were utilized for harrowing and leveling. Although mechanized harvesting was very low, a much higher proportion reported using rotary weeders. The low use of mechanized harvesting services can be attributed to constraints in access. Although mechanized service providers have increased, they were first provided by MRGM only. More farmers from the Tebere section (SA1) exited MRGM following challenges faced after liberalization and lost access to machinery service on credit,

Table 5.3 Fertilizer application and rice yield

	2011	2016	2018
NPK per ha (kg/ha)	139.28 (57.36)	86.76 (236.21)	66.54 (28.56)
Yields (tons/ha)	4.96 (1.52)	5.36 (3.71)	6.19 (1.45)
N	259	256	82
Sample	SA1, SA2	SA2, OG1, OG2	SA1

Note Standard deviations are in parentheses

explaining the reduced adoption of tractors and slower adoption of mechanized harvesting.

Table 5.3 presents fertilizer application and the rice yield of the sample farmers. The farmers applied, on average, 140 kg of NPK (nitrogen, phosphorus, and potassium) fertilizer per hectare in 2011, which is more intensive than many agricultural countries in Asia, such as India, the Philippines, Bangladesh, Thailand, and Nepal (see Fig. 1 in Njeru et al. 2016). Fertilizer application declined over the sample periods as farmers left MRGM and lost access to input credit. However, the average rice yield increased from 4.96 tons/ha in 2011 to 6.19 tons/ha in 2018. We do not know precisely why the rice yield increased over time. However, rice production was low from 2008 to the early 2010s due to unfavorable rainfall (Kikuchi et al. 2021), while the improved rice yield may be due to the enhanced water access in the Mwea Irrigation Scheme. The Water Management Development Project of the World Bank was improved between 2007 and 2013, while JICA has implemented a modernization-rehabilitation project since 2017 (Kikuchi et al. 2021).

Furthermore, the price of Mwea rice increased following the rice millers' adoption of improved rice milling technologies during this period (Mano et al. 2022). The farmers may have been encouraged to more carefully implement improved rice cultivation practices, such as threshing and drying, to improve the paddy quality. We will investigate these possibilities in our future projects.

5.5 Discussion

Under the leadership of Professor Otsuka, we investigated the possibility of the rice Green Revolution in SSA by closely examining the case of the Mwea Irrigation Scheme in Kenya from diverse angles in the past ten years. As opposed to popular demand for input credit intervention, the farmers in the Mwea Irrigation Scheme can receive credit from the farmers' cooperative and rice traders, enabling them to apply fertilizers properly (Njeru et al. 2016). The liberalization of irrigation management enhanced the rice farming performance and the returns to irrigation investment, making the Mwea Irrigation Scheme one of the successful large-scale irrigation schemes in SSA (Kikuchi et al. 2021). The liberalization also facilitated the entry and development of related sectors. In particular, the rice millers adopted modern milling machines, improving the quality and price of milled rice produced in the Mwea Irrigation Scheme (Mano et al. 2022). This chapter further explored the technology adoption of rice farmers and found that the farmers used four-wheel tractors for rotavation and oxen for leveling the rice field, facilitating the adoption of labor-intensive rice cultivation practices. The farmers achieved a high rice yield of 6 tons/ha, exceeding the performance of prosperous rice-producing countries in Asia. However, the development of the machinery service market is still limited in the Mwea Irrigation Scheme, and there is still room for improvement. All these findings strongly suggest that the rice Green Revolution is occurring in the Mwea Irrigation Scheme.

Recollections of Professor Keijiro Otsuka

We are former students of Professor Keijiro Otsuka. He taught us the importance of visiting the fields and learning the reality from farmers, entrepreneurs, traders, and workers. We are fortunate to have opportunities to continue working with him and pursuing the possibility of the rice Green Revolution in SSA by examining the development process of rice farming and related sectors in the Mwea Irrigation Scheme. We have examined the effect of credit on input application and rice productivity (Njeru et al. 2016), the economic viability of the Mwea Irrigation Scheme (Kikuchi et al. 2021), and technology improvement in the rice milling sector toward the development of rice value chains and the quality and price of local rice to compete with imported rice from Asia (Mano et al. 2022). Because the Mwea Irrigation Scheme is the leading rice production area in SSA, we have learned many important lessons that may contextualize and improve our understanding of the rice Green Revolution in SSA. We are currently thrilled to prepare for the upcoming survey in Mwea to explore the adoption process of rice cultivation practices and the complementary roles of land preparation using draft animals and power tillers in the process of the rice Green Revolution.

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Chapter 6
How Can We Achieve Green Revolution in Sub-Saharan Africa? The Case of Tanzania

Yuko Nakano and Eustadius Francis Magezi

Abstract How can we achieve a rice Green Revolution in Sub-Saharan Africa? In this chapter, we evaluate the progress of the rice Green Revolution and discuss potential policy interventions to achieve it in Tanzania. For these purposes, we summarize four studies that have been conducted by the authors. Especially, we focus on the effectiveness of irrigation, agricultural training, and microcredit for technology adoption and productivity enhancement of rice cultivation. We found a high potential for the rice Green Revolution in Tanzania and that it can be achievable with proper policy interventions. We propose irrigation development and agricultural training as effective means to achieve the rice Green Revolution in Tanzania.

6.1 Introduction

Agricultural development is indispensable for poverty reduction and food security in Sub-Saharan Africa (SSA), where more than half of the population engages in agriculture. Among other crops, the importance of rice has been increasing. Although rice production in SSA doubled from 2008 to 2018, consumption has also been rapidly increasing, resulting in increased imports from Asia. Given that the arable land per population decreases over time due to the population increase, a rice Green Revolution is eagerly anticipated in SSA.

Professor Keijiro Otsuka has led the research project 'An Empirical Analysis on Expanding Rice Production in Sub-Saharan Africa,' funded by the Japan International Cooperation Agency Ogata Sadako Research Institute for Peace and Development (JICA-RI) since 2009. The project's goal is to understand the current status of rice cultivation and identify the strategies to achieve a rice Green Revolution in SSA. The project covers several countries, including Tanzania, Mozambique, Uganda,

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Ghana, Senegal, Côte d'Ivoire, and Kenya. One of the authors of this chapter (Yuko Nakano) used to be a PhD student of Professor Otsuka and has been working on agricultural development in SSA with him for more than 15 years. The other author (Eustadius Francis Magezi) has recently joined the JICA-RI project, and both authors are responsible for the surveys and analyses in Tanzania.

In this chapter, we evaluate the progress of the rice Green Revolution in Tanzania and discuss potential policy interventions to achieve it. For these purposes, we summarize four studies that have been conducted by the authors. Especially, we focus on the effectiveness of irrigation, agricultural training, and microcredit for technology adoption and productivity enhancement of rice cultivation. Green Revolution is often considered the seed and fertilizer revolution (Gollin et al. 2021). However, as Otsuka and Larson (2016) point out, the importance of basic agronomic practices, such as improved bund construction, plot leveling, and transplanting in rows, which enhance proper water and weed management, should be emphasized.[1] Thus, we focus on the adoption of modern varieties (MVs) and chemical fertilizers and the adoption of improved agronomic practices.

The first study used an extensive dataset collected in three major rice-growing regions in Tanzania (referred to as extensive survey hereafter). We provide an overview of the progress of the Green Revolution from 2009 to 2018 and argued the importance of irrigation for the intensification of rice cultivation. The second and third studies are case studies on the effectiveness of agricultural training (Nakano et al. 2018a, b). We found that agricultural training effectively increased technology adoption and paddy yield in irrigated and rainfed areas. In the last study, we conducted a randomized controlled trial (RCT) to examine the impact of microcredit on rice cultivation technology adoption and productivity (Nakano and Magezi 2020). We found weak or no evidence that improved access to credit enhanced technology adoption or productivity. Based on these studies, we provide policy implications for achieving Green Revolution in SSA.

The structure of this chapter is as follows. Section 6.2 describes the results of the extensive survey. Section 6.3 summarizes the two case studies on the effectiveness of agricultural training, while Sect. 6.4 shows the results of the RCT on the impact of microcredit. Finally, Sect. 6.5 provides the policy implications and concludes the chapter.

6.2 Extensive Survey

The first purpose of this chapter is to evaluate the progress of the Green Revolution in Tanzania. We used a dataset collected in the extensive survey conducted in 2009 and 2018, whose purpose was to grasp the country-wide situation of rice cultivation.

[1] Improved bund construction entails piling soil solidly around the plots, while plot leveling involves flattening the ground for better storage and equal distribution of water on paddy fields. Transplanting seedlings in rows allows rice growers to control plant density precisely and remove weeds easily.

The survey was carried out in 76 villages of six districts in three major rice-growing regions: Kilombero and Mvomero districts in the Morogoro Region, Kahama and Shinyanga rural districts in the Shinyanga Region, and Mbarali and Kyela districts in the Mbeya Region. Ten rice-growing households were randomly selected within each village, resulting in a total number of 760 observations in the 2009 baseline survey. In the 2018 follow-up survey, the same households were revisited, and we interviewed a replacement household if the original household at the baseline was missing. We requested farmers to identify the most important plot for rice production and asked in detail about rice cultivation practices in those plots. After the data cleaning, we obtained an unbalanced, two-year panel data with a total number of 1,448 households.

Table 6.1 presents the changes in technology adoption and productivity of rice cultivation from 2009 to 2018. The results of the *t*-tests mean comparison between 2009 and 2018 are shown by asterisks. An important finding in this table is that the adoption of technologies and paddy yield significantly increased over time in both rainfed and irrigated areas. The adoption of MVs (called SARO 5) increased from 8.9 to 14.4% in rainfed areas and from 31.8 to 57.7% in irrigated areas.[2] Chemical fertilizer use per hectare increased from 8.8 to 24.2 kg in rainfed areas and from 35.4 to 89.6 kg in irrigated areas. Among other improved agronomic practices, the adoption rate of transplanting increased from 29.5 to 42.2% in rainfed areas, while transplanting in rows increased from 29.2 to 43.1% in irrigated areas. Accordingly, paddy yield significantly increased from 1.9 tons per hectare (tons/ha) to 2.3 tons/ha in rainfed areas and from 3.7 to 4.2 tons/ha in irrigated areas.

These results suggest that the Green Revolution in Tanzania is in progress. It is also important to note that the paddy yield of 4.2 tons/ha in irrigated areas is comparable to Asian countries. This shows the high potential of irrigated rice farming in Tanzania, indications that the Green Revolution is already taking place in irrigated areas in Tanzania. The problem, however, is that the ratio of the irrigated plots is still low (18% in 2018). These results suggest the importance of irrigation in adopting improved technologies and yield enhancement.

6.3 Effectiveness of Agricultural Training

The second purpose of this chapter is to find out which interventions can effectively achieve a Green Revolution. This section introduces two case studies that examine the effectiveness of agricultural training, as the knowledge gap is often cited as one of the major constraints to technology diffusion. First, Nakano et al. (2018b) examine the effectiveness of farmer-to-farmer training in the Project for Supporting Rice Industry

[2] SARO 5 (TXD306) has semi-aromatic characteristics and is the most popular MV in Tanzania. It was developed in the government agricultural research institute in Dakawa (ARI Dakawa) and was released in 2002. It is a crossbred variety between Supa/Pyongyang 8 from North Korea and Supa/Subarimati originally from the International Rice Research Institute (IRRI).

Development in Tanzania (TANRICE), conducted by JICA in the Ilonga irrigation scheme in the Kilosa District, Morogoro Region in 2009.

TANRICE offered intensive training on rice cultivation to 20 farmers (i.e., key farmers) at the nearby training institute (Ministry of Agriculture Training Institute—Ilonga) for 12 days. After that, each key farmer was expected to invite five other farmers (i.e., intermediate farmers) to training sessions held at a demonstration plot within the irrigation scheme. Following these sessions, both key and intermediate farmers were expected to disseminate technologies to the remaining farmers (i.e., ordinary farmers).

Table 6.2 reports paddy yield changes and technology adoption for key, intermediate, and ordinary farmers before and after the training. We performed *t*-tests and *chi*-square tests, comparing between key and ordinary farmers and between intermediate and ordinary farmers. The first main finding is key farmers' rapid technology adoption and productivity growth. In fact, the paddy yield of key farmers increased rapidly from 3.1 to 4.4 tons/ha soon after the training and continued to be high, reaching 5.3 tons/ha in 2011. The rapid increase of their paddy yield is attributed to the high adoption rate of improved technologies. Immediately after the training, the adoption rate of MVs for key farmers increased from 46.2 to 69.2%, and chemical fertilizer use from 63.4 kg per hectare (kg/ha) to 115.8 kg/ha. Key farmers also started to adopt improved agronomic practices. The adoption rate of plot leveling increased from 46.2 to 76.9%, while that of transplanting in rows increased from 23.1 to 76.9% in 2009. This suggests that key farmers' performance improved significantly right after the training and remained high afterward.

On the contrary, the increase in yields for intermediate farmers was not rapid. After receiving training in 2009, however, their adoption rates of modern technologies, such as MVs, improved bund construction, transplanting in rows, and the use

Table 6.1 Technology adoption and productivity of rice cultivation in rainfed and irrigated areas in Tanzania (2009 and 2018)

	Rainfed		Irrigated	
	2009	2018	2009	2018
Adoption rate of MVs (%)	8.9	14.4[b]	31.8	57.7[c]
Chemical fertilizer use (kg/ha)	8.8	24.2[c]	35.4	89.6[c]
Share of bunded plot (%)	50.1	59.9[c]	89.0	94.2[a]
Share of leveled plot (%)	55.5	46.6[c]	76.6	67.9[b]
Adoption rate of transplanting (%)	29.5	42.2[c]	92.9	85.4[b]
Adoption rate of transplanting in rows (%)	5.6	6.5	29.2	43.1[c]
Paddy yield (tons/ha)	1.9	2.3[c]	3.7	4.2[b]
Observations	539	618	154	137

Note c, b, a indicate statistical significance at 1%, 5%, and 10%, respectively, in *t*-test comparisons between 2009 and 2018 for each rainfed and irrigated plot of chemical fertilizers also began to increase. As a result, intermediate farmers eventually achieved higher paddy yields than ordinary farmers. Although the effects of training in terms of magnitude and immediacy were much greater for key farmers than for intermediate farmers, as years went by, intermediate farmers were also able to catch up with key farmers.

The paddy yield of ordinary farmers increased slowly from 2.6 tons/ha in 2008 to 3.7 tons/ha in 2012. The increased technology adoption should have contributed to this yield increase. From 2008 to 2012, the adoption rate of MVs for ordinary farmers gradually increased from 26.7 to 32.9%, chemical fertilizer use from 46.5 to 83.2 kg/ha, and the adoption rate of transplanting in rows from 11.1 to 36.9%. Compared to key and intermediate farmers, the change for ordinary farmers was delayed. This lag suggests a knowledge spillover from key and intermediate farmers to ordinary farmers. In fact, the yield gap between key and ordinary farmers widened up to 2.3 tons/ha in 2010. The gap, however, had decreased to 1 ton/ha in 2012. These results suggest that the performance of key farmers improved rapidly, while that of intermediate and ordinary farmers improved gradually, but they eventually caught up with key farmers.

Another notable finding is that key farmers achieved yields as high as 5.3 tons/ha. Again, this shows the high potential of irrigated rice farming in Tanzania and that the rice Green Revolution is achievable as long as proper policy intervention is provided.

Nakano et al. (2018b) further estimated a fixed effect difference-in-differences (DID) model, a propensity score, DID model, and the hypotheses that ordinary farmers caught up with key farmers were supported. By incorporating social relationship variables into special econometric models, the paper found that social relationships played a significant role in technology diffusion. Overall, our results suggest the effectiveness of farmer-to-farmer training for the intensification of rice cultivation, especially in irrigated areas.

Another study on the effectiveness of agricultural training was conducted in Kilombero District, Morogoro Region of Tanzania (Nakano et al. 2018a). Kilombero Plantation Limited (KPL), a large-scale rice milling company, provided agricultural training on a modified version of low-input rice cultivation technologies, known as the system of rice intensification (SRI),[3] to surrounding small-scale farmers. The major recommended practices include (1) use of an MV (i.e., SARO 5); (2) chemical fertilizer use; (3) seed selection method using salty water; (4) straight-raw dibbling or transplanting; and (5) wide spacing of 25 × 25 cm (cm) or more. These recommended practices differ from the original SRI, which prescribes no MVs or chemical fertilizers. Therefore, we call this set of recommended technologies the modified SRI (MSRI).

[3] SRI is a set of low-input irrigated rice cultivation technologies developed during the 1980s in Madagascar. SRI is said to produce higher paddy yields by prescribing (1) raising seedlings in a carefully managed, garden-like nursery; (2) early transplanting of 8–15-day-old seedlings; (3) adopting single, widely spaced transplanting; (4) early and regular weeding; (5) carefully controlled water management; and (6) using compost as much as possible, without adopting new varieties or other purchased chemical inputs.

Table 6.2 Technology adoption and paddy yield by TANRICE training status (Nakano et al. 2018b)

	2008 Pre-training	2009	2010 During training	2011 Post-training	2012
Key farmer					
Paddy yield (tons/ha)	3.07[a]	4.40[c]	4.81[c]	5.34[c]	4.67[b]
Adoption rate of MVs (%)	46.15	69.23[c]	75.00[c]	54.44[c]	66.67[c]
Chemical fertilizer use (kg/ha)	63.42	115.82[c]	137.73[c]	178.26[c]	131.28[c]
Adoption rate, improved bund (%)	15.38[b]	23.08[b]	31.25[c]	40.00[b]	15.38
Adoption rate, plot leveling (%)	46.15	76.92	81.25	86.67	76.92
Adoption rate, transplanting in rows (%)	23.08	76.92[c]	93.75[c]	93.33[c]	92.31[c]
Observations	13	13	16	15	13
Intermediate farmers					
Paddy yield (tons/ha)	2.47	2.57	2.84	4.63[c]	3.93
Adoption rate of MVs (%)	30.43	44.44[a]	54.84[b]	34.38	49.48[b]
Chemical fertilizer use (kg/ha)	22.20[b]	49	79.05	103.85[b]	95.23
Adoption rate, improved bund (%)	13.04[b]	18.52[b]	22.58[b]	33.33[b]	33.33[c]
Adoption rate, plot leveling (%)	43.48 [50.69]	70.37 [46.53]	74.19 [44.48]	79.17 [41.49]	62.5 [49.45]
Adoption rate, transplanting in rows (%)	13.04 [23]	44.44[c] [27]	64.52[c] [31]	45.83[b] [24]	58.33[b] [31]
Observations					
Ordinary farmers					
Paddy yield (tons/ha)	2.57	2.67	2.53	3.58	3.67

(continued)

Table 6.2 (continued)

	2008 Pre-training	2009	2010 During training	2011 Post-training	2012
Adoption rate of MVs (%)	26.67	26.76	32.26	23.62	32.85
Chemical fertilizer use (kg/ha)	46.52	58.31	69.72	85.79	83.16
Adoption rate, improved bund (%)	2.96	4.93	7.74	16.15	11.54
Adoption rate, plot leveling (%)	54.81	64.08	69.03	76.15	66.92
Adoption rate, transplanting in rows (%)	11.11	19.01	25.81	26.92	36.92
Observations	135	142	155	130	130

Note c, b, a indicate statistical significance at 1%, 5%, and 10%, respectively, in *t*-test comparisons between ordinary and key and ordinary and intermediate farmers in each year

The survey was carried out from February to March 2014 and covered the cultivation season from October 2012 to May 2013. We selected three training villages and two nearby villages where no training was held (non-training villages). In each village, we interviewed, on average, 37 training participants and 35 non-participants, generating a total sample size of 283 households. We asked farmers to list all of their farming plots during the interviews. Among those listed, we selected two paddy plots (one MSRI plot and one non-MSRI plot) for plot-level analysis. A plot was regarded as an MSRI plot when farmers reported using the plot for MSRI rice cultivation.

Table 6.3 compares the adoption of technology and paddy yield between trainees and non-trainees in the training village and farmers in the non-training village in 2013. An important finding is that trained farmers achieved an average paddy yield of 4.7 tons/ha in their MSRI plots. This is significantly higher than the yield of 2.9 tons/ha in the non-MSRI plots of trainees and 2.6 tons/ha in the non-MSRI plots of non-trainees in training villages. The high yield in MSRI plots can be attributed to the high adoption rates of technologies in these plots. For MSRI plots, the adoption rate of MV was as high as 90.9%, straight-row dibbling 78.2%, wide spacing 56.4%, and seed selection using salty water 71.8%. After more careful statistical examination, Nakano et al. (2018a) concluded that the adoption of MSRI increases the paddy yield by 1.3–1.8 tons/ha.

On the other hand, the adoption rate of technologies and paddy yield in the non-MSRI plots of trainees or non-trainees in training villages is not significantly higher than the farmers in non-training villages. These observations suggest that spillover effects from trainees to non-trainees are limited. Our field observation tells us that

Table 6.3 Technology adoption and paddy yield by MSRI training status, 2013. (Nakano et al. 2018a)

	Training village				Non-training Village	
	Trainees' MSRI Plot	Trainees' Non-MSRI Plot	Non-trainees			
	(a)	(b)	(c)	(d)	a − b	a − d
Paddy yield (tons/ha)	4.7	2.9	2.6	2.9	1.8[d]	1.8[c]
Share of modern variety (%)	90.9	10.1	5.6	2.4	80.7[c]	88.5[c]
Chemical fertilizer use (kg/ha)	52.4	6.1	2.5	2.5	46.3[c]	49.9[c]
Share of straight-row dibbling (%)	78.2	0	0.8	2.4	78.2[c]	75.8[c]
Share of straight-row transplanting (%)	7.3	0	0.8	1.2	7.3[c]	6.1[b]
Share of plots adopting spacing of 25 × 25 cm or more (%)	56.4	0	1.6	2.4	56.36[c]	54.0[c]
Seed selection using salty water (%)	71.8	3.8	0	1.2	68.0[c]	70.6[c]
Number of technologies adopted	3.7	0.3	0.2	0.1	3.5[c]	3.6[c]
Size of cultivated area (ha)	0.4	1.1	1	1.2	− 0.7[c]	− 0.8[c]
Observations	110	79	126	83		

Note c, b, a indicate statistical significance at 1%, 5%, and 10%, respectively, in *t*-test comparisons between each category

trainees are still at the trial stage and are trying MSRI in a small part of their plots. Given that the survey was carried out soon after the training, whether MSRI would be widely adopted by both trainees and non-trainees is still not conclusive. Further investigation is needed on this issue.

6.4 Impact of Microcredit

Another often cited constraint for technology adoption is the lack of access to credit. Nakano and Magezi (2020) conducted an RCT to examine the impact of microcredit on technology adoption and productivity of rice cultivation. Collaboratively with BRAC, a globally-known microfinance institute, we provided microcredit specifically designed for agriculture to randomly selected farmers in two irrigation schemes in Kilombero District, Morogoro Region in Tanzania in 2012. Eligible farmers were invited to a microcredit program that provided USD 50, half provided in cash and the remaining half as fertilizer vouchers redeemable at a local agrochemical store. Eligible and non-eligible farmers for the BRAC program were randomly selected, while some eligible farmers decided to take loans by themselves (referred to as borrowers).

Table 6.4 shows technology adoption and productivity by household status in the microcredit program. The results of *t*-test comparisons between treatment and control groups and between borrowers and control groups are shown by asterisks. We found that credit borrowers increased the application of chemical fertilizer and adoption rates of improved bunds in their rice plots. The average amount of chemical fertilizer application by borrowers is 78 kg/ha, and the adoption rates of improved bunds are about 13%. However, the borrowers do not achieve higher paddy yield or profit than the control group farmers. The paddy yield for the borrowers is 3.2 tons/ha, while that of control group farmers is 3.1 tons/ha.

Nakano and Magezi (2020) further examined the impact of the credit program on the adoption of technology and productivity of rice cultivation by estimating intention to treatment effect and local average treatment effects. We found little to no evidence that microcredit positively impacted chemical fertilizer use, paddy yield, profit, or total household income. By doing subsample analyses, we also found

Table 6.4 Technology adoption and productivity of rice cultivation by the availability of microcredit, 2012 (Nakano and Magezi 2020)

	Control	Treatment	Borrower
Use of chemical fertilizer (kg/ha)	53.2	61.3	78.0[c]
Modern variety (%)	24.7	23.3	32.7
Adoption of improved bund (%)	6.0	7.8	12.50[a]
Adoption of leveling (%)	38.5	39.0	40.0
Adoption of transplanting in row (%)	13.2	13.2	15.0
Yield (tons/ha)	3.1	3.0	3.2
Income (USD/ha)	896.6	833.1	855.2
Profit (USD/ha)	401.6	403.8	516.5
Observations	182	205	80

Note c, b, a indicate statistical significance at 1%, 5%, and 10%, respectively, in *t*-test comparisons between control group and each category that those with good access to irrigation water did not increase chemical fertilizer application by using credit because their application rate is high even without credit. On the other hand, farmers with poor access to irrigation water increased chemical fertilizer application using credit. However, their paddy yield, income, or profit did not improve. Although it is not conclusive, low fertilizer return may be why credit users with poor access to irrigation water could not achieve high yield even when they increased chemical fertilizer use.

6.5 Conclusion

In this chapter, we summarize four studies conducted by the authors to provide an overview of the rice Green Revolution's progress and determine effective policy interventions to achieve it. The first important finding is that 57.7% of farmers adopt MVs and achieved yields as high as 4.2 tons/ha in irrigated areas in major rice-growing regions in the country. Also, TANRICE key farmers achieved yields of nearly five tons/ha. These results clearly show the importance of irrigation investment. It is also implied that the Green Revolution has already occurred in some limited areas and can be achievable with proper policy interventions.

While our results from the extensive survey suggest the importance of irrigation for technology adoption and yield increase in rice cultivation, it also showed that only 18% of sample plots were irrigated. Observing large differences in technology adoption and paddy yield in rainfed and irrigated areas, irrigation development should be one of the top policy means to achieve a rice Green Revolution. However, the past failure of government-led large-scale irrigation schemes, mainly due to management problems, has caused some pessimism for irrigation investment in SSA. Recently, more attention has been paid to small-scale irrigation development, which is considered more manageable for farmers. However, there is no guarantee that small-scale irrigations are, in fact, effectively managed by the farmers. Whether we should invest in small-scale or large-scale irrigation projects in terms of cost-effectiveness and efficacy of the management is an important issue to be investigated in the future.

While the importance of irrigation development is clear, it may take some time and cost to develop it country-wide. Since more than 80% of rice plots are currently in rainfed areas in Tanzania, we have to find effective means to enhance productivity in these areas. Our results show that agricultural training effectively increases technology adoption and paddy yield both in irrigated and rainfed areas. In fact, MSRI trainees achieved as high a yield as 4.7 tons/ha under favorable rainfed conditions. This suggests that farmers can achieve a high yield even in rainfed areas as long as proper technologies are adopted. These results are consistent with other studies conducted in other African countries under the JICA-RI project. Based on this, our second policy recommendation is to provide agricultural training to fill the knowledge gap.

One concern is whether the farmer-to-farmer extension is effective even in rainfed areas. Our results show that MSRI was not adopted by non-trained farmers in the training villages. Knowledge spillover may not easily occur in rainfed areas with more heterogeneous agroecological conditions, and paddy fields are more geographically widespread than in irrigated areas. This point, however, is still not yet answered since our survey was conducted soon after the training, and spillover effects may take some time to occur. Since the costs to provide training to all the farmers in SSA are enormous and unrealistic, we need to seek a cost-effective extension method especially suitable for rainfed areas. This point also should be a future research question. The enhancement of local government extension agencies' capacity and research institutes that can modify the technologies suitable for local contexts will also be an important issue in this regard.

Contrary to expectations, it was found that microcredit did not affect technology uptake and productivity of rice cultivation positively. Nakano and Magezi (2020) found that the increased fertilizer use did not enhance paddy yield or profit for these farmers with limited access to irrigation water. These results may imply that improving credit access is not the first priority in achieving a rice Green Revolution under the current situation in Tanzania.

Although not conclusive, low yield response rates to chemical fertilizer application can be one of the possible reasons for the ineffectiveness of credit. If this is the case, improving the returns to chemical fertilizer by enhancing access to irrigation facilities or technical training should be done before improving access to credit. This is in line with the argument of Otsuka and Kijima (2010), who emphasized the importance of agricultural training before the development of the input market. Note, however, that this does not deny the importance of the credit market in the future. If the returns to chemical fertilizer are improved and demand for chemical fertilizer increases, access to the credit market may become important.

We found a high potential for the rice Green Revolution in Tanzania, and it can be achievable with proper policy interventions. Among other policy interventions, we propose irrigation development and agricultural training as the effective means to achieve the rice Green Revolution in Tanzania. Our discussion would also have implications for other SSA countries facing similar problems as Tanzania.

Recollections of Professor Keijiro Otsuka

I am fortunate to work with Professor Otsuka, who shares my interest in poverty reduction and agricultural development in Sub-Saharan Africa. When I was a Ph.D., student, he made an enormous effort to revise my thesis written in my poor English. I totally owe what I am today to Professor Otsuka and would like to show my sincere gratitude and respect to him. I shall try to contribute to academia and the development of strategies for poverty reduction and agricultural development in SSA by doing quality research—*Yuko Nakano.*

For my Ph.D., studies, I started doing research under the JICA-RI project. Professor Otsuka's advice and comments are always of great help, and I sincerely appreciate him. I will continue working hard in my research to contribute to finding solutions to developmental challenges, especially in Africa.—*Eustadius Francis Magezi.*

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Chapter 7
A UFO? Assessment of System of Rice Intensification from the Agricultural Economics Perspective

Kazushi Takahashi

Abstract There has been a heated debate among researchers over the impact of a set of new rice-growing cultivation methods, known as the system of rice intensification (SRI). Farmers' field-level observations showed that the yield of SRI was more than that of conventional management practices. However, these observations were criticized because of the lack of scientific bases. Indeed, well-managed experimental fields showed no yield gains in SRI practice. In an attempt to reconcile these conflicting observations, this chapter revisits the yield potential of SRI by reviewing recent empirical evidence in agricultural economics that employs a rigorous estimation strategy. All the papers reviewed consistently showed a positive and statistically significant impact on rice yield. Thus, I argue that the yield potential of SRI may be real and not something like an agronomic unconfirmed field observation (UFO) that was once cynically expressed to evoke an unidentified flying object. In addition, I argue that careful management practice exemplified by SRI is important for improving rice yield, which has also played a crucial role in the rice Green Revolution in Asia.

7.1 Introduction

One of Professor Keijiro Otsuka's major works is investigating the adoption process and socioeconomic impacts of the rice Green Revolution. His achievements in this field are exemplified in the edited volume by David and Otsuka (1994), which summarizes the experience of the rice Green Revolution in various Asian countries. Recently, Professor Otsuka has been actively examining and advocating the possibility of applying the Asian-style Green Revolution to Africa (Otsuka and Larson 2013, 2016). In collaboration with Professor Otsuka, Yuki Mano, and myself, another edited volume will be published in 2023 on the rice Green Revolution in Sub-Saharan

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Like many other agricultural technologies, the research and development of the modern variety (MV) of rice during the Green Revolution era in Asia was a science-based innovation, and its validity has been repeatedly tested and proven before they were introduced to farmers. The Asian Green Revolution did not end with a one-shot development of miracle rice with high-yield potential; rather, it underwent continuous improvements, such as the development of rice varieties that are resistant against various pests and diseases and with better eating quality in terms of taste, softness, and aroma (Otsuka and Larson 2013). During the adoption and diffusion process, agricultural extension agents conveyed to farmers the technologies evidenced in experimental stations of scientific research institutes.

The system of rice intensification (SRI) follows a different development path from conventional plant breeding. SRI was inductively developed and assembled based on field observations and trials by Fr. Henri de Laulanié, a French missionary priest/agronomist who worked with rice farmers in Madagascar for several decades. Since the first published report in a technical journal in 1993 (de Laulanié 1993), SRI has attracted the attention of development practitioners and researchers as it has demonstrated significant yield improvements without relying on additional external inputs (e.g., MVs and chemical fertilizers). However, until recently, empirical verification of the yield potential of SRI was scarce, and many early reports on SRI were informal, anecdotal, or from gray literature rather than peer-reviewed sources with scientific rigor (Berkhout and Glover 2011). One conference report even demonstrated an extraordinarily high yield of greater than 20 tons/ha in Madagascar (Rafaralahy 2002), which invited criticism from crop scientists, such as Dobermann (2004) and Sheehy et al. (2004), who argued that the reported yield was beyond the theoretically maximum achievable output. Sinclair and Cassman (2004) derided SRI as an unconfirmed field observation (UFO).

Although SRI research in agricultural economics is still limited, empirical results have accumulated over several decades. This chapter aims to review recent literature on SRI in agricultural economics and derive a tentative but somewhat generalizable view of SRI's yield-enhancing effects.

7.2 System of Rice Intensification (SRI)

7.2.1 Origin and Characteristics of SRI

SRI, pioneered in the mid-1980s, originated from unusual practices in the farmers' fields that Father Henri de Laulanié observed in Madagascar (Uphoff 2006). Several farmers there transplanted single seedlings instead of clumps of three to five plants per hill, unlike prevailing worldwide practices. Moreover, they did not continuously flood their rice fields. To determine whether such low-input practices jeopardize productivity, de Laulanié attempted to grow single seedlings in unflooded soil during vegetative growth. After several attempts, he developed the practice of planting seedlings in a square grid to utilize the mechanical hand weeder perpendicularly in two directions. This, in addition to reducing the burden of weeding, helped aerate the soil. These practices, together, led rice plants, especially their roots, to grow vigorously. He then established a training center to teach young farmers the new cultivation system. From 1983 to 1984, late rains forced him and his students transplanted premature seedlings in some parts of the field. This led to the accidental discovery that transplanted young seedlings tillered better and thus, produced higher yields than transplanted older seedlings.

Building on these observations and further trial and error (e.g., shifting from the use of chemical fertilizer to compost after the government removed the fertilizer subsidy in the late 1980s), de Laulanié and his successors gradually synthesized the following set of high-yielding practices: (1) Early transplanting of young seedlings (less than 15 days old, preferably 8–12 days), contrary to the conventional practice of transplanting 20–60 day-old seedlings; (2) transplanting one or two seedlings per hill, in contrast to a bundle (4–5) of seedlings per hill; (3) wide spacing (more than 20 × 20 cm [cm]), in contrast to narrow (10–15 cm) or random spacing between hills; (4) alternate wetting and drying (AWD) to maintain moist, aerobic soil conditions, in contrast to continuous flooding from transplanting to maturity. Moreover, the proponents of SRI often advocate using compost or manure instead of chemical fertilizers to enrich soils with organic matter (Raharalahy 2002; Uphoff 2006), even though de Laulanié did not initially emphasize any fertilization method. Early and regular weeding, preferably with a mechanical rotary weeder, is also highly recommended as a rotary weeder helps remove weeds that can defeat young seedlings and churn and aerate the soil.

Unlike the Asian Green Revolution technologies, SRI does not require additional external inputs, such as fertilizer-responsive MVs, which genetically improve yield potential, chemical fertilizers, and protective agrochemicals. Instead, SRI has been claimed to elicit more productive phenotypes from existing rice genotypes by changing the management of the plants, soil, water, and nutrients (Uphoff 2003; Sato and Uphoff 2007). The reduced costs of external inputs (e.g., seeds and chemicals) were important considerations as many Malagasy farmers were poor and credit constrained. Although SRI generally requires more labor inputs for careful crop, soil, and water management, labor is relatively abundant for the poor. Therefore, SRI is often considered a pro-poor management practice despite its complex, knowledge-intensive nature, and has indeed been disseminated among low- and medium-income farmers in more than 50 developing countries.

The four to six core SRI principles described above are typically recognized as a package, as they are believed to have synergistic effects (Stoop et al. 2002; Uphoff et al. 2008). However, actual practices can vary among farmers across places as SRI can be adapted to each specific locality and has been continuously evolving based on participatory on-farm trials. The age and space of transplanted seedlings are flexibly adjusted. SRI variants can even include direct seedlings under rainfed conditions, wherein careful crop and water management may be difficult. Uphoff (2003) claims that SRI is a 'philosophy' or even 'paradigm shift' rather than a prescribed set of technologies that farmers should firmly follow, as is common in many other agricultural technologies (Berkhout and Glover 2011).

7.2.2 *Controversy Surrounding SRI Yield Potential*

Since its first introduction by de Laulanié in 1993, various on-farm trials have demonstrated significant SRI yield gains over conventional management practices (Uphoff 1999, 2003; Stoop et al. 2002; Sato and Uphoff 2007). However, partly because of its nontraditional development path, SRI has proven extremely controversial.

This debate escalated after Rafaralahy (2002) reported that yields per hectare exceeded 20 tons in Madagascar. For example, Sheehy et al. (2004) conducted comparisons between SRI and conventional management practices at three well-controlled experimental stations in China and found no significant yield differences among them. Sheehy et al. (2004) also presented a theoretical model of rice yield and emphasized that the reported 'fantastic' SRI yields by Rafaralahy (2002) would exceed the photosynthetic efficiency of rice and are likely the result of measurement errors. Similarly, Dobermann (2004) argued that SRI methods do not have inherent advantages over conventional best management practices, and their performance may depend on soils and other environments. He hypothesized that SRI may be particularly suitable for poor cultivation environments with acidic iron-rich soils and limited water availability, as in Madagascar, but its benefits would be small in more favorable environments. McDonald et al. (2006) reviewed 40 published journal articles and concluded that outside of Madagascar, where soil conditions are especially suitable for SRI practices, SRI has negligible or even negative impacts on rice yields relative to best management practices. Sinclair and Cassman (2004) echoed their claims and labeled SRI an agronomic UFO.

Skepticism of SRI has been addressed by Uphoff (2004), Stoop and Kassam (2005), and Uphoff et al. (2008), among others. Uphoff (2004) challenged the claims of limited applicability and gains of SRI by highlighting that SRI has been practiced in many regions beyond Madagascar, which is evidence of its intrinsic value. Stoop and Kassam (2005) criticized Sheehy et al. (2004), arguing that a single standardized field experiment cannot reveal SRI's full potential. Uphoff et al. (2008) emphasize that the methodology used by McDonald et al. (2006) is flawed because selected observations do not represent the universe of SRI experiences and because many of their observations only partially adopted the core principles of SRI, hindering full synergistic advantages among practices.

Some controversy seems to arise as SRI is not clearly defined, even by its proponents. As explained earlier, Uphoff, a champion of SRI proponents, tended to emphasize SRI as an adaptable suite of principles for rice cultivation. However, when he criticizes others, he highlights the importance of adopting all principles as a package. As Bouman (2012) precisely emphasizes, "[p]roponents of SRI highlight results of superior SRI performance with practices that only partially follow the original or that are heavily modified, while they reject results of inferior SRI performance based on the fact that practices were incompletely or wrongly implemented (p. 2)". According to this view, rather than SRI triggering positive impacts on yield, the package of rice management practices providing better yields should be called SRI. The lack of a clear working definition of SRI makes this controversy fruitless.

This chapter does not endorse or criticize SRI's potential by revisiting the aforementioned physiological controversy. Rather, the recent empirical literature on agricultural economics in various contexts are reviewed, keeping internal validity (consistency and unbiasedness) and external validity (generalizability) in mind. I will attempt to explain the definition of SRI and the identification strategy employed in each paper as clearly as possible so readers can evaluate the credibility of the results on their own.

7.3 Assessment from the View of Agricultural Economics

7.3.1 Conceptual Framework

Before going into the details of each paper, let me explain the basic concept of how to compare adopters and non-adopters of SRI. All agricultural economics papers cited in this chapter explicitly or implicitly follow Rubin's causal model in the following form:

$$y_i = D_i y_{i1} + (1 - D_i) y_{i0}, \tag{7.1}$$

where D_i represents an adoption indicator with $D_i = 1$ if farmer/plot i adopts SRI, and $D_i = 0$ otherwise. The ith unit has two potential outcomes: y_{i1} (outcome of adopting SRI) and y_{i0} (otherwise). The causal impact of SRI adoption is expressed as

$$y_{i1} - y_{i0}. \tag{7.2}$$

Equation (7.2) can create an ideal ceteris paribus condition wherein any observable and unobservable factors other than SRI adoption are 'identical.' However, because two potential outcomes cannot be observed simultaneously for any particular individual unit, most economics studies estimate the average treatment effects (ATE), $E[y_{i1} - y_{i0}]$ (where $E[]$ is an expectation operator), or the average treatment effects on the treated (ATT), $E[y_{i1} - y_{i0}|D_i = 1]$, by creating appropriate counterfactual groups based on a randomized controlled trial (RCT) or other statistical methods.

Note that as the two statuses above are distinguished only between with and without SRI, any associated changes cannot be controlled for. For example, if SRI requires more labor inputs but requires less water, seed, and fertilizer expenses, crop scientists may note that the resultant yield differences cannot be sorely attributed to the difference in technology parameters with and without SRI as input uses are different between the two. Although economics has developed a technique for estimating the total factor productivity (TFP), few studies have adopted it in SRI studies (Berkhout et al. 2015). Thus, this chapter considers the overall impact of SRI adoption (incorporating mediating impacts through changing input uses) when referring to yields. While past controversy has centered on yield potential, I will also discuss income and profitability as much as possible, allowing us to properly assess SRI's true potential, taking costs and other associated changes in adoption into consideration.

7.3.2 Empirical Evidence of the Impacts of SRI

Barrett et al. (2004) presented the first seminal work on the yield potential of SRI. They collected original data from 111 randomly selected farmers from four sites in Madagascar who practiced both SRI and traditional cultivation methods (referred to as SRT). Although no explicit delineation between SRI and SRT was provided, footnote 6 (Barrett et al. 2004, p. 872) explains that farmers closely adhere to all the recommended core practices of SRI, which is plausible, considering that Madagascar is a mecca of SRI. SRI had an unconditional average yield of 6.3 tons/ha, compared to SRT's 3.4 tons/ha. As this yield difference includes selection effects, the authors employed a variant of the random coefficient switching regression model, referred to as differential yield function estimation. This allowed them to decompose the total yield-enhancing effects into SRI itself and other plot and household characteristics. Their findings indicate that SRI increases yield by 84% relative to SRT, of which half is attributable to the adoption of SRI itself, including accompanying changes in input uses (and the rest to differential household and plot characteristics).

Approximately a decade since Barrett et al. (2004) published their article in the *American Journal of Agricultural Economics*, two papers from Southeast Asia were published: one by Noltze et al. (2013) with data from Timor Leste, and the other by Takahashi and Barrett (2014) with Indonesian data.

Noltze et al. (2013) applied the endogenous switching regression model (ESR) to examine SRI impact. Their sample comprised 475 plots from 397 households, of which approximately 35% used SRI. SRI plots were defined as plots adopting the four core principles (early transplanting, single seedling, wide spacing, and AWD). The unconditional average yield of SRI was 2.9 tons/ha, whereas that of non-SRI was 3.2 tons/ha. While ESR can be an unbiased estimate even when all covariates in the first-stage estimation of SRI adoption overlap with the second-stage estimation of the yield function, it provides more credible estimates with at least one instrumental variable (IV). The authors used the percentage of SRI training participants in the farmer's village as IV. ATT estimated from ESR revealed that, on average, SRI will have 46% yield gains relative to conventional practices. However, its yield gains are not transformed into sufficient household income gains: SRI farmers increase their household incomes by only 2.3%.

My work in Takahashi and Barrett (2014) reached similar conclusions. In addition to substantial yield gains with negligible income gains, we identified the underlying mechanism. We used data from 1,202 plots among 864 sample farmers in South Sulawesi, Indonesia, wherein about 14% adopted SRI. An SRI plot is defined as one adopting at least one of the four core principles of SRI. The unconditional average yield of SRI was 5.5 tons/ha, whereas that of non-SRI was 3.0 tons/ha. Because of the lack of plausible IVs, we employed propensity score matching (PSM) for the estimation. As PSM can control only selection-on-observables, we also applied sensitivity tests to check whether unobservable factors contaminated our estimation results. ATT from PSM revealed 64% yield gains from adopting SRI. However, household income was not significantly different between farmers who adopted SRI practices and those who did not. This is because SRI increases rice income at the expense of off-farm incomes, owing to larger requirements of family labor for careful water and crop management, which induces labor reallocation into rice cultivation away from off-farm activities. Sensitivity tests revealed that unobservables may not significantly change the statistical inference. Because it may be questionable to call a plot applying only one principle as an SRI plot, we further implemented a robustness check with a stricter definition of SRI, wherein an SRI plot is defined as one that applied all four core principles. The results remained the same qualitatively.

The next three papers used samples from the same project in Tanzania. The project site is in the Kilombero District, Morogoro Region, wherein modified SRI was promoted by a large-scale rice farming company, Kilombero Plantation Limited. Unlike the four core principles of SRI typically promoted, the following six technologies were considered SRI practices at this site: (1) sorting of rice seeds, (2) direct planting or transplanting of one or two seeds per hole/hill, (3) wide-spaced seeds/seedlings on a 25 × 25 cm square grid pattern, (4) mechanical weeding using simple handheld weeders, (5) use of chemical fertilizer, and (6) use of an improved seed variety known as SARO 5. Alem et al. (2015) defined SRI plots as those in which four of the six technologies were practiced. According to this definition, 194 plots in their sample were SRI plots, and 140 were non-SRI plots. The unconditional average yield of SRI was 2.7 tons/acre (equivalent to 6.6 tons/hectare), whereas that of non-SRI was 1.06 tons/acre (equivalent to 2.6 tons/ha). The estimated results via ESR, using the number of years farmers have lived in the village and social networks measured by the number of group memberships as IVs, indicated that SRI increases yield by 58%. An obvious concern is that such yield gains stem from the use of MVs and chemical fertilizers, as only 12% and 5% of non-SRI plots (vs. 97% and 86% of SRI plots) apply them, respectively. To address this valid concern, the authors redefined SRI as plots that apply practices (1), (3), and (4) previously mentioned. This robustness check provided a qualitatively similar result, with 60% yield gains from SRI over conventional practices. As for household income, the results are mixed, depending on the price of rice used for calculation. The reported farm gate price is approximately 46% lower for MVs than for traditional varieties. Thus, if the price differences are genuine and SRI farmers tend to face lower prices, their household income becomes lower than non-SRI farmers. Conversely, if farmers are assumed to face the same rice price, SRI farmers generate approximately 40%

higher incomes than non-SRI farmers. While income effects are thus ambiguous, robust yield-enhancing effects have also been reported by Sarr et al. (2021), who used the same dataset as Alem et al. (2015). Applying an ESR variant, Sarr et al. (2021) showed that SRI increased yield by 43% on average.

Nakano et al. (2018), in which Professor Keijiro Otsuka was a coauthor, used their original dataset from Kilombero District, Tanzania. This sample comprised 398 plots from 281 households with 110 SRI and 79 non-SRI plots owned by SRI adopters; the rest were owned by non-SRI adopters. The distinction between SRI and non-SRI plots was based on farmers' self-reports. The unconditional average yield of SRI was 4.7 tons/ha, and that of non-SRI was 2.6–2.9 tons/ha. The difference-in-differences and PSM methods were separately used to address potential endogeneity. Their estimation results on ATT via PSM showed that SRI yield increased by 62%, and rice profits, defined as the gross output values minus paid-out costs and imputed costs of family-owned resources (e.g., labor and capital), increased by 285%, demonstrating a substantial profitability potential. While their study does not investigate the impact on total household income, any offsetting loss of earnings from other income sources is properly considered as long as the computation of imputed values of family-owned resources is correct.

Taken together, these observational studies indicate robust findings of the yield-enhancing effects of SRI over conventional practices. However, it must be noted that each study may have several caveats. For example, while Barrett et al. (2004) provided one of the most reliable estimates, their method was somewhat complex, and Chen and Yen (2006) highlighted several analytical flaws challenging its internal validity. Other studies using ESR may encounter a problem in that the selected IVs do not satisfy exclusion restrictions, whereas the studies that use PSM, including my own, may be criticized because it can control only selection-on-observables, no matter what sensitivity tests to unobserved confounders are executed.

To date, the most credible estimate of SRI impacts has been conducted by Barrett et al. (2022) based on an RCT, which is considered the gold standard for policy evaluation. They collaborated with the BRAC in rural Bangladesh and randomized SRI training intensities to farmers, where some villages received two-year training, some villages received one-year training, and the rest received none. Moreover, eligibility for participation in training within a village was randomized. So, their sample comprised 1,464 farmers in control villages (C or no one received training); 806 eligible and 507 non-eligible households in one-year training villages (T1 and U1, respectively); and 892 eligible and 462 non-eligible households in two-year training villages (T2 and U2, respectively). While BRAC promoted the four core principles of SRI, plus the use of organic matter amendments (e.g., compost and manure) and mechanical weeders, the adoption rates of these additional practices and AWD were low. Accordingly, Barrett et al. (2002) defined SRI plots as following the three basic principles of plant management: (1) early transplanting, (2) one to two seedlings per hill, and (3) wide spacing. SRI's adoption rate, thus defined, was 0% among C, 9% among U1, 38% among T1, 12% among U2, and 53% among T2 groups two years after the first training intervention, with the unconditional average yield of 5.3 tons/ha, 6.1 tons/ha, 6.2 tons/ha, 6.2 tons/ha, and 6.3 tons/ha, respectively.

The local average treatment effect estimator, which used the random assignment of training as IV, showed statistically significant impacts of SRI on yield and rice profits with magnitudes of 25% and 44% growth, respectively.

Overall, while some ambiguities may remain due to the lack of a firm definition of what constitutes SRI, all these cited studies identify the positive impact of SRI on yield in different contexts. Each study's results will not be necessarily generalizable as they are contingent on and specific to the area and period studied. However, repeated observations of yield-enhancing effects of SRI and its variants from one place to another may collectively indicate that the results might be externally valid (i.e., generalizable). Therefore, the key takeaway message of this chapter is that the yield-enhancing effects of SRI are becoming less controversial compared to conventional practices (if not to alternative best management practices) and seem to no longer be a UFO in the field of agricultural economics. Meanwhile, there should be some reservations about whether SRI is a truly promising technology in terms of profit maximization given the increased labor requirement, at least in the early phase of adoption (Barrett et al. 2004; Takahashi and Barrett 2014), even though accumulating evidence demonstrates positive returns (Nakano et al. 2018; Barrett et al. 2022).

7.4 Discussion and Conclusion

This chapter reviewed recent literature in agricultural economics on the yield-enhancing effects of SRI and found positive impacts under various circumstances. Although I am not a crop scientist, I conjecture that careful management practices from nursery to harvest would reduce the efficiency loss to reach the production possibility frontier, if not advance the frontier itself. Indeed, while the Asian rice Green Revolution has often been linked to intensive use of MVs and agricultural chemicals only, Otsuka et al. (2022) argued that it was management-intensive in nature, requiring the selection of good quality seeds, the implementation of proper land preparation (e.g., leveling and bunding), and transplanting in rows, with careful weeding and water management. Genetic improvement through the development of new fertilizer-responsive MVs and application of chemical fertilizers may enhance intrinsic yield potential, while improved management practices might be necessary for exploiting its full potential. In my (and in all likelihood, Professor Otsuka's) view, these combinations of science-based innovations and farmers' adaptation were key to the success of the Asian rice Green Revolution. The lack of understanding of the importance of disseminating appropriate management practices through agricultural training and farmer-to-farmer extension is a key bottleneck in applying Green Revolution technologies to SSA (Otsuka et al. 2022). Hence, it appears that a part of SRI's system and even philosophy, whether SRI proponents like it or not, is not very different from that of the Green Revolution. While exceptional yield reports, such as those exceeding 20 tons/ha, once sparked 'rice wars,' the solid positive findings on average yields in different contexts indicate that the 'rice wars' over SRI are ending, at least among agricultural economists, and attention should now shift to other unresolved issues, including its profitability.

Recollections of Professor Keijiro Otsuka

I owe what I am today to Professor Otsuka. When I was still in the master's program at GRIPS, I told him that I wanted to pursue a doctoral degree. He said, "If you go to universities in the US, the risk for failure is high, but returns on success will also be high. If you stay in a Japanese university, the risk is low, but the return may not be so high." Hearing that, I chose the latter because of less risk. But the doctoral course at GRIPS was much harder than I thought, and I couldn't complete it within the standard time frame. However, thanks to Professor Otsuka's persistent guidance, I eventually completed it in six and a half years. I am very deeply moved to be able to currently work as a professor at GRIPS and work in the office that Professor Otsuka used to use. I was almost tricked by Professor Otsuka. Studying under his supervision in Japan has provided me with very high and long-lasting returns!

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Chapter 8
RePEAT: Looking Back on 20 Years of Achievements

Yoko Kijima and Rayner Tabetando

Abstract The Research on Poverty, Environment, and Agricultural Technology (RePEAT) project was initiated in 2003 by a small group led by Takashi Yamano, Keijiro Otsuka, and Frank Place. The original focus was to understand how to enhance the income of small farm households in East African countries by increasing crop production combined with improved cattle raising and agroforestry. Until now, the number of contributors and the coverage of this project have been expanding. This chapter summarizes the findings and achievements of the project by reviewing the papers that used RePEAT data. It also discusses the future directions of the project.

8.1 Introduction

Twenty years ago, the first round of RePEAT surveys was conducted in Uganda, Kenya, and Ethiopia. Before actual data collection started, Takashi Yamano, Keijiro Otsuka, and Frank Place visited these countries many times for preparation, and the name of the project 'RePEAT' came to mind as they visited the fields. The sampling in Uganda and Kenya was based on the surveys conducted before the project by the International Food Policy Research Institute (IFPRI) led by John Pender and the Smallholder Dairy Project (SDP).[1] Their approval to use their sample for the project was instrumental. For sampling in Ethiopia, Takashi's student at Michigan State University (MSU), Berhanu Gebremedhin, provided a huge help. The project has benefited from experienced survey teams from Makerere University (Dick

[1] SDP was a research project jointly conducted by the Ministry of Agriculture, Livestock and Fisheries, the Kenya Agricultural Research Institute, and the International Livestock Research Institute.

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Sserunkuuma, George Sentumbwe); Tegemeo Institute; World Agroforestry Center; International Livestock Research Institute; and Ethiopian Development Research Institute (EDRI).

Research members based at the National Graduate Institute for Policy Studies at the time of surveys include Keijiro Otsuka, Takashi Yamano, Yoko Kijima, Tomoya Matsumoto, Chikako Yamauchi, and Alistair Munro, with the help of Rie Muraoka and Ryo Takahashi. Many graduate students that they supervised used RePEAT data for their dissertation.

RePEAT is a pioneering work in creating a panel dataset from Africa.[2] This is a research work whose brain and the initiator is Professor Keijiro Otsuka. To date, no other development economist has done extensive and deeply intensive work on household surveys in Africa.

This chapter lists up to 62 research outputs produced using RePEAT data and categorizes them by topics covered, countries, and survey rounds used. This catalog helps future users of RePEAT data have an overview of the project and identify which research areas are understudied.

Section 8.2 of this chapter describes the basic characteristics of the RePEAT survey and Sect. 8.3 reviews the existing literature, which used the data from the RePEAT survey. Finally, Sect. 8.4 discusses the future of the project.

8.2 Description of the Survey

The population of the survey is composed of farm households in rural areas. While the number of original sample households is 940, 934, and 420 in Uganda, Kenya, and Ethiopia, respectively, due to attrition in the long panel data (10–14 years), the number of households that are consistently present in all rounds is 647, 605, and 376. In the last survey round for each country, additional households were added to the sample. In Ethiopia, 100 communities were initially selected for the community survey, but due to budget constraints, households were selected from 40 communities instead. The 2014 survey, however, expanded the household survey into these 100 communities and added missed households in the originally selected communities (Yamano et al. 2011a, b). Thus, 1,366 households were interviewed in 2014. In the 2018 Kenya survey, sample households were added and replaced, resulting in the total number of households becoming 1,228. In the 2015 Uganda survey, the replacement and addition of households were done. The northern region was also included in the survey (the total number of sample households is 1,735).

The project aims to understand the problems and constraints rural farm households in East Africa face by constructing panel datasets. How they can move away from

[2] Since 2010, farm household panel data capturing agricultural income have been collected in Africa, such as the Living Standards Measurement Survey Integrated Survey on Agriculture (LSMS-ISA). Prior to RePEAT, there was panel data in Kenya conducted by Egerton University Tegemeo Institute/MSU Rural Household Survey in 2000 and 2004.

these constraints is also investigated. Questionnaires contained detailed questions to capture farm household income comparable among three countries.

8.3 Studies by Theme and Country

The references list 62 studies that used RePEAT data. In Table 8.1, they are categorized by theme and country. There are five sets of studies. We summarize their main objectives and findings and highlight their contributions to the literature.

The first set of research topics is related to agriculture, such as agricultural productivity, agricultural technology adoption, agricultural intensification, soil quality and soil management, demand for fertilizer, agricultural market participation, integrated farming system, and price analyses of agricultural outputs and inputs. Given that RePEAT sample households mainly depend on agriculture for their livelihood, enhancing agricultural productivity is crucial for their welfare. The adoption of modern technologies (hybrid seeds and chemical fertilizer) and the use of organic matter to manage soil quality are critical for enhancing production in these countries (Matumoto and Yamano 2013). For these analyses to be conducted, the survey collected soil samples from the field and created objective measures of soil quality, which is normally "unobserved" in the literature (Yamano and Kijima 2011).

The second set comprises studies about land and the environment, such as land markets, land conflicts, climate change, forest management, and communal grazing lands. As the population pressure increases, access to land becomes scarcer, which requires the land rental market to function better for better resource allocation. Detailed questions about land transactions and land tenure for all the parcels households revealed how the land rental market is used, specifically from whom and to whom (or the other way around), leads to different welfare implications. In Uganda and Kenya, land rental markets function to make land allocation more efficient and more equitable as the land is rented out from less productive to more productive farmers, and land is transferred from land-abundant to land-constrained households (Kijima and Tabetando 2020). Another feature of the RePEAT survey was that it was flexible enough to expand questionnaires and area coverage to examine issues faced by farmers. By conducting surveys just after the political violence in Kenya and expanding the sample to Northern Uganda, where many households were displaced due to armed conflict, the causes of land conflicts were examined. The formal land title may help when there are unexpected events. During the political violence in Kenya, those with no land titles were more likely to be victimized (Yamano and Tanaka 2014). Those displaced in Northern Uganda for a longer time were likely to have land conflicts after returning home.

The third set of studies focuses on poverty, ranging from typical measures (per capita consumption expenditure and income) to food security, livelihood diversification, and income from nonfarm employment and migration. As farm households tend to be affected by weather-related shocks, leading them to transitory poverty, diversifying their income source is an important livelihood strategy. This is even

Table 8.1 Research categorized by theme and country

	Uganda	Kenya	Ethiopia
Agricultural productivity	Kijima and Tabetando (2020); Larson et al. (2014); Matsumoto and Yamano (2013); Mwesigye and Barungi (2021)	Kijima and Tabetando (2020); Larson et al. (2014); Matsumoto and Yamano (2013)	Haddis and Kijima (2022); Kijima and Gonzalez (2013)
Agricultural technology adoption	Matsumoto (2014); Matsumoto et al. (2013)		
Agricultural intensification	Mugizi and Matsumoto (2021b)	Mugizi and Matsumoto (2020); Muraoka et al. (2018)	
Soil quality, soil management	Gray (2011); Matsumoto and Yamano (2013); Mugizi and Matsumoto (2021b); Yamano and Kijima (2011)	Matsumoto and Yamano (2013); Mugizi and Matsumoto (2020); Yamano and Deininger (2008); Yamano and Kijima (2010); Yamano and Kijima (2011); Yamano et al. (2008)	Yamano and Kijima (2011)
Fertilizer	Matsumoto (2014); Matsumoto and Yamano (2011b); Yamano (2011); Yamano and Arai (2011b)	Kiprono and Matsumoto (2018); Matsumoto and Yamano (2011b); Yamano and Arai (2011b)	Matsumoto and Yamano (2011a); Yamano and Arai (2011b)
Market participation	Muto and Yamano (2009); Muto and Yamano (2011)	Kiprono and Matsumoto (2018)	
Milk production and market	Balirwa et al. (2016)Yamano et al. (2011a, b)	Kijima et al. (2010); Kijima et al. (2011); Muraoka et al. (2018); Yamano et al. (2011a, b)	
Integrated farming system	Yamano (2011)	Muraoka et al. (2016)	
Price analyses	Yamano and Arai (2011a); Yamano and Arai (2011b)	Yamano and Arai (2011a); Yamano and Arai (2011b)	Yamano and Arai (2011b)
Infrastructure, market access	Yamano and Arai (2011a)	Kiprono and Matsumoto (2018); Yamano and Arai (2011a)	

(continued)

Table 8.1 (continued)

	Uganda	Kenya	Ethiopia
Land tenure	Mwesigye et al. (2017)		
Land market	Ainembabazi and Angelsen (2011); Kijima and Tabetando (2020)	Kijima and Tabetando (2020); Muraoka et al. (2018)	Haddis and Kijima (2022)
Land conflict	Mugizi and Matsumoto (2021a); Mwesigye and Matsumoto (2016)	Yamano and Deininger (2008); Yamano et al. (2008); Yamano and Tanaka (2014)	
Climate change	Tabetando and Kijima (2022)	Munro (2020); Tabetando and Kijima (2022)	
Forest, tree planting	Call et al. (2017)		
Communal grazing lands	Call and Jagger (2017)		
Poverty	Kijima et al. (2006); Kijima and Tabetando (2020); Matsumoto et al. (2006); Matsumoto et al. (2009); Munyegera and Matsumoto (2016); Otsuka et al. (2010)	Kijima and Tabetando (2020); Kijima et al. (2006); Matsumoto et al. (2009); Otsuka et al. (2010)	Haddis and Kijima (2022); Kijima and Gonzalez (2013); Kijima et al. (2006); Matsumoto et al. (2009); Otsuka et al. (2010)
Income composition	Yamano and Kijima (2010); Yamano and Kijima (2011)	Yamano and Kijima (2011)	Yamano and Kijima (2011)
Food security		Muraoka et al. (2018)	
Livelihood diversification	Tabetando and Kijima (2022)	Tabetando and Kijima (2022)	
Nonfarm employment	Kijima et al. (2006); Matsumoto et al. (2006); Matsumoto et al. (2009)	Matsumoto et al. (2006); Matsumoto et al. (2009)	Matsumoto et al. (2006); Matsumoto et al. (2009)
Migration, remittance	Gray (2011); Matsumoto et al. (2006); Muto (2012); Munyegera and Matsumoto (2016)	Matsumoto et al. (2006); Simiyu (2013a); Simiyu (2013b)	Haddis and Kijima (2022); Matsumoto et al. (2006)
Risk sharing	Tabetando and Matsumoto (2020); Takahashi (2017)		

(continued)

Table 8.1 (continued)

	Uganda	Kenya	Ethiopia
Armed conflict; Post-election violence	Kijima et al. (2022); Mugizi and Matsumoto (2020); Tanaka and Yamano (2015)	Simiyu (2013b); Yamano and Tanaka (2014)	
Mobile phones	Muto (2012); Muto and Yamano (2009); Muto and Yamano (2011); Takahashi (2017); Yamano, Otsuka, and Place (2011a, b)	Yamano, Otsuka, and Place (2011a, b)	
Mobile money	Munyegera and Matsumoto (2016); Munyegera and Matsumoto (2018); Tabetando and Matsumoto (2020)	Simiyu (2013b)	
Financial service	Munyegera and Matsumoto (2018)		
Education	Asankha and Yamano (2011); Nagashima and Yamauchi (2020); Nishimura et al. (2007); Nishimura et al. (2008); Otsuka et al. (2010); Tabetando (2019); Tabetando and Matsumoto (2020); Tanaka and Yamano (2015); Yamano et al. (2006)	Nishimura and Yamano (2013); Otsuka et al. (2010)	Otsuka et al. (2010)
Health	Egami and Matsumoto (2020); Manang and Yamauchi (2020)		
Lab-in-the field experiments	Kijima et al. (2022); Masekesa and Munro (2020); Tabetando (2019); Tanaka and Munro (2014); Tanaka and Yamano (2015)		
Randomized controlled trial	Matsumoto (2014); Matsumoto et al. (2013)		
Survey instrument		Munro (2020)	

more essential in recent years as droughts and floods have occurred more often due to climate change. Using the RePEAT surveys can capture the kinds of diversification strategies households have taken in the long-term. In Kenya and Uganda, income and crop diversification positively impacted household per capita income (Tabetando and Kijima 2022). Another way to mitigate the negative impact of the shocks is to have coping strategies, such as saving, borrowing, and getting a loan. The recent development of information and communication technologies (ICTs) plays a critical role in reducing the transaction cost of accessing such financial services and increasing remittances received (Munyegera and Matsumoto 2016).

The fourth set of studies is on human capital investment. In Uganda and Kenya, a free primary education policy has been implemented. That allowed us to test if exogenous shocks of reduced education cost affected child education investment decisions, especially for girls in poorer households. It is hoped that later when these children become mothers, they may invest more in their children's human capital. However, the quality of education in public primary schools have deteriorated due to increased enrollment, which affects school choice to private schools (Nishimura and Yamano 2013).

The final set of studies is about research methodologies. In Uganda, a randomized controlled trial (RCT) was implemented between 2009 and 2012 to investigate the price elasticity of demand for maize hybrid seeds and chemical fertilizer (Matsumoto 2014). Furthermore, in 2012 and 2015, lab-in-the-field experiments to elicit preferences were conducted in Uganda (Tanaka and Munro 2014; Masekesa and Munro 2020). This is another way of utilizing the panel data covering the entire country. In the last round of the Kenya survey, one section was used to test whether how questions are asked results in different responses or not (Munro 2020).

In sum, more studies are using Uganda data, followed by Kenya data. One reason is that Uganda's survey team has been flexible and experienced in allowing the addition of more questions on themes that did not originally exist (such as health) and different research methodologies.

Table 8.2 shows the list of these studies by survey round used and country. Most of the studies use panel data from one country. However, as mentioned earlier, questions and research methodologies were added in the 2015 Uganda survey, which increased the number of studies using only fifth-round data. Studies with international comparisons were produced since the first and second rounds of questionnaires were almost the same among the three countries. So far, the datasets of the three countries collected in the first two rounds have been publicly available from the website (http://www3.grips.ac.jp/~21coe/e/data/content/main.html). But there is now website for the other rounds. Making data public and enhancing accessibility to the datasets is also an urgent issue.

Table 8.2 Research categorized by survey rounds and country

Survey Rounds	Uganda	Kenya	Ethiopia	Uganda and Kenya	3 Countries
All rounds	Tabetando and Matsumoto (2020); Tabetando (2019); Mugizi and Matsumoto (2021b); Egami and Matsumoto (2020)		Haddis and Kijima (2022)	Tabetando and Kijima (2022)	
All except the last round	Munyegera and Matsumoto (2018); Manang and Yamauchi (2020)	Mugizi and Matsumoto (2020)		Kijima and Tabetando (2020)**	
1–3 rounds	Mwesigye, Matsumoto, and Otsuka (2017); Asankha and Yamano (2011); Ainembabazi and Angelsen (2011)				
1st and 4th rounds	Mwesigye and Barungi (2021)	Munro (2020)			
1st and 3rd rounds	Mwesigye and Matsumoto (2016)	Muraoka et al. (2016); Muraoka et al. (2018); Kiprono and Matsumoto (2018)			

(continued)

8.4 Concluding Remarks

This chapter reviewed studies that used data from the RePEAT project in three East African countries from 2003 to 2018. As of February 2022, 62 journal papers and book chapters have been published. Research topics have covered ones related to

Table 8.2 (continued)

Survey Rounds	Uganda	Kenya	Ethiopia	Uganda and Kenya	3 Countries
1st and 2nd rounds	Yamano and Kijima (2010); Yamano (2011); Takahashi (2017); Nishimura et al. (2007); Muto and Yamano (2011); Muto and Yamano (2009); Muto (2012); Kijima et al. (2006); Call et al. (2017)	Yamano and Tanaka (2014); Nishimura and Yamano (2013)	Matsumoto and Yamano (2011a)	Yamano et al. (2011a, b); Yamano and Arai (2011a); Matsumoto and Yamano (2013); Matsumoto and Yamano (2011b); Larson et al. (2014); Gray (2011)	Yamano and Kijima (2011); Yamano and Arai (2011b)
2nd and 3rd rounds	Matsumoto et al. (2013); Matsumoto (2014)				
3rd and 4th rounds	Munyegera and Matsumoto (2016)				
1st round only	Yamano et al. (2006); Nishimura et al. (2008); Call and Jagger (2017)	Yamano et al. (2008); Yamano and Deininger (2008); Kijima et al. (2011); Kijima et al. (2010)			Otsuka et al. (2010); Matsumoto et al. (2006); Matsumoto et al. (2009)
2nd round only	Balirwa et al. (2016)	Simiyu (2013a); Simiyu (2013b)*	Kijima and Gonzalez (2013)		
3rd round only	Tanaka and Yamano (2015); Tanaka and Munro (2014)				

(continued)

Table 8.2 (continued)

Survey Rounds	Uganda	Kenya	Ethiopia	Uganda and Kenya	3 Countries
5th round only	Nagashima and Yamauchi (2020); Mugizi and Matsumoto (2021b); Masekesa and Munro (2020); Kijima et al. (2022)				

Notes * These studies also used the 2009 post-election violence special round. ** All rounds of the Uganda survey were used. 8.4 Concluding Remarks

the project's original purposes (poverty reduction, environment, and agricultural technology) and expanded to incorporate emerging issues in the survey villages, such as the introduction of mobile money, land conflicts, and climate change. Studies were also done to understand household welfare other than income and expenditure (education and health). The unique datasets provided Ph.D. students in the National Graduate Institute for Policy Studies (GRIPS) with rare and valuable opportunities to utilize the panel data, conduct lab-in-the-field experiments on the sample households, add some questions in questionnaires, and examine new research questions as a part of the project.

As initially intended by Professor Keijiro Otsuka, the RePEAT project will continue as it is aptly named 'repeat.' The project needs to examine new challenges faced by rural households. Furthermore, as the original sample households became older than the national average, national representativeness is no longer guaranteed though efforts to add extra households into the sample have been made in the last waves. Given limited funding and the increase in labor costs for conducting the survey, the project team must balance increasing the sample size with adding new questions.

8.5 Recollections of Professor Keijiro Otsuka

I first met Professor Otsuka in 2014 during my first year as a Ph.D. student at GRIPS. I was immediately attracted to his profound understanding of development issues in Sub-Saharan Africa. His course titled Strategies for Economic Development transformed my understanding of development economics. I am very thankful to him for all his effort to train a new breed of African academics and policymakers. We will not stop disseminating his ideas and values to our friends, colleagues, and students.

—Rayner Tabetando.

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Part II
Land Tenure and Sustainable Natural Resource Management

Chapter 9
Fifty Years of Research on Land Tenure Policies and Land Markets: What Are the Major Lessons?

Stein T. Holden

Abstract This study makes a broad review of important contributions by economists to the understanding of land and labor contracts in agriculture and the analyses of major land tenure reforms in the twentieth century. Possible disincentive effects associated with share tenancy received much attention in the early theoretical literature and have later been scrutinized empirically with the availability of better data and better methods. With the development of better impact assessment methods and the experimental revolution in economics, land tenure reforms have increasingly also been assessed based on stronger data and better methods. However, using random treatments in such institutional reforms may neither be feasible nor recommendable in many cases. Still, experimental approaches may be used to investigate short-term impacts and help to reveal otherwise unobservable variables, such as risk preferences and trustworthiness, that affect land and labor contracts. With a good understanding of important contextual characteristics and new and better data, land tenure and land policies remain a vibrant and important area of research for applied economists. Rural transformation and adaptation to climate change put new pressures on rural factor markets and land tenure institutions in economies where shocks and pervasive market imperfections remain important challenges.

9.1 Introduction

Professor Keijiro Otsuka was one of the early contributors to the scientific literature that comprehensively assessed and confronted theories on land and labor contracts in rural communities with empirical evidence (Otsuka and Hayami 1988; Otsuka et al. 1992; Hayami and Otsuka 1993). These much-cited contributions to the literature followed a period when many development economists were obsessed with theoretical explanations for the dominance and persistence of share tenancy in many rural societies, much stimulated by the claimed 'Marshallian inefficiency' that Alfred

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Marshall (1890) identified as a potential weakness of share tenancy contracts (Cheung 1969; Bardhan 1979, 1989; Bardhan and Srinivasan 1971; Bell 1977; Bell and Zusman 1976, 1989; Eswaran and Kotwal 1985; Stiglitz 1974). The potential persistence of inefficient contracts challenged the belief that institutions and markets evolve toward more efficient equilibria. This 'wicked problem'[1] of share tenancy, including the puzzle that 50–50 output sharing is a dominant empirical characteristic, attracted many strong brains. Multiple theoretical explanations were proposed and, over time, also tested with varying levels of rigor in heterogeneous contexts. Professor Otsuka and coauthors were, to the best of my knowledge, among the first to relate 'Marshallian inefficiency' to policy interventions that, for the same reason, may be coined as 'policy failures' as well as 'market failures' as they represented interventions that intervened in what was perceived as 'imperfect' markets and thereby unintentionally enhanced inefficiency and often with undesirable distributional outcomes (Otsuka et al. 1992; Otsuka 2007; Holden et al. 2013).

Ideology and contested resource, power, and welfare distributions were important drivers of political reforms in the twentieth century and resulted in, to a varying degree, radical reforms that affected the political economy of rural areas. The pre- and post-reform land tenure characteristics had substantial impacts on rural factor markets, power relations, and their economic and social impacts. This political heterogeneity also made it hard to make scientific inquiries to critically examine the causal effects of such reforms. Substantial differences existed in perspectives across social science disciplines between economists, who put much focus on efficiency and the functioning of markets, and some social scientists who, to a larger extent, emphasize distributional and power relations and have been skeptical of market forces. Over time, the research on land tenure reforms has moved toward becoming more evidence-based in keeping with the evolution of theory, impact assessment methods, and the availability of better data. Many nation-states experienced the consequences of large ideology-based experiments and learned the hard way from their own experiences.

In this chap, I try to summarize some of the key changes that have caused scientific research to have had an increasing influence on land tenure policies over the last 50 years. In Sect. 9.2, I will describe some fundamental issues that frame the functioning of agrarian rural economies. In Sect. 9.3, I give an overview of important theoretical developments and contextual variations of land and labor contracts in agrarian economies. Sect 9.4 summarizes some important lessons from the large land tenure–related policy experiments in the twentieth century. Sect 9.5 summarizes important developments in policy impact assessment methods and their applications to land tenure–related reforms, new and better datasets that jointly have enhanced the scope for better policy analyses, and some remaining limitations before I conclude.

[1] We call it a 'wicked problem' because of the inherent difficulties in identifying the causal relations between observable endogenous contract characteristics, imperfect market characteristics, and observable and unobservable landlord and tenant characteristics (such as motivations, beliefs, trust, reputation, and economic and social preferences).

9.2 Some Fundamentals

Economists were, for quite some time, obsessed with measuring efficiency and how to move economies toward first-best, perfectly competitive markets. With efficient markets, there would also be more goods to distribute to enhance social welfare. The definition and allocation of private property rights became a cornerstone of the ideal perfect market economy. Interventions could only be defended if they removed market failures in situations where markets were missing or imperfect.

However, the real world, especially the rural world where land is a fundamental resource in food production and a base for livelihood, suffers from some fundamental characteristics that are not conducive to achieving perfect market conditions. This may be described as the fundamental production relations in agriculture (Binswanger and Rosenzweig 1986). Land is immobile and thereby determines the spatial nature of food production and other forms of agricultural production. Most agricultural production is rainfed and depends on seasonal rainfall and temperature patterns, creating the unique seasonal nature of agricultural production. The spatial dispersion also has strong implications for the degree of market integration; and location-specific and partly irreducible transaction costs that influence imported inputs and exported outputs. The dependence on stochastic weather and other risks, covariate shocks, and uncertainties have contributed to imperfect or missing intertemporal markets for insurance and credit. Pervasive imperfections in labor markets associated with moral hazard and potential incentives to shirk, combined with seasonality in demand for labor, explain the dominance of family farms and family labor in agricultural production almost everywhere in the world. Such rural economies are therefore characterized by some forms of pervasive and irreducible transaction costs and information asymmetries. This led Greenwald and Stiglitz (1986) to characterize them as constrained Pareto-inefficient. While the Theory of Second Best warned against believing in simple solutions to deal with apparent market failures, Greenwald and Stiglitz advocated a more intervention-friendly approach to enhance the performance of imperfect market economies. Later the removal of poverty traps received more attention.

While the Green Revolution, in combination with infrastructure investments (roads, irrigation) and related institutional innovations, greatly enhanced the development of factor markets in most rural areas, rural land, labor, credit, and insurance markets remained imperfect. The variation in political histories across nation-states also created a large heterogeneity in farm size distributions, from the very egalitarian distributions after radical reforms in China, Vietnam, and Ethiopia to the extremely skewed distributions in Latin American countries. With large variation in population densities, we also see an enormous variation in average farm sizes from micro-farms in India, Bangladesh, and Rwanda, to extremely large farms in Australia, Argentina, and Canada. I will focus primarily on the more densely populated developing countries. Land tenure issues become more important and often challenging to resolve when land is scarce. In the next sect, I will go through the evolution of important theories that economists have used to explain land and labor contracts in agriculture.

9.3 Developments in Theory and Contextual Variations of Land and Labor Contracts

Alfred Marshall (1890) had a profound impact on how economists developed and refined theories on land and labor contracts. The potential disincentive effects associated with output sharing have been subject to many theoretical and empirical assessments, as summarized in the introduction (Otsuka et al. 1992). A summary of the major sophistications of theories and additional contextual modifications follows.

From certainty to stochastic production risk and implicitly missing insurance markets. Cheung (1969) introduced the idea that sharecropping implied risk sharing among landlords and tenants and became an essential element of later analyses. Input sharing combined with output sharing can balance contract incentives (Braverman and Stiglitz 1986). Low elasticity of substitution between essentially complementary factors of production combined with factor market imperfections and pervasive transaction costs, and tenure insecurity associated with tenure reforms, lead to heterogeneous outcomes in resource use efficiencies across contract partners and contracts (Holden et al. 2010).

From principal-agent models to bargaining models. In many situations, the landlord may be less able to dictate all contract conditions, and bargaining models may be more relevant. Several elements of the contracts may be bargained over, such as input sharing, output sharing, crop choice, and contract duration and renewal conditions (Ackerberg and Botticini 2002; Gebrehiwot and Holden 2020).

From risk-neutral to risk-averse landlords and tenants. From the rich landlord-poor tenant to the more common reverse tenancy with poorer landlords, it has become more relevant to assume that both parties are risk-averse in developing-country settings where both landlords and tenants are fairly poor (Ghebru and Holden 2015).

From static (one-period) to dynamic (recursive) models. With the expansion from one-period to recursive dynamic models, issues like land quality and conservation investments and contract renewal conditions depending on trust and reputation can influence contract outcomes and motivate effort and partner selection. Such contracts may address dynamic land quality externalities and moral hazards through threats of eviction and make contract renewal conditional on good performance (Banerjee and Ghatak 2004; Kassie and Holden 2007).

Covariate weather shocks in a reverse tenancy setting can induce distress rentals and unfavorable fixed-rent contracts for poor landlords to obtain urgently needed cash (Gebregziabher and Holden 2011; Ricker-Gilbert et al. 2021; Tione and Holden 2021a). This also highlights the implicit credit associated with payment at harvest rather than at planting time, as fixed rents typically are paid upfront.

Complementary indivisible factors of production, animal traction power, and reverse tenancy. These have been observed in India (Jodha 1985), Eritrea (Tikabo 2003), and Ethiopia (Ghebru and Holden 2015). Imperfect or missing markets for rental tilling services may be due to the strong seasonality in agriculture, strict timing requirements of land cultivation in rainfed agriculture, and moral hazards associated with the management of rented animals.

Overall, contextual heterogeneities require careful adjustment of theoretical models for them to adequately represent and explain local land and labor contracts and land productivity differentials.

9.4 Lessons from Some Real-World Land Tenure-Related Policy Experiments

Radical tenure reforms that built on the analysis of the capitalistic system by Karl Marx and others had a tremendous impact on the land tenure systems in many countries. Anti-market revolutions were major drivers of rural transformations in Eastern Europe, China, Vietnam, Ethiopia, and to varying but lower degrees in other countries. The elimination of private property rights and establishment of state property were fundamental and were combined with the allocation of user rights of varying strength that evolved following many failed attempts to run collective and state farms. In China, establishing the household responsibility system was a game-changer that recreated many of the benefits inherent in family farms.

Other than the radical land reforms above, land-to-the-tiller reforms in many Asian countries, such as Bangladesh, India, Nepal, Pakistan, and the Philippines, aimed to enhance land access for land-poor and landless tenants. De facto evidence indicates that landowners, in many cases, managed to evict tenants, and tenants were often converted to permanent laborers or were provided short-term unregistered contracts only (Otsuka et al. 1992). In Nepal, high-caste landowners also rented land to other inefficient high-caste households rather than more efficient low-caste households (Aryal and Holden 2013). The reform, therefore, failed to improve land access for the land-poor and may also have enhanced the inefficiency associated with short-term sharecropping contracts because tenure insecurity affected tenant selection and the ability to use renewal conditions to enhance tenants' incentives.

Secure private property rights have been seen as a key to efficient land use in market economies. Land titling programs that provided documented land rights have been the approach used in most developed countries. Some early attempts at land titling for the same purpose were done in developing countries, such as Thailand and Kenya (Feder and Onchan 1987; Place and Migot-Adholla 1998). It was believed that land titling would enhance the functioning of credit markets by facilitating the use of land as collateral, like in western countries (de Soto 2001). Several other attempts at classical land titling in Africa did not perform as well as hoped (Benjaminsen et al. 2009). The titling upon demand approach, in particular, became too costly for many landholders and favored the wealthy.

Low-cost land registration and certification was a new approach that was first implemented on a large scale in Ethiopia from 1998, first through an orchestrated participatory approach with simple technologies (Deininger et al. 2008). With the improved access to electricity and computer and digital technologies, the low-cost approach was expanded in several countries in Africa and Asia. It was used to strengthen landholders' property rights and tenure security in countries with weak user rights to land, such as Ethiopia, China, India, Rwanda, and Vietnam. Studies in Ethiopia have shown that this reform has strengthened tenure security, investment in conservation, and land rental market participation (Deininger et al. 2011; Holden et al. 2009, 2011, 2013). Credit market improvements following the reform may take longer to appear as they depend on the development of sales markets for land and for banks to be able to use foreclosure.

Customary tenure reforms were also attempted in many African countries in response to growing population pressure, individualization of land holdings, and the emergence of land markets (Holden et al. 2010; Holden and Otsuka 2014; Wily 2011). The sharp increase in the demand for land in the 2008–2012 period associated with high energy and food prices also triggered land grab fears and more coordinated international and national actions to better protect land rights (Deininger and Byerlee 2012). While this period revealed that large tracts of land were up for grabs, many large investors gave up their projects when the energy prices fell in the following years. Large heterogeneities both within and across countries make it hard to generalize about the impacts of such customary tenure reforms. However, there is a high risk that elite capture will play an important role in such reforms, and the poor and vulnerable are at high risk of being marginalized (Wily 2015).

9.5 Development in Policy Impact Assessment Methods and Datasets and Their Limitations

While the early literature on land and labor contracts focused on finding theoretical explanations for observed regularities, a few studies carried out careful empirical investigations regarding the correctness of the theoretical assumptions and explanations. With the development of better data collection efforts with survey data and the use of better econometric methods, there was also a gradual improvement in the empirical verifications. Shaban (1987) established a new and higher standard for assessing land-use efficiency on sharecropped versus fixed-rent and owner-operated land of owner-cum-tenants. By using models with household fixed effects, he was able to control for unobservable household characteristics and allowed a within-household comparison of input use and productivity on sharecropped and owner-operated plots. His study in India supported the Marshallian disincentive hypothesis as productivity was found to be lower on sharecropped than on owner-operated land. However, the approach may not help reveal the impacts of underlying tenure reforms that would have to be captured based on repeated data collections over time and framing of natural experiments based on such policy changes.

A further refinement of the analysis of contract efficiency also needs to deal with selection biases associated with partner (tenant) selection and plot selection for rent. If landlords prefer to rent out their poorest quality plots, the Shaban approach may not be able to control for unobservable land quality, and the approach may then exaggerate the degree of Marshallian inefficiency associated with sharecropping contracts. In settings with variations in contract characteristics, such as variation in output sharing rates, input sharing rates, contract duration and termination conditions, a mixture of kin and non-kin tenants, a mixture of oral and written contracts, and variation in who has the responsibilities for land conservation, etc., one may theorize about the importance of these heterogeneities. It is nearly impossible to identify the determinants of each and estimate their effects unless some natural experiment can be identified. In most cases, one is left to speculate based on estimated correlations.

The systematic review by Lawry et al. (2017) illustrates the difficulty of finding studies that satisfy the high-quality standards of modern impact assessment related to measuring impacts from land tenure policies and reforms. After reviewing 27,000 studies, they ended up with only 20 studies upholding a high-quality impact assessment standard. Out of these, ten studies were in Africa, and of these, five were in Ethiopia. Two lessons emerge from this. First, there is a need for more high-quality studies. Second, the limited geographical coverage of the existing high-quality studies provides reason to question their external validity, given the large heterogeneity in contexts.

Experimental methods hold the potential to provide new evidence on the impact of new tenure reforms and policy interventions (e.g., spatial discontinuity and pipeline difference-in-difference designs can help reveal at least short-term local impacts of such reforms) (Ali et al. 2014; Deininger et al. 2011). Randomized controlled trials (RCT) have been advocated as a 'gold standard' for identifying causal effects but have also been criticized for not having such potential related to policy variables that cannot easily be randomized or where the causal mechanisms are highly context-specific (Deaton 2010). Selection issues are at the heart of contract choice. Random allocation of contracts under a double-blind standard is challenging to use when treatments are observable for the groups being treated, and the treatment effects emerge gradually over time. Elimination of the selection component of selection–based contracts through randomization can only make a partial assessment of the benefits of such contracts.

The increasing availability of more nationally representative household panel datasets, such as the Living Standard Measurement Study–Integrated Surveys on Agriculture (LSMS-ISA), provide useful insights, including on some land tenure issues and land market participation in the smallholder sector in many African countries (Jayne et al. 2021; Tione and Holden 2020, 2021a, b). One of the limitations of these surveys is that they do not include sufficient samples of medium and large farms to facilitate careful analysis of land exchange across these farm size categories.

Other data include the Land Matrix (https://landmatrix.org/), which compiles data from national investment registries on large-scale land investments. While this database has many omissions and limitations, it may be further improved and become the basis for more reliable investigations over time (Anseeuw et al. 2013; Cochrane and Legault 2020).

Land registry data are a potential source for analyzing land and farm size distributions in countries where land registration has been implemented. Such data may help map variations over space and time and may even be used to assess the gender distribution of land over time and space (Holden and Tilahun 2020). Spatial data hold a lot of potential for more refined analyses in combination with maps. The tricky issue is ensuring the anonymity of subjects studied when spatial microdata are presented.

None of the data sources above provide data on landholders' preferences, such as their risk preferences, that have been identified as potentially important for contract choice. Likewise, they do not provide data on trust; trustworthiness; and reputation, beliefs, or expectations, such as the perceived tenure insecurity of landlords and tenants. These variables are potentially important in relation to land contract decisions in communities where such types of information and its distribution may play an important role. While some studies have combined surveys and experiments to reveal additional insights on such variables, such studies are still few and represent an area where more research would be useful. An exception is a study by Holden and Tilahun (2021), who used a trust experiment to elicit a measure of tenants' trustworthiness in Ethiopia and found that more trustworthy tenants were more likely to access rented land in a context with rationed access to such land.

9.6 Conclusions

This chap has drawn a broad line through major land tenure reforms during the twentieth century and highlighted important areas where economists contributed theoretically and empirically by generating new insights to better understand land tenure and policy impacts, especially land and labor contracts in agriculture. The insights gained as well as improved data access can also be used to analyze contemporary issues, such as rural transformation processes and the tackling of climate change. Land rental markets have become particularly important in facilitating rural transformation as land sales markets have been constrained by law, fragmented holdings, and owners unwilling to sell even if they do not use the land efficiently themselves.

The evolution of value chains and commercialization of agriculture through contract farming has further improved market integration in many rural areas. Whether this revolution leads to the end of smallholder farm production has been raised. However, with continued population growth in most rural areas, we see a growing scarcity of land, increasing land values, and decreasing farm sizes in many developing countries. Strong growth in the nonfarm economy combined with reduced population growth may trigger a rural transformation with reduced dependence on agriculture, rising rural wages, and conversion to larger farm units in more agrarian countries, as observed in many western countries and, also recently, in China (Huang and Ding 2016). Interventions to reduce transaction costs in spatially–dispersed land rental markets have been instrumental in speeding up this process in China. In contrast, the farm size distribution has been fairly stable in Vietnam over the period 1992–2016, even though rural wages have increased (Liu et al. 2020). Instead, farm households have gradually increased their engagement in the nonfarm economy and adopted labor-saving technologies on their farms. Efficient markets for renting machinery rather than land renting have facilitated the capital for labor transformation in Vietnam. This substitution of capital for labor is driven by growing wage rates but may not happen in areas where population growth is high. The recent pandemic and climate change represent short-term and longer-term threats to employment and continued wage increases, hindering or delaying this transformation process.

Climate change and the recent and ongoing pandemic have demonstrated stronger than ever before that we live on a small planet, and collective actions at the global as well as local levels are needed to mitigate risks and change policies and behavior to ensure more sustainable development that protects the interests of future generations. In this context, the security and role of property rights and markets are growing in importance, and they are under threat due to natural disasters, economic crises, climate change/covariate weather shocks, and political conflicts and war. The respect for human rights and the emphasis on poverty reduction as a central Sustainable Development Goal are also under threat, as seen by the inability of the UN to handle recent conflicts, destitute migration, and hunger catastrophes. Increasing tensions between the world's superpowers also jeopardize efforts toward finding solutions to the threats from climate change.

9.7 Recollections of Professor Keijiro Otsuka

I first met Keijiro Otsuka at IFPRI in 1995 when I visited there for a job interview. In 2005, I invited him (and Frank Place) to coedit our book *Land Markets in Africa.* We had several workshops with young talented African economists that contributed chap to the book. Funding by the Environment for Development network facilitated workshops in Ethiopia, Kenya, and Beijing. We were also invited to Tokyo to complete the book published by RFF Press in 2008. Based on this experience, we agreed to coedit another book, *Land Tenure Reform in Asia and Africa,* and invited Klaus Deininger as the third coeditor. Also, we arranged several workshops with the book contributors for this book, and the book was published by Palgrave. In between and after, we met at various conferences and also made some joint field trips in Ethiopia, although factors outside our control undermined our plans for more extensive joint work. I always admired the dedication and hard work of Professor Otsuka, and he was always well prepared when we met to work on our book projects. I am honored to contribute to his Festschrift.

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Chapter 10
Property Rights and Natural Resource Management in Developing Countries

Ryo Takahashi

Abstract As forestland and grazing land grow scarcer and rural poverty persists in developing countries, sustainable natural resource management (NRM) for income generation and poverty reduction is imperative. Although securing property rights on forestlands is fundamental for sustainable resource management, the conditions under which one institution outperforms the others in the efficiency of forest management have not yet reached a consensus. In contrast, forest management under common property regimes (e.g., community forest management) is commonly adopted in developing countries in Asia and Africa. As argued by Ostrom, community forest management is effective in protecting forest resources, but it may fail to provide proper incentives for intensive forest management activities. This paper argues that the community management system performs efficiently for non-timber forests, whereas a mixed management system of private and common ownership is a desirable institution for timber forest management in developing countries. This empirical research conducted a randomized experiment in Ethiopia and confirmed that the mixed management system significantly stimulated intensive forest management activities, such as pruning, guarding, and watering.

10.1 Introduction

With the growing scarcity of forestland and grazing land and the persistence of rural poverty in developing countries, it has become imperative to achieve sustainable natural resource management (NRM) for both income generation and poverty reduction (Palmer et al. 2020). Although securing property rights over forestlands is fundamental for sustainable resource management (Arnot et al. 2011; Feder and Feeny 1991), a consensus has not yet been reached on the conditions under which one institution outperforms others in the efficiency of forest management. The debate

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continues on whether private or common ownership improves forest management sustainability.

Forest management under common property regimes ('community forest management') has been adopted in developing countries across Asia and Africa (Agrawal and Chhatre 2006; Ferraro and Agrawal 2021). Ostrom (1990), Baland and Platteau (1996), and Hayami and Godo (2005) argue that community forest management is effective in protecting forest resources because of the community's strong ability to prevent the excessive extraction of common-pool resources. More precisely, compared with private forest management, community forest management has the advantage of protecting forest resources because the total protection cost can be shared among community members through rotational monitoring. Rustagi et al. (2010) and Kosfeld and Rustagi (2015) suggest that monitoring cooperation among community members persists primarily because of the costly norm enforcement in the community. Further, Sakurai et al. (2004) have confirmed that community forests are less expensive to protect than private forests, especially in the case of small private forests, which require full-time monitoring.

Especially in developing countries, the reduction of protection costs is critically important for forest conservation because the risk of illegal logging and theft is typically high due to the greater demand for forest products (e.g., timber, firewood, feed grasses, medicinal plants, honey, mushroom, and spices). Several empirical studies have been conducted in various regions to identify the impact of community forest management on forest protection (Christensen et al. 2021; Eisenbarth et al. 2021). One of the prominent early studies was conducted in Nepal by Edmonds (2002). This study found that the extraction of forest resources reduced after the use rights of forests was transferred from the state to the local community. Further, Takahashi and Todo (2012) utilized satellite imagery to estimate changes in forest areas and showed that the introduction of community forest management successfully conserved forests in Ethiopia. However, empirical evidence on the effectiveness of community management has been mixed (Arts and De Koning 2017; Baynes et al. 2015; Slough et al. 2021). For example, after using the propensity score matching method to control for endogeneity, Takahashi and Otsuka (2016) found that forest quality declined more in community forests than in privately-owned forests in Ethiopia. Similarly, Kijima et al. (2000) also reported that private forest management is more efficient than community forest management in Japan because of differences in the motivation for tree management. Thus, the conditions under which one institution outperforms the others in forest management efficiency are unclear.

Another shortcoming of the existing literature on community forest management is that most previous studies have primarily focused on forest protection or the prevention of excessive resource extraction. Comparatively, less attention has been devoted to investigating how to promote investments in reforestation. Professor Keijiro Otsuka has argued that to rehabilitate timber forests, it is essential to conduct intensive management or silvicultural operations, such as planting, weeding, thinning, pruning, singling, and watering (Otsuka et al. 2015; Otsuka and Place 2001). In this regard, community forest management may fail to provide the appropriate incentives for intensive forest management. In most cases, as the benefits from common forests are more or less equally shared among community members (Balana et al. 2010), the individual incentives for intensive tree management are likely to be diluted under community forest management because of the free-rider problem. Hence, political interventions may be desirable to facilitate the rehabilitation of community timber forests to provide the necessary incentives for tree management.

In the second section of this chapter, referring to the work of Professor Otsuka, I discuss the optimal management institutions for timber and non-timber forests and the potential of mixed management systems for timber forest rehabilitation. The third section reports the findings of an experimental study conducted in Ethiopia that investigated the impact of mixed management systems on forest management efforts, followed by the conclusion.

10.2 Optimal Management Institutions and Mixed Management System

10.2.1 Optimal Management Institutions of Timber and Non-timber Forests

Otsuka et al. (2015) have pointed out that forests can be divided into timber and non-timber (Table 10.1). Usually, non-timber forest resources regrow without much care; thus, the marginal returns to management efforts are low. In contrast, intensive management is mandatory to maximize profits from timber products. Accordingly, timber and non-timber forests have high and low management intensity characteristics, respectively.

Their study further classified timber and non-timber forests into two types, depending on the protection cost of forest areas. The protection cost tends to be low in areas where forest resources are abundant, or the demand for forest resources is low. The former is typical of sparsely populated areas in developing countries, whereas the latter is typical of developed countries. By contrast, protection costs increase when there is a higher demand for forest products. As argued, it is essential to provide sufficient protection to forest areas where there is a risk of illegal logging or the theft of forest products, which is often the case in many developing countries.

Table 10.1 Characteristics of timber and non-timber forests and optimal institutions

Forest type	Management intensity	Protection cost	Optimal institution
Non-timber	Low	Low	Any
	Low	High	Community management
Timber	High	Low	Private management
	High	High	Mixed private-community management

Note Referring to Tables 1 and 2 of Otsuka et al. (2015)

Based on the above discussion, forests can be divided into four categories, according to the intensity of their management intensity and the protection costs. If the forest type is a non-timber forest with low protection costs (e.g., non-timber forests in sparsely populated areas), institutions do not matter because these forests neither require management nor protection efforts for rehabilitation. However, in the case of non-timber forests where the cost of protection is high (e.g., non-timber forests in densely populated areas in developing countries), the most important aspect of forest management is protection. In this context, community forest management is particularly efficient because of the advantages of substantially reduced protection costs, as suggested by Ostrom and others. In contrast, community forest management may not be an optimal institution for timber forests due to a lack of incentives for intensive management. Instead, suppose the protection cost is low due to the low demand for forest products, as in developed countries. In that case, private management is likely to be efficient.

The critical issue that remains is identifying the appropriate institution for timber forests, where the cost of protection is high. This point is particularly important for developing countries because most timber forests in these regions are classified in this last category. Community forest management of timber forests with high protection costs is not expected to increase the management efforts because of incentive issues, while private management is also inefficient because landholders have to pay high protection costs. Therefore, neither private nor community management may be optimal for timber forests in developing countries. Thus, Professor Otsuka proposed a mixed management system of private and common ownership (hereafter, the 'mixed management system') as a potential solution (Otsuka et al. 2015; Otsuka and Place 2001).

10.2.2 Mixed Management System of Private and Common Ownership

The mixed management system is characterized by: (1) the communal protection of trees and other resources and (2) the individual management of these resources. Such a system can be realized by granting communal use rights for forestland and individual ownership rights for trees to the community members. In this system, as the ownership of forestland is given to the community, collective activities unrelated to tree management, such as collecting non-timber forest products (fodder grasses, honey, medicinal plants, mushrooms, and spices), are likely to be carried out by the community. Therefore, the community enforcement of protection activities (i.e., rotational monitoring) can work the same way as traditional community forest management, resulting in lower protection costs under the mixed management system.

Additionally, the mixed system fully motivates individual members to carry out intensive tree management because individual tree rights holders can accrue all the benefits from their owned trees. The benefits are not only limited to income from the extracted timber trees but also include the by-products of intensive management, such as thinned trees and pruned branches.

Another advantage of such a mixed management system is that it may reduce the risk of forest conversion, particularly in the case of forests under private management. If the expected benefit from forest conversion is greater than the profit from forestland, individual landholders are likely to convert forestland to agricultural land, resulting in accelerated deforestation. On the contrary, as land ownership under the mixed management system is granted to the community rather than individual tree rights holders, community land cannot be converted without the community's agreement. As a result of this transaction cost of obtaining community agreements for land conversion, the risk of deforestation by land conversion is lower in the mixed management system than in the private management system.

Overall, a mixed management system fully utilizes communities' capacity to protect trees and other natural resources and the motivation of individual community members.

10.3 Impact of Mixed Management System on Tree Management

Mixed management systems, in which forestland is owned by the community and trees are owned by individual members, may be an efficient approach to enhance the rehabilitation of forests in developing countries. However, until recently, no studies have empirically investigated the effects of mixed management systems on forest management. In 2018, through a collaboration between four universities (Kobe University, Mekelle University, Norwegian University of Life Sciences, and Waseda University), a team of researchers, including Professor Otsuka, conducted a randomized controlled trial (RCT) in Ethiopia to empirically investigate the impact of the mixed management system on NRM. This section describes the general situation regarding deforestation in Ethiopia and then explains the description and results of the experiment conducted by Takahashi et al. (2020).

10.3.1 Deforestation in Ethiopia

Deforestation and land degradation (i.e., vegetation cover loss, soil erosion, and nutrient depletion) have been major environmental issues in Ethiopia for some time now. According to the Food and Agriculture Organization of the United Nations (FAO 2022), approximately 10% of the country's forestland has been lost within two decades. Like in other developing countries, the harvesting of forest products has been the primary driver of deforestation in Ethiopia (Takahashi and Todo 2012;

Yahya et al. 2020). More precisely, given the high demand for timber forest products (i.e., thinned trees, pruned branches, and timber trees) and non-timber forest products (i.e., feed grasses, honey, medicinal plants, mushrooms, and spices), there is a strong incentive to conduct extraction activities in these forest areas, thus increasing the pressure on them.

The Tigray region of northern Ethiopia has a similar deforestation issue. To prevent deforestation and rehabilitate vegetation in Tigray, the local government implemented a restriction policy that strictly prohibited access to communal forests and grazing lands and the use of common-pool resources. The restriction policy came into effect in 1991, and since then, 13% of the total land in Tigray has been reserved for rehabilitation (Holden and Tilahun 2020). Although the duration of the restriction for land rehabilitation was not formally set, the restricted communal lands were closed for 5–15 years.

After land rehabilitation, some of the restricted communal lands were distributed to groups of landless youths within the community (hereafter referred to as 'youth groups'). Each youth group had approximately ten members who were allowed to utilize the allocated communal lands for livelihood activities, such as forestry, apiculture, horticulture, mining, and livestock rearing. In addition, members of the youth group conducted collective activities unrelated to tree management, such as collecting feed grasses in the allocated community land. Like community forest management in other developing countries, the benefits from allocated communal land were equally shared among the group members. Furthermore, to protect the forest resources within the allocated communal land, members of these youth groups usually carried out monitoring activities on a rotational basis. According to Holden and Tilahun (2020), the youth groups followed the sustainable NRM principles suggested by Ostrom (1999, 2010). Thus, the communal lands allocated to these groups may be defined as forest areas under community forest management.

10.3.2 Experimental Design and Data Collection

To identify the impact of the mixed management system, an RCT was conducted in Tigray, targeting 68 youth groups (a total of 728 members) that received communal lands from the allocation (Takahashi et al. 2020). The experimental intervention was implemented between May and June 2018, and a questionnaire survey was conducted before the intervention and one year after it. Among the 68 youth groups, 26 groups were randomly selected as the treatment group that had an opportunity to manage their community forestland under the mixed management system. The remaining 42 groups, defined as the control group, continued their conventional community management activities (i.e., conducting livelihood activities using common-pool resources and collecting non-timber forest products).

To implement the mixed management system, the members of the 26 treatment groups were granted individual tree rights that allowed them to extract their owned trees at any time. Furthermore, tree rights holders could continue holding their tree rights by planting new tree seedlings in the same location, which increased their incentive to engage in sustainable forest management. In this experimental setting, while the ownership of individual trees was transferred from the youth group to the individual members of each treatment group, ownership of the entire land continued to be common property for both the treatment and control groups. Therefore, community agreements remained essential for land-use change. Moreover, it was fundamentally important to secure the tree rights; otherwise, short-term resource extraction would become a rational choice. Hence, the study provided a paper document indicating that the local authorities (i.e., Bureau of Agriculture and Natural Resources) had permanently granted tree rights to the individual members of the treatment groups.

In this study, 172 members in the treatment groups agreed to receive individual tree rights, with an average of 81 trees per member in the allocated forestland. However, 25 members (12.7%) of the treatment group declined the offer of tree rights. This was mostly because they perceived that group rights were preferable. Although the balancing test confirmed no significant difference in the management efforts and extracted volume of forest products between the treatment and control groups before the intervention, there was still a concern about selection bias by the non-accepters within the treatment group. An instrumental variable (IV) method and an intention-to-treat model to estimate the treatment effects were applied to address this. In this essay, I only show the results of the IV estimation, indicating how the provision of individual tree rights affected management effort (i.e., the number of working days spent on tree management) and the volume of extracted timber and non-timber forest products.

10.3.3 Estimation Results

The estimation results for the number of working days based on the IV method are shown in Fig. 10.1, which shows the impact of tree rights on the number of working days and the extracted volume, respectively. The values on the vertical axis of the figure are the log differences in the outcomes of interest, which is the rate of change in each indicator before and after the provision of tree rights.

The results show that the number of working days for three types of management activities—guarding, watering, and pruning—significantly increased after the provision of tree rights. The coefficient shows that the impact on guarding is particularly large, increasing the number of working days by 105%. Before the experiment, each youth group member allocated an average of 19 days per year to guard, equivalent to 190 days per year at the group level. Thus, the estimation results suggest that after providing tree rights, the treatment youth group engaged in guarding activities throughout the year. This increase may reflect an increase in the value of the forest resources in the mixed management area.

Further, the results show that the provision of tree rights significantly increased the number of working days for watering by 66%, while there was no significant

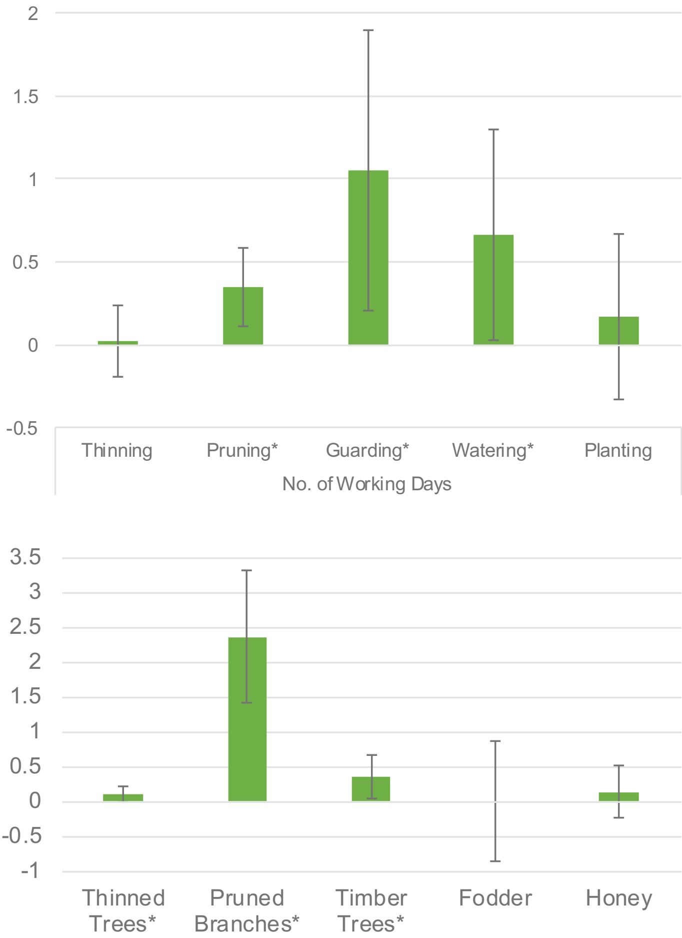

Fig. 10.1 The impact of tree rights on the number of working days and the extracted volume

difference in planting activity. One potential reason for these results is that members of the treatment groups may be more motivated to take care of their allocated trees rather than plant new tree seedlings. In the long-term, individual tree rights holders have an incentive to conduct planting activities because of the motivation to maximize their profits from forest resources. However, if a sufficient number of trees are allocated to the right holders, they may prefer to increase profits from the allocated trees by carrying out short-term management activities, such as watering, rather than planting new seedlings. Because this study only examines the short-term impact of tree rights provision due to data constraints, we may observe a significant increase in labor input to take care of planted trees.

The results of the extracted volume shown in Fig. 10.1 indicate that tree rights holders extracted more timber resources related to tree management (i.e., thinned trees, pruned branches, and timber trees). These results are expected. As tree rights holders can obtain all the benefits from the allocated trees, there is a greater incentive to harvest the timber resources. Although the extracted volume of timber trees increased after introducing tree rights, such an increase does not necessarily mean that the tree rights provision caused excessive extraction of forest resources or forest degradation. To regenerate forest ecosystems, selective extraction of timber trees is an important forest management activity (Karsenty and Gourlet-Fleury 2006; Langmaier and Lapin 2020). In fact, the average volume of timber extracted after the intervention was only 6 kg in the treatment group.

In contrast, the extracted volume for non-timber forest products, such as fodder and honey, did not change after the provision of tree rights. Before this experiment, both groups (treatment and control) engaged in resource extraction activities unrelated to tree management, such as collecting feed grasses and honey. In this experiment, land ownership in the treatment group remained a common property even after the intervention, and thus, it is reasonable to assume that members of the treatment groups continuously had an incentive to conduct conventional non-timber resource extraction activities. None of the communities investigated in this study changed their conventional activities after the provision of tree rights. Thus, we believe that tree rights only increased the volume of timber resources extracted.

10.4 Conclusion

In this chapter, by referring to Professor Otsuka's previous work, I have attempted to describe the optimal property institutions for NRM, specifically in the case of timber forest management in developing countries. It is fundamentally important to select appropriate institutions for each type of forest, considering the factors of management intensity and protection costs. In the context of timber forests in developing countries, while both management and protection efforts are essential for rehabilitating forest resources, private and community forest management can only stimulate either of these efforts individually.

A mixed private and community management system has been proposed as a novel potential solution to this challenge. In fact, the findings from a randomized experiment in Ethiopia confirm that the introduction of the mixed management system can successfully stimulate intensive forest management. This is evidenced by the increased number of workdays allocated to pruning, guarding, and watering activities. Further, the extracted volumes of forest products related to tree management, such as thinned trees, pruned branches, and timber trees, increased after introducing the new system, whereas the extraction of non-timber products did not change through the intervention.

These arguments and findings provide useful information for sustainable forest management. Currently, many development organizations focus primarily on protecting forest resources by simply introducing community forest management, which cannot intensively manage forest resources. In contrast to this, the practical advantage of a mixed management system is its adaptability to varying situations in developing countries. As a substantial portion of forests is already under de facto common property regimes (Agrawal et al. 2008), a mixed management system can be introduced by granting individualized property rights for timber trees on community forest lands. Although more empirical investigations are required to examine the effects of mixed management systems, this system has the potential to be an alternative approach to achieving sustainable forest management in developing countries.

Recollections of Professor Keijiro Otsuka

I am honored to participate in the Festschrift honoring Professor Keijiro Otsuka for his tremendous lifetime achievements. I have known Professor Otsuka since 2013 when he served as a member of the review committee for my doctoral dissertation. After receiving my Ph.D., I was very fortunate to have the opportunity to work with him as a postdoctoral researcher at GRIPS for a year and a half. So far, I have written three papers with him on NRM and had the opportunity to go on a field survey in Ethiopia. Through my experience in research with Professor Otsuka, I have truly learned a lot about the attitude one should take toward research, the importance of field observations, and social contribution through research. I would like to take what I have learned from Professor Otsuka and pass it on to the next generation.

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Chapter 11
Sustaining Natural Resources in African Agriculture: What Have We Learned in the Past Two Decades?

Frank Place

Abstract Calls for increased attention to natural resource management (NRM) in African agriculture have been around for many decades. They became more vocal around the turn of the century following decades of poor yield growth and emerging data showing concerns about land quality and productivity. In recent years, these intensified further with the specter of climate change and continuing rural population growth challenging agricultural systems on the continent. Researchers have responded to these challenges, advancing research frameworks and hypotheses, deploying more research tools, and conducting more studies. However, it is unclear that all this response has significantly advanced our state of knowledge on the extent and nature of land degradation in agricultural land, the particular practices that work in different socioeconomic contexts, and how best to induce their uptake by households facing different priorities and constraints. This chapter will motivate this conclusion and offer options for moving forward in some of these topical areas.

11.1 Introduction

It was not easy to identify the best approach to take in writing this chapter. Initially, I planned to review recent studies on natural resource management (NRM) adoption in Africa, teasing out lessons and then offering some policy-relevant conclusions. However, after probing the literature, it was clear that synthesizing studies would be a great challenge given the heterogeneity in NRM coverage, geographical coverage, and research designs. I then took a different approach; to focus this chapter on how much we have advanced our knowledge and understanding of NRM in Africa. This knowledge is unpacked into subtopics: (1) extent of soil degradation, (2) our research methods used to study NRM adoption, (3) extent of adoption of NRM practices on farms, and (4) our understanding of adoption processes. Given the limitations on chapter length, I have been quite selective on the references used, and this should

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not be taken as a systematic review of the literature. I conclude with some overall observations of whether or not progress has been made and where attention should be paid in the future.

11.2 State of Land Degradation in Africa

In 1991 a novel and influential study concluded that land degradation was an enormous problem globally, including in Africa, and called for urgent attention (Oldeman et al. 1991). Though this relied on expert opinion, several smaller-scale studies would find evidence that supported this general observation. Its conclusion that as much as 65% of the land is degraded is still being cited in 2021 publications (e.g., Mansourian and Berrahmouni 2021). New tools for assessing degradation became available, such as high-resolution remote sensing and near-infrared spectroscopy. These held promise that we would soon have access to up-to-date information on many soil quality indicators and show how different forms of land degradation were changing over time. We would also have at our disposal time-series databases for use by researchers from any discipline, including those interested in incentives for investing in NRM, for example, in earlier studies using remote sensing (e.g., Otsuka and Place 2001) or soil quality data (e.g., Yamano et al. 2011). Unfortunately, this has not been the case. The integration of data related to land degradation into socioeconomic studies has been spotty. The science has proven to be very challenging. Remote sensing is good at identifying some topsoil parameters but not as good for others. High-quality data in certain selected sites are not so easily extrapolated to neighboring 'pixels,' and other approaches to identifying underlying soil health, such as normalized difference vegetation index (NDVI) or net primary production (NPP), can be related to other factors that are not always easy to isolate from soil quality parameters. With these caveats in mind, Kirui et al. (2021) found high rates of land degradation across sites in four African countries; Le et al. (2016) found land degradation in Africa to be less pervasive in cropland than in other land uses; Nziguheba et al. (2021) found that the proportion of cropland unresponsive to fertilizer application is low. An expert opinion-based approach to identifying key soil constraints was presented by Stewart et al. (2020). Therefore, we still are unclear on the extent and nature of land degradation across Africa and have missed opportunities to integrate that information into studies that address the use of NRM practices.

11.2.1 Study of NRM in African Agriculture

Despite the limitations in our understanding of specific degradation problems in particular locations, there has been a healthy interest to pursue our understanding of NRM practices by farmers, especially smallholder farmers, in Africa. The conventional view driving this was that there was underinvestment in NRM and that new configurations of NRM are needed to sustainably increase productivity and adapt to climate change. In the late 1990s and early 2000s, a significant number of socioeconomic studies were generated, investigating a range of NRM practices in sites throughout Africa. Some key studies of the time were conducted by the Consultative Group on International Agricultural Research (CGIAR) and included in the edited volumes of Otsuka and Place (2001), Barrett et al. (2002), and Pender et al. (2006). Some advances in synthesis were made, but those efforts also identified limitations, such as lack of consistency in defining NRM practices, measurement challenges, and improving the statistical rigor of empirical studies. In those days, experimental designs in NRM adoption and impact research were absent.

In the years since then, progress has been modest. There has been more attention given to sets or combinations of practices, and now it is more common to find studies looking at the adoption and impact of conservation agriculture (CA), sustainable intensification, integrated soil fertility management (ISFM), agroecology, regenerative agriculture, or climate-smart agriculture (CSA). These are based on principles, but typical studies of farmer adoption focus on specific practices that may operationalize one or more of the principles. Furthermore, specific practices are often components of more than one integrated NRM approach. For example, crop rotation is a key component of CA but is also recognized as important for regenerative agriculture, CSA, and agroecology. The application of organic nutrients similarly ticks the box of several different integrated NRM practices. There is nothing wrong with multiple approaches claiming a practice as theirs, but it becomes confusing when authors use adoption of crop rotation to indicate partial adoption of CA in one case or of CSA in another case when the study did not, in fact, seek to understand why the farmer practices crop rotations and whether they are done in concert with other practices. This issue is taken up regarding CA by Ward et al. (2018), Ngoma et al. (2021), and Tambo and Mockshell (2018).

Measurement of NRM is still a challenge. A review of recent empirical work shows that NRM practices are almost always measured by discrete variables (e.g., presence or absence at a particular point in time). Glover et al. (2016) questioned the utility of studying 'adoption' as a binary action and called for a better way to assess technological change on farms. Farmers are continuously modifying technologies and practices, while our surveys are simply capturing the presence or absence of an NRM practice that, in some cases, may not be easily described by an enumerator. More quantification of the extent of the practice (e.g., number of trees, size of the area under an NRM practice), as well as the quality of the application (e.g., is there good or poor coverage of the crop residue), would provide more insight, but this is rarely done in practice, due to difficulty or costs of measurement. Even when quantification is done, as for trees on the farm in the more recent Living Standards Measurement Surveys–Integrated Surveys on Agriculture (LSMS-ISA), the results do not always appear to be highly reliable, as noted by Miller et al. (2016). A recent exception is Mwaura et al. (2021), who showed that while the use of manure, crop rotations, mulching, and legume intercropping were all common in the central Kenya highlands, the proportion of land area under such practices was low—below 25%

in almost all cases. Therefore, although this measurement weakness was recognized decades ago, we have not made progress in overcoming it.

Finally, the same challenges of fragmented case studies, inadequate contextual description, variability in the use of explanatory variables, and modeling of NRM-dependent variables that characterized the state of the science around the turn of the century are still found in today's research. Fragmentation is shown by the dominance of case studies of modest numbers of farmers in limited geographies and the scope of NRM practices studied. It is often the case that a study aims to understand the use of a limited set of NRM practices. Where studies do cover a broader scope of NRM practices, there is much variation in how these are modeled, sometimes as independent practices, sometimes as interrelated binary decisions (Martey and Kuwornu 2021), and sometimes as combinations of practices (e.g., the number of practices or in multinomial logit regressions expressing different combinations in Horner and Wollni 2020). Furthermore, one would struggle to find two studies using the same sets of explanatory variables. And finally, while the majority of studies have focused on the household as a decision-maker, some recent work has looked at individual decision-making and thus, opened up exploration into the influence of gender (Bernier et al. 2015). These issues make it nearly impossible to synthesize findings—for example, to understand how household labor may constrain the use or adoption of various NRM practices in different contexts. Discussion of when certain specifications are preferred over others is needed.

11.3 The State of NRM in African Agriculture

Our information on the extent of adoption of NRM practices in Africa is imperfect, partly because of the measurement challenges noted above. Numerous cross-sectional studies note adoption rates of selected NRM practices, indicating a mixed picture of adoption depending on the location and NRM practice. For example, within the theme of agroforestry, there is evidence of widespread adoption of farmer-managed natural regeneration in the Sahel (Reij et al. 2009), where the parkland system has been practiced for many decades while planting of trees for soil improvement in Zambia is low (Stevenson and Vlek 2018). CA has long been disseminated in Africa, but in no country outside of South Africa is it commonly adopted (Corbeels et al. 2014). On the other hand, Kosmowski et al. (2020) analyzed recent national surveys in Ethiopia and found that soil and water conservation practices were widespread, practiced by 72% of households (over 9 million in total). Also, in Ethiopia, the use of CA was much lower, with about 10% of households using minimum tillage and about 5% practicing minimum tillage along with crop rotation and residue cover of soil. This highlights that adoption of full sets of recommended practices, such as CA or ISFM, is very low, even if some of their components are commonly used. For example, Sheahan and Barret (2017) found that the correlation between the use of organic nutrients and mineral fertilizer, both components of ISFM, was low in Niger, Tanzania, Uganda, and Malawi, and only significant in Nigeria and Ethiopia.

A few of the studies noted above drew upon the LSMS-ISA, and indeed the survey instrument has improved its ability to capture NRM practices in each round. To date, this seems an undermined source for analysis and ideally should be better utilized in the future.

11.4 Understanding Adoption of NRM in Agriculture in Africa

Decades ago, five broad hypotheses were formulated as to why the adoption of NRM practices could be lower than suggested by their technical performance in trials. These are:

- Technologies/practices are not well understood by farmers enough to evaluate or implement them
- Technologies/practices do not offer many technical advantages in any kind of time horizon
- Benefits from technologies/practices are too far in the future to be of interest
- There are critical constraints to the implementation of technologies/practices related to upfront costs that cannot be easily overcome
- Technologies/practices are not profitable or otherwise suitable for farmer conditions under existing economic/policy regimes, notably in comparison with alternative uses of labor/capital/land.

Perhaps as no surprise, studies on NRM adoption in recent literature came to the same conclusions as earlier literature—that all of these hypotheses appear to be valid for given NRM-location combinations. One key advancement in knowledge over the years has been on the interactions of gender with each of these hypotheses, which are discussed in the following sections.

11.4.1 Lack of Awareness or Understanding

A number of recent studies confirm that lack of awareness or knowledge remains a constraint to adopting certain NRM practices. Aker and Jack (2021) ran a randomized controlled trial (RCT) to test for information and capital constraints to investment in half-moon microcatchments for rainwater harvesting in Niger. They found that training was key to boosting adoption rates—additional cash transfers did not have an incremental effect. Martey and Kuwornu (2021) found that in a region in Ghana that hosted several projects, including the Alliance for a Green Revolution in Africa's (AGRA) soil health program, the adoption of soil fertility management practices was common, with nearly half of farmers using three or more practices on their farms. Mango et al. (2017) collected data on farmer awareness and adoption of various soil and water management practices in the Chinyanja triangle of Malawi, Mozambique, and Zambia. They found a considerable variation in the awareness of individual practices. For example, only 2% and 4% had knowledge about mulching and rainwater harvesting, respectively, while 38% had knowledge about using contour ridges. Finally, a review of incentives for adopting sustainable land management practices found that access to extension is often a positive factor in uptake (Pineiro et al. 2020).

11.4.2 Lack of Technical Advantages

The likelihood that inappropriate NRM practices are vigorously disseminated has diminished in recent years due to the accumulated testing of practices in different contexts and a better understanding of which plant species grow better in certain soils, altitudes, and climates. This has led to geographical information system (GIS) databases of 'best' or 'good-fit' practices, such as conservation approaches and technologies (www.WOCAT.net) and agroforestry species (World Agroforestry Centre 2009). However, as noted earlier, increased attention has been paid to the need for integrated practices, which generates a more complicated challenge to what works best in different conditions. To give one example, Gram et al. (2020) examined the evidence in a metareview of how well fertilizer and organic nutrients separately or in combination relate to CSA principles of improved agronomic efficiency of nitrogen, reduced yield variability, and build-up of soil organic carbon. At low rates of nitrogen fertilizer, fertilizer alone does well, but combinations with organic sources are best when nitrogen fertilizer rates are higher. On the other hand, fertilizer is the worst option for yield variability and soil organic carbon, indicating tradeoffs. Giller et al. (2021) examined the evidence that regenerative agriculture can deliver on problems, such as poor soil health or low levels of agrobiodiversity, and found that the evidence is mixed.

11.4.3 Benefits Are Too Far in the Future

Many NRM practices require upfront investment costs, while benefits may not be realized until many years later. This will dissuade farmers with high discount rates from investing in such practices. Ngoma et al. (2018) found high risk aversion and impatience (short-term time horizons) among farmers in Zambia. Similarly, Bell et al. (2018a, b) found that subsidies or early payments for environmental services can increase the adoption of CA in Zambia. Regardless of the incentives offered, farmers who do not have secure long-term rights to land will not be interested in investing in long-term NRM practices. Indeed, one of the most consistent findings in the literature is that farmers operating on rented land are much less likely to adopt

NRM practices than owner-operators although they are equally or more avid users of inputs (Place et al. 2021). This seems to be an issue of growing importance as the prevalence of land renting is growing in many African countries (Jayne et al. 2021).

11.4.4 Constraints to Their Implementation

There has been significant investigation on the relationships between NRM adoption and land and labor factors of production and, to some extent, capital constraints. For labor, a general conclusion has been that household labor has either a positive or benign effect on the adoption of NRM practices—it is very rare to find a negative relationship. The case of farm size is more mixed—generally insignificant, but with some positive and negative relationships found. The pattern for wealth variables is similar to that for farm size.[1] The latter two results are encouraging because it suggests NRM practices are accessible and beneficial to households and farms at varying asset levels. Labor appears, therefore, to be a key constraint. Recent studies also reinforce this pattern (e.g., Mwaura et al. 2021 on labor effects in central Kenya) and have probed further to distinguish different cases. For example, Wordofa et al. (2020) found that farmers in Oromia, Ethiopia perceived that many introduced soil conservation measures required considerable establishment or maintenance labor costs even though their technical effectiveness was appreciated. Horner and Wollni (2020) analyzed over 6,000 maize, wheat, and teff plots in Ethiopia as part of a randomized soil fertility project. They found that ISFM adoption resulted in more than 50% more labor used on the three crops. Although this was compensated for on average by higher returns, households reduced labor to other crops or nonfarm activities in some regions, offsetting these gains.

11.4.5 Economic Returns/Profits Are Too Low

Compared to studies of NRM adoption, studies that compare costs and benefits and profits from NRM practices are relatively few. Such studies are challenging because costs and benefits are different at different stages of the practice and, thus, ideally require a multi-year assessment. In their review, Ngoma et al. (2021) noted that studies related to CA show mixed results. One of the positive cases is Tambo and Mockshell (2018), who analyzed data from farmers across nine African countries. They found that CA significantly increased household income. On the other hand, Horner and Wollni's (2020) study in Ethiopia found that returns to unpaid labor for organic nutrient additions are low in humid zones, unless improved seeds are also part of the package, but are relatively high in drier zones. This again points to the heterogeneity of findings that characterize these studies.

[1] From author's own analysis of 35 African NRM adoption studies between 2001 and 2017.

11.4.6 Constraints and Benefits Are Different for Men and Women

Almost all studies of the adoption of NRM practice are conducted at the household level, with scant attention to individual decision-makers. However, there are gender dimensions within each of the hypotheses above. For example, women have less access to information or labor than men. Bernier et al. (2015) found that women are much less informed than men about climate-smart practices in Kenya, and this affects their ability to invest in such practices; when they are informed, they adopt practices at the same rates as men. Mponela et al. (2021) found a more nuanced relationship depending on the NRM practice. A positive relationship was found between women's empowerment (participation in decision-making domains) and adoption of legumes, a negative relationship with manure, and a statistically insignificant relationship with mineral fertilizer. Meinzen-Dick et al. (2014) reviewed literature that contributes to an analysis of gender and sustainability. They found that several factors may motivate better or worse stewardship by women than men. On the positive side, women are interested in conserving natural resources for food, water, firewood, and medicinal products, which may traditionally be among her tasks to collect. On the other hand, rights to resources among women are often less secure than for men, providing less incentive for longer-term stewardship. More research is needed on gender and NRM in Africa, not least because of continuing transformation processes that create significant change in rural areas regarding household composition and decision-making.

11.5 Key Conclusions

Reflecting on the review above, eight concluding remarks emerge:

Studies on NRM adoption in African agriculture have continued since the early works decades ago. It, therefore, remains an important issue, perhaps even more so given the growing importance of climate change.

On the negative side, there has not been much improvement in the quality or insights from these new studies. We still have small case studies, cross-sectional studies, measurement using discrete variables, and challenges with analyses (e.g., endogeneity). Some of the early innovations (e.g., using remote sensing, integrating soils, and socioeconomic data from 2001 and 2011) have not expanded.

What has emerged is a proliferation of NRM terminology with many new integrated approaches—regenerative agriculture, organic farming, ISFM, CA, agroecology, CSA, and sustainable intensification—all being the subject of analysis. Each of these methods is complex and lends itself to disaggregation and analysis, and has increased the complexity of this area of inquiry.

There remains some debate about the severity of resource degradation and the extent of adoption of NRM in African agriculture due to measurement challenges and, in some cases, lack of investment in research.

The major reasons for why adoption may be low or limited in Africa are still the same as espoused many years ago. Some new evidence supports each of these, suggesting that they remain important in different situations. There have been attempts to understand the best fits for different situations, but this remains elusive due to challenges in synthesizing fragmented literature.

We are not advanced in our overall understanding of what key constraints are binding in different contexts, nor what types of incentives or other interventions could cost-effectively spur adoption. There is a sense that multiple interventions are necessary, including human capital investments in education and training. But we are far from understanding this well.

Moving forward on the research side, two avenues seem to be warranted. The first is to make better use of improved coverage of NRM in the LSMS-ISA datasets. A second approach would be to undertake a large, coordinated study of NRM adoption (and impact), ideally building on the LSMS-ISA datasets, to advance our understanding of what factors are most constraining to different NRM practices, as well as what NRM practices are likely to be good fits in different situations. This would require a blending of methods (qualitative/quantitative/GIS/soils sampling). As for good-fit NRM practices, it may be more important for research to identify principles and characteristics of promising practices for different situations, given the heterogeneity of conditions. Where best fits are identified, more RCTs on interventions to strengthen NRM uptake are a second recommendation.

On the development side, a great deal of literature would suggest that scaling specific NRM practices (as opposed to principles) will have mixed success in NRM. On the other hand, place-based approaches, in which community-based field staff work with communities over long periods, seem to better translate NRM principles into functional practices within extension or development programming. A critical need is to enhance the skills in NRM of public extension officers (Jayne et al. 2019) as there is no other viable mechanism for improving NRM knowledge among farmers—there is little private sector incentive in labor-intensive practices and NGOs have broad agendas.

Recollections of Professor Keijiro Otsuka

Peter Hazell connected Kei with me in the mid-1990s while Kei was at IFPRI for several years and I was at the World Agroforestry Centre (ICRAF) in Nairobi. Kei was leading a global study on tenure and NRM, and I became his collaborator for studies in eastern and southern Africa. That proved to be exciting in many ways, and what I will remember the most was the initial diagnostic fieldwork—traversing large parts of Uganda and Malawi to collect insights on the dynamics taking place in many different contexts. Every day when we would come back from the field to our hotel, Kei would spend some time in his room organizing what he heard into an economic framework, and we would discuss this over dinner. This was such an important step in the process of identifying hypotheses, developing study designs, and ultimately in writing papers. We did have success in that collaboration, and I am grateful to have worked with and kept up a friendship with Kei ever since.

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Chapter 12
Integrated Farming Management Practices in Sub-Saharan Africa: Toward a Sustainable African Green Revolution

Rie Muraoka

Abstract This study investigates the possibilities and limitations of integrated farming management practices, such as sustainable intensification, integrated soil fertility management, climate-smart agriculture (CSA), and conservation agriculture (CA) in Sub-Saharan Africa (SSA), based on a literature review. We first introduce the concept of these practices as a means to improve land productivity while maintaining agricultural sustainability. Subsequently, we show the adoption determinants and their effects based on recently published empirical studies in SSA. Finally, we conclude with the policy implications and research agenda to disseminate optimum integrated farming management practices and achieve a sustainable African Green Revolution in SSA.

12.1 Introduction

Sub-Saharan Africa (SSA) still suffers from poverty and food insecurity as 40% of its population live below the USD 1.90-a-day poverty line in 2018, and 24% were undernourished in 2020. This is the highest prevalence of poverty and hunger in the world (FAO et al. 2021; Schoch and Lakner 2020). Many poor and undernourished people live in rural areas and engage in small-scale agriculture (Sibhatu et al. 2015). The agriculture of most rural farm households in SSA depends on small-scale crop and livestock production systems (Haile et al. 2017). Common characteristics of their farming are low productivity, low adoption rates of improved technologies, and vulnerability to climate and price shocks (Otsuka and Muraoka 2017). Therefore, a sustainable African Green Revolution is necessary for rural small-scale farmers in the SSA to escape poverty and food insecurity.

The adoption of yield-enhancing technologies is necessary to improve land productivity. However, the global consensus is that just adopting modern technology,

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such as improved varieties and inorganic fertilizers, is not enough to improve the productivity and profitability of rural smallholder farming in SSA in the long-run (Peterson and Snapp 2015; Pingali 2012). One reason for this is soil degradation. Soil degradation is a great challenge, especially in SSA, because increasing population pressure on land leads to a reduction in fallows and more continuous farming, which, in turn, depletes soil nutrients (Drechsel et al. 2001; Tittonell and Giller 2013). Using data from western Kenya, Marenya and Barrett (2009) empirically demonstrate that maize yield response to nitrogen fertilizer application is low when soil organic matter (SOM) is low. The low response rate to nitrogen application results in low profitability from the use of inorganic fertilizer (Burke et al. 2019). Therefore, it is important to replenish soil nutrients and maintain soil fertility in smallholder farmlands to achieve a high yield response rate and profitability of inorganic fertilizer application.

Moreover, climate change is likely to harm productivity and exacerbate the volatility of smallholder farming in SSA, where cropping mostly depends on rainwater. It is estimated that temperature rise, variable rainfall, and frequent dry spells caused by climate change may result in a 10–20% decrease in crop yield by 2050 in most tropical and subtropical regions of SSA (Jones and Thornton 2009). Moreover, climate change may also bring new pests and crop diseases (IPCC 2014). Thus, adaptive strategies are necessary to minimize the damage caused by climate change.

Integrated farming management practices, composed of multiple agricultural technologies and management practices, have been gaining attention and are recommended by national and international organizations to address the abovementioned issues (FAO 2015; Takahashi et al. 2020). These technologies include modern yield-enhancing technologies, such as improved varieties and inorganic fertilizers, and natural resource-conserving technologies, such as organic fertilizers, legume intercropping or rotation, minimum tillage, permanent soil cover by crop residues, and soil and water management. These are expected to improve land productivity and farming sustainability while minimizing environmental damage. A growing body of literature focusing on the impacts and adoption determinants of integrated farming management practices has emerged in the last 5 years. In this study, we first aim to elucidate how we could diffuse these technologies and practices in SSA by examining the adoption determinants found in the literature. Subsequently, we attempt to determine the effects of these factors on farm productivity, income, and food security by reviewing recent empirical studies. Thus, this study clarifies how we can promote optimum integrated farming management practices among rural small-scale farmers in SSA.

12.2 What Are Integrated Farming Management Practices?

Integrated farming management practices aim to improve land productivity and profitability in the long run without deteriorating the local environment. These types of integrated farming management practices, which are sustainable (agricultural) intensification (practices) (SI), integrated soil fertility management (ISFM), climate-smart agriculture (CSA), and conservation agriculture (CA).

SI could be defined as the process of raising land productivity without adverse environmental impacts (Pretty et al. 2011; The Montpellier Panel 2013). SI has five main domains: productivity, economic sustainability, human well-being, environmental sustainability, and social sustainability (Petersen and Snapp 2015; Smith et al. 2017). Although SI does not refer to a specific set of agricultural inputs or management practices (Kim et al. 2021), it usually consists of yield-enhancing technologies, such as improved seeds and inorganic fertilizers, and resource-conserving technologies, such as legume intercropping or rotation, use of organic fertilizers and crop residues, and minimum tillage (Manda et al. 2016; Pretty et al. 2011). The components of SI vary depending on local contexts and individual farmers' preferences (Kassie et al. 2013).

Although ISFM is pretty similar to farm management practices with SI, it focuses more on soil management. ISFM utilizes inherent soil nutrient stocks, locally-available soil amendments, and modern technologies, such as chemical fertilizers and improved seeds, to enhance crop yield while maintaining soil fertility (Vanlauwe et al. 2015).

CSA is an approach similar to SI, but it is a more adaptive strategy against climate change. CSA generally has three goals: (1) enhancement of productivity, (2) adaptation and building resilience to climate change, and (3) reduction of greenhouse gas (GHG) emissions (FAO 2017; Lipper et al. 2014). It also has components similar to SI, and the components change depending on the local context. Amadu et al. (2020) classified farm-level CSA practices into six categories, organized from least to most resource-intensive: (1) residue addition or application to soil, (2) non-woody plant cultivation, (3) assisted regeneration, (4) woody plant cultivation, (5) physical infrastructure, and (6) mixed measures.

CA is an approach similar to CSA. It achieves long-term productivity and environmental benefits by adopting three approaches: (1) minimum tillage, (2) permanent soil cover by crop residues, and (3) crop rotation (FAO 2022).

In the remainder of this section, common technologies and integrated farming management practices, such as SI, ISFM, CSA, and CA, are introduced.

12.2.1 Improved Seeds

The diffusion of improved varieties is considered the most important means of boosting crop yield and improving the well-being of farmers in developing countries (Evenson and Gollin 2003). Previous studies have found that the adoption of improved crop varieties increases yield, crop and household income, consumption, and child nutrition (Bezu et al. 2014; Zeng et al. 2015, 2017). Adopting improved varieties is an important component of SI (Wainaina et al. 2018), ISFM (Horner and Wollni 2021), and CSA (Teklewold et al. 2019).

12.2.2 Inorganic Fertilizer

Inorganic fertilizer application is another important yield-enhancing technology in integrated farming management practices such as SI, ISFM, and CSA. The combined use of improved seeds and inorganic fertilizers is widely recommended in SI (Wainaina et al. 2018), ISFM (Horner and Wollni 2021), and CSA (Teklewold et al. 2019) because the use of inorganic fertilizers is necessary to gain the full yield potential of improved varieties. The joint use of improved seeds and inorganic fertilizers is the core of the Asian Green Revolution (Johnston and Cownie 1969).

12.2.3 Organic Fertilizers

Organic fertilizers usually include animal manure and composted crop residues and do not include crop residues retained on farmland (Scognammillo and Sitko 2021). They are expected to provide the soil with carbon, nitrogen, and phosphorous and enhance water retention under low precipitation (Ngwira et al. 2014). A typical method to implement SI, ISFM, and CSA involves the simultaneous application of inorganic and organic fertilizers. Kajisa and Palanichamy (2011) use household panel data in India and empirically demonstrate that applying organic fertilizers improves the marginal product of inorganic fertilizers, especially in soils with low fertility.

12.2.4 Intercropping/Rotation with Legumes

Another common practice is intercropping or rotation with legumes. Legumes fix nitrogen from the air and supply it to the soil (Mhango et al. 2013). They can also enhance crop yield sustainably by reducing plant diseases, weeds (e.g., Striga), and insects and increasing soil carbon content (Hutchinson et al. 2007; Manda et al. 2016). Additionally, crop diversification through intercropping or legume rotation can reduce production and market risks (Rusinamhodzi et al. 2012). Amare et al. (2012) empirically show that maize–pigeon pea adoption significantly increased income and consumption using household data from Tanzania.

12.2.5 Zero or Minimum Tillage

Zero or minimum tillage is one of the core components of CA because conventional tillage may lower SOM, the density of microorganisms and fauna in the soil, and its water-holding ability, and increase susceptibility to erosion and evaporation from the soil surface (Montt and Luu 2020).

12.2.6 Permanent Soil Cover by Crop Residues

Permanent soil cover by crop residues improves soil fertility and moisture retention and increases SOM (Manda et al. 2016). It is often combined with minimum tillage to enhance soil aeration and fertility, carbon sequestration, and water-holding capacity (Hobbs et al. 2008). Rusinamhodzi et al. (2012) found that minimum tillage can positively affect light-textured soil in low-rainfall environments when combined with retaining crop residues.

12.3 Adoption Determinants of Integrated Farming Management Practices

Although national and international organizations have attempted to diffuse integrated farm management practices, their adoption rates remain low in SSA (Arslan et al. 2015; Kassie et al. 2013; Teklewold et al. 2013a). Empirical studies using SSA data find that assets, nonfarm income, age, education, gender, labor availability, experience, social capital and networks, social safety nets, access to extension services, markets and credits, physical characteristics of plots, and soil characteristics affect the adoption of SI, ISFM, CSA, and CA (Arslan et al. 2014; Ehiakpor et al. 2021; Kassie et al. 2013, 2015a; Manda et al. 2016; Matoke et al. 2019; Mutenje et al. 2019; Teklewold et al. 2013a, b, 2019; Zeweld et al. 2020).

Several studies have revealed that weather variability, such as erratic rainfall or drought, accelerates the adoption of drought-tolerant maize, maize-legume intercropping, minimum tillage, use of crop residue as soil cover, and soil and water conservation technologies, such as stone bunds (Arslan et al. 2014; Asfaw et al. 2016; Issahaku and Abdulai 2020; Mutenje et al. 2019). This suggests that farmers use these technologies as adaptive strategies to mitigate climate change risk.

Tenure security is another key determinant in adopting SI, ISFM, CSA, and CA technologies. It takes time to receive the return on investment in several soil-conserving technologies, such as using organic fertilizers, minimum tillage, and permanent soil cover by crop residues. Thus, farmers do not have an incentive to invest in these technologies if they are unsure whether they can use the plots in the future. Using data from Kenya, Nkomoki et al. (2018) found that farmers with customary land tenure had 17.4, 17.2, and 9.1% lower probabilities of adopting legume intercropping and agroforestry and planting basins, respectively, than those with statutory tenure.[1] Other studies also found that tenure security enhances the

[1] Customary land belongs to traditional rulers (chiefs) in the community and its use rights are provided to villagers (Nkomoki et al. 2018). Since it has not received formal consent, there is no land tenure security. On the other hand, statutory land tenure secures exclusive ownership and protects from eviction by land title deed documents that guarantee full property rights on the land (Nkomoki et al. 2018).

adoption of SI, ISFM, CSA, and CA technologies (Ehiakpor et al. 2021; Kamau et al. 2014; Kassie et al. 2013; Teklewold et al. 2013b, 2019).

Different technology attributes and farmers' resource endowments result in different SI, ISFM, CSA, and CA technology adoption patterns. Adopting these technologies requires substantial labor, and it takes several years to realize their benefits (Jayne et al. 2019). For example, Schmidt et al. (2017) showed that soil and water conservation must be maintained for at least 7 years to significantly increase the value of production. Therefore, resource-rich farmers are more willing to make such investments than resource-poor farmers, who prioritize their immediate daily life needs (Jayne et al. 2019). Asfaw et al. (2016) stated that adopting crop residues as soil cover and organic fertilizers is characterized by low capital investments and high labor inputs, and results take time. On the other hand, inorganic fertilizers and improved seeds require high capital investments and low labor inputs but provide quick results. Thus, the difference in resource endowments and the needs of farmers are likely to result in different patterns of technology adoption.

12.4 Effects of Integrated Farming Management Practices

The actual effects of adopting these farming management practices are revealed only by empirical impact assessments using real data obtained from farmers' fields. This section aims to clarify the effects of adopting these measures by reviewing recent empirical studies using micro-level data (household or plot level) of SSA countries.

Empirical studies indicate that returns, (i.e., including crop yields, household income, and food security), are maximized when yield-enhancing modern technologies (e.g., improved seeds and inorganic fertilizers), and resource-conserving technologies (e.g., organic fertilizers, legume intercropping, minimum tillage, and soil and water conservation technologies), are adopted jointly (Kim et al. 2019; Khonje et al. 2018; Manda et al. 2016; Marenya et al. 2020; Mutenje et al. 2019; Teklewold et al. 2019; Wainaina et al. 2018). The solo adoption of resource-conserving technologies does not always bring positive returns. For example, a global meta-analysis conducted by Pittelkow et al. (2015) using 5,463 paired observations from 610 studies shows that zero tillage reduces yield compared to conventional tillage. However, they also show that if zero tillage is implemented with two other CA practices (crop residue retention and crop rotation), its adverse impacts are minimized. Furthermore, Vanlauwe et al. (2014) argued that in addition to three CA practices (minimum tillage, permanent soil cover by crop residues, and crop rotation), inorganic fertilizers could enhance organic residue availability and crop yield in SSA.

Studies revealed that resource-conserving technologies can reduce yield variability when farmers encounter weather shocks. Kassie et al. (2015b) elucidated that the joint adoption of crop diversification and minimum tillage reduced the downside risk in the maize yield in Malawi. Similarly, Zeweld et al. (2020) demonstrated that farmers facing unpredictable rainfall could significantly enhance agricultural production by adopting soil and water conservation and organic fertilizers in Ethiopia. Furthermore, Maggio et al. (2021) showed that adopting organic fertilizers and maize-legume intercropping would positively affect crop production, especially under extremely high-temperature deviations in Uganda. These evidences indicate that adopting resource-conserving technologies could be an adaptive strategy to mitigate the effect of climate change on smallholders in SSA. However, Arslan et al. (2015) found that the positive effects of inorganic fertilizers are lower under false rainfall onsets, and the positive effects of improved seeds vanish under very high growing season temperatures, which indicates that solo adoption of yield-enhancing technologies is insufficient to mitigate negative climate shocks.

12.5 Toward a Sustainable African Green Revolution

Given the population growth, limits of arable land expansion in SSA, and ongoing climate change, integrated farming management practices (i.e., SI, ISFM, CSA, and CA), which aim to improve land productivity while conserving natural resources, are being widely promoted by national and international organizations to improve smallholders' welfare and food security in SSA. This chapter attempts to elucidate adoption constraints and understand the actual effects of their adoption on farmers' farmlands by reviewing recent empirical studies.

Empirical studies based on smallholder data in SSA indicate that farmers could realize the maximum benefits of integrated farming management practices by adopting yield-enhancing and resource-conserving technologies in combination rather than in isolation. These studies also demonstrate that integrated farming management practices could mitigate climate shocks. Since these management practices are knowledge- and management-intensive, farmers' education and training through extension services are necessary to widely diffuse these practices among rural smallholders.

Farmers often need to wait several years to recover the investment benefits of integrated farming management practices. Therefore, land tenure security is important in incentivizing smallholders to make such long-term investments. Resource-rich farmers are more likely to make such investments than resource-poor farmers, who need to maintain their subsistence. Thus, access to credit should be guaranteed to make the adoption of these farming practices affordable even for the poorest farmers (Asfaw et al. 2016). Access to input and output markets should be developed to enable smallholders to obtain necessary inputs, such as improved seeds and inorganic and organic fertilizers, and sell their outputs.

It is important to understand that integrated farming management practices, such as SI, ISFM, CSA, and CA, are location-specific technologies, given the heterogeneity in soil, agroecological, input and output prices, and market conditions in various places. Hence, optimum integrated farming management practices should be developed and adjusted according to local situations and resource endowments. We expect that the productivity and profitability of integrated farming management practices could be further enhanced by investing in research and development, which would lead to a sustainable African Green Revolution in SSA.

Finally, we would like to point out that the available evidence is generally limited to the impact of integrated farming management practices on yield and income (Takahashi et al. 2020). Very few studies have analyzed profitability. This is problematic because complex knowledge-intensive technologies, such as SI, ISFM, CSA, and CA, which require care and judgment, are mainly performed by family labor. Although it is challenging to estimate profit because of the difficulty in imputing family labor costs, more research is needed to assess the profitability of new technologies. This is essential to determine their viability and scalability.

Recollections of Professor Keijiro Otsuka

I first met Professor Kejiro Otsuka in 2015 in a microeconomics class at the National Graduate Institute for Policy Studies (GRIPS). He then guided my dissertation while doing my Ph.D. studies at Michigan State University and supervised me while I was a postdoc in GRIPS. He guided me on the possibility of the Green Revolution in Sub-Saharan Africa with various micro-empirical research. His diligence and enthusiasm in his research on development economics to make the world a better place have greatly impacted me. It showed me how an empirical economist should be. I am honored and delighted to be his student and be part of the Festschrift to celebrate his tremendous accomplishments.

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Chapter 13
Impacts of Transboundary Crop Diseases on Sustainable Crop Production: The Case of Maize Lethal Necrosis (MLN) in Africa

Khondoker Abdul Mottaleb

Abstract More than half of the world's population relies on wheat, maize, and rice for their daily dietary energy. In 2019, the daily per person average calorie intake was 2,963 kilocalories (kcal), in which the share was more than 18.2% (538 kcal) for wheat, 5.4% (159 kcal) for maize, and 18.3% (542 kcal) for rice. It is projected that by 2050, the total global population is expected to reach between 8.9 and 10.6 billion from 7.8 billion in 2020. Thus, it will be imperative to produce more wheat, maize, and rice to ensure the food security of the world's burgeoning population. While it is imperative to produce more food, the emergence and re-emergence of lethal crop diseases and their spread from the epicenters to new regions continuously threaten crop yield, farmers' income, and the world's food security. For example, the emergence of maize lethal necrosis (MLN) in Africa has generated a credible threat to global and African food security. This study quantified MLN-induced maize production loss in Kenya, DR Congo, and Tanzania. Applying the time-series projection method, this study estimates that the loss in maize production due to MLN was 442 thousand tons in Kenya, nearly 12 thousand tons in DR Congo, and 663 thousand tons in Tanzania. As more pest- and disease-related crop losses are expected due to the changes in global climate, this study concludes by suggesting that it is imperative to invest more in research and development of disease-resistant crop varieties globally to ensure food and nutrition security, particularly in the global south.

13.1 Introduction

Currently, an estimated 821 million people—10.9% of the world's population—do not have enough to eat (FAO et al. 2019). At the same time, 149.2 million children

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below five years old are stunted, 45.4 million are wasted, 38.9 million are overweight, and more than 40% of all men and women (2.2 billion people) are obese or overweight (Development Initiatives 2021a). By 2050, the global population is expected to reach between 8.9 billion to 10.6 billion people, and an estimated 2 billion people will face hunger under the business-as-usual scenario (UN 2019). Cereals like wheat, rice, and maize are the major dietary energy sources in many emerging economies in Sub-Saharan Africa, Latin America, and Asia, where most undernourished people live. To eliminate hunger by 2030 as per the United Nations (UN) Sustainable Development Goals (SDGs), more cereals and nutrition-enriched cereals, in particular, must be supplied to food-insecure countries in Asia and Africa. A few projections indicate that it will be imperative to supply 70–110% more food by 2050 to ensure global food security (FAO 2009; Tilman et al. 2011). The question as to how to supply more food comes to the fore.

One of the important ways to produce more food, particularly quality food, is by minimizing the pest- and disease-induced crop production losses. Due to pests and diseases, loss in crop production has been present since the dawn of human civilization. In the last three decades, however, the world has witnessed an unprecedented emergence, re-emergence, and globalization of lethal pests and diseases of crops, which have threatened the sustainability of the global food system (Bhattacharya 2017; Bueno-Sancho et al. 2017; Mehrabi and Ramankutty 2019; Pennisi 2010; Singh et al. 2019; Wellings 2007). For example, the re-emergence of a more aggressive variant of stem or black rust in wheat, known as UG99, in Uganda, Kenya, Ethiopia, Yemen, Syria, Iran, Afghanistan, Pakistan, and India (Beddow et al. 2015; Singh et al. 2019; Yahyaoui et al. 2008); the emergence of wheat blast in Bangladesh (Islam et al. 2016) and Zambia (Tembo et al. 2020); desert locust infestation in the Horn of Africa (Devi 2020; Salih et al. 2020); and maize lethal necrosis (MLN) in Kenya (Wangai et al. 2012), Ethiopia, Uganda, Tanzania, Rwanda, and the DR Congo (CIMMYT 2020). The ever-increasing trade and travel in a globalized world and global warming due to climate change are the major contributing factors to the globalization of crop pests and diseases (Anderson et al. 2004; Deutsch et al. 2008; Savary et al. 2019).

While there is a consensus about the destructive impacts of pests and diseases of crops on sustainable crop production, there is no consensus on the size and severity of the crop damage induced by pests and diseases. For example, assuming a 10% loss in cereal production due to pests and diseases, Marlatt (1904) estimated that in 1904, the monetary value of production loss in cereals in the USA was USD 200 million. Cramer (1967) stressed that the total loss in wheat and maize were 23.9% and 34.8% in 1964–65. Oerke et al. (1994) calculated that the actual global loss in wheat and maize due to pests and diseases were 34% and 38.3%, respectively. Using the latest data and dividing the crop production area into 19 regions, based on the crop production intensity and conditions, Oerke (2006) estimated that the total loss in crop production due to weeds, pests, and diseases are 28.1% for wheat, 31.2% for maize, and 37.4% for rice. Using the expert solicitation method, Savary et al. (2019) estimated that global annual crop losses due to pests, diseases, and weeds are 21.5% in wheat, 22.5% in maize, and 30% in rice.

Importantly, crop loss due to pests and diseases is country- and region-specific. Due to the advent of modern technology, improved agronomic practices, and seeds, such as hybrid and transgenic seeds, agricultural production and intensity have been evolving considerably in the twenty-first century. This suggests conducting country- and crop-specific case studies to quantify the economic loss in crop production due to pests and diseases. This study aims to estimate the loss in maize production in Kenya, DR Congo, and Tanzania due to the outbreak of MLN.

MLN is a disease in maize caused by the combination of maize chlorotic mottle virus (MCMV) and any of the viruses belonging to the Potyviridae family (Mahuku et al. 2015). The disease can destroy maize yield by 100% in a severe case. MLN was first reported in Peru in 1974 (Castillo and Hebert 1974; Hebert and Castillo 1973) and in the USA in 1976 (Niblett and Claflin 1978). Later, the disease was reported in several countries in the Americas, Asia, and Africa (Teyssandier et al. 1983). For a detailed list of the countries affected by MLN, please see Boddupalli et al. (2020). In 2011, for the first time in history, MLN was first reported in southwestern Kenya (Wangai et al. 2012), and by 2013, this lethal maize disease had spread to all maize-cultivating areas of Kenya (CIMMYT 2022b). In DR Congo, MLN emerged in 2013 (Lukanda et al. 2014), and in Tanzania, MLN was first reported in 2012 (CIMMYT 2022a) (Fig. 13.1). Using FAOSTAT (2022a) data and applying the time-series estimation procedure, this study demonstrated that the loss in maize production due to MLN outbreak in the sampled countries, where maize is a major staple food, was significant.

The case is worth investigating for two important reasons. First, it is imperative to develop and scale-out improved agronomic practices and resistant and resilient crop varieties, to minimize the loss in crop production due to pests and diseases. To develop and scale-out resistant varieties and improve agronomic practices, it is necessary to ensure adequate international donor agencies' financial support for research and development. However, to convince donors and international development agencies,

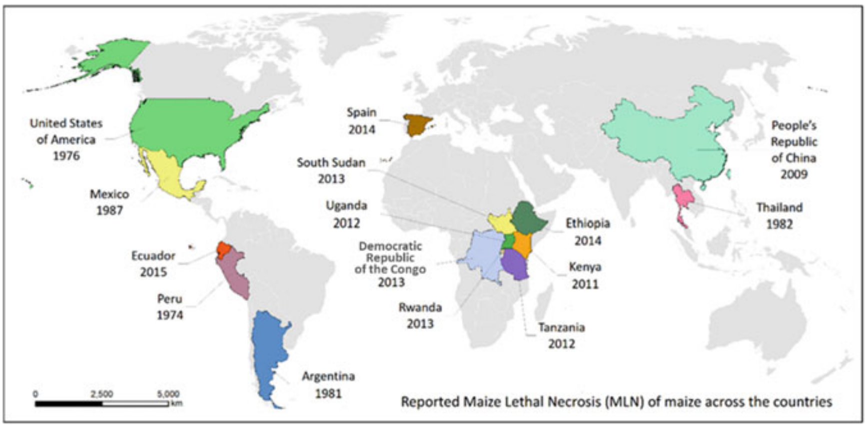

Fig. 13.1 MLN-affected countries in the world and year of emergence

it is necessary to showcase the loss in crop production based on country-, crop-, and disease-specific cases.

Second, maize is the most produced crop in the world. In 2019, total production in the world was around 765 million tons for wheat and 749 million tons for rice; but maize production was 1,141 million tons, and the crop was cultivated in 166 countries (FAOSTAT 2021a). Globally, 66% of the total wheat and 82% of the total rice produced is consumed as food (FAOSTAT 2021b). In the case of maize, less than 13% of total maize in the world is used as food, and nearly 59% is used as feed. The world's yearly per capita maize consumption is 19 kg, and maize supplies 159 kcal of the daily dietary energy requirement per person (FAOSTAT 2021b). Maize in Africa, however, is the major staple food. More than 66% of the total maize produced in Africa is consumed as food (FAOSTAT 2021b). The yearly average maize consumption in Africa is more than 43 kg per person, and maize supplies 383 kcal of the daily dietary energy requirement. Among the sampled countries, 99% of maize produced in Kenya is used as food, 84% in DR Congo, and 57% in Tanzania (FAOSTAT 2021b). As maize is the major food item, outbreaks of the devastating MLN have generated severe havoc on the food security of the sampled countries, where the food security situation is already precarious. The economic quantification of the loss in maize production due to the MLN outbreak in the three sampled countries demonstrates that the loss was significantly large. This study strongly urges international research organizations and donor agencies to extend support to mitigate the problem to ensure food security and income of the smallholder farmers in Kenya, DR Congo, and Tanzania.

Studies on quantifying loss in maize production due to the MLN outbreak in Africa are few. Gitonga and Snipes (2014) estimated that in 2014, 60,000 ha of maize area in Kenya was affected by MLN, which was 9% of the country's total maize area, with an estimated production loss of USD 50 million. Using qualitative information collected through focused group discussion in Kenya, De Groote et al. (2016) estimated a loss of 0.5 million tons of maize worth USD 187 million. Mahuku et al. (2015) reported up to 90% (equivalent to 126 thousand tons) loss in maize yield in Kenya in 2012 in the affected fields, valued at USD 52 million. The novelty of the current study is that it is based on real production data that are matched with the real-time outbreak of MLN in the sampled countries. Moreover, it is based on a simple time-series estimation process, which is relatively easy to understand.

The rest of the study is organized as follows. Section 13.2 presents materials and methods, Sect. 13.3 includes descriptive findings, Sect. 13.4 presents the simulation results, and Sect. 13.5 includes the conclusion and policy implications.

13.2 Materials and Methods

13.2.1 Data

To quantify the economic impacts of MLN on maize production in Kenya, DR Congo, and Tanzania, this study relied on the FAOSTAT dataset—an online web portal of the Food and Agriculture Organization of the United Nations (FAOSTAT 2022a). Maize is the major food item in the sampled countries. In 2019, the total domestic supply of maize (domestic production + imports) in Kenya was 8 million tons, of which 91% (7.28 million tons) was consumed as food (FAOSTAT 2021b). In DR Congo in 2019, the domestic supply of maize was 2.25 million tons, of which 80% (1.8 million tons) was consumed as food (FAOSTAT 2021b). In Tanzania in 2019, the total domestic supply of maize was 5.33 million tons, of which 61% (3.24 million tons) was consumed as food (FAOSTAT 2021b). To quantify the maize production loss due to the MLN outbreak in the sampled countries, this study used the area, production, and yield of maize in the sampled countries.

13.2.2 Estimation Process: Predicting Maize Yield

The MLN emerged for the first time in Kenya in 2011 (Wangai et al. 2012); in Tanzania in 2012 (CIMMYT 2022a); and in DR Congo in 2013 (Lukanda et al. 2014). To assess the loss in maize production due to the MLN outbreak, the per ha yield loss was estimated as follows:

$$E(y_l) = E\left(\overline{\overline{y}}_e\right) - y_{ta}$$

where $E(y_1)$ is the estimated yield loss per ha (ton/ha), $E\left(\overline{\overline{y}}_e\right)$ is the predicted (expected) yield, and y_{ta} is the actual yield of maize in the MLN-affected year. Total production loss ('000 tons) due to MLN (Q_1) was calculated as:

$$Q_1 = E(y_l) \times A_{ta}$$

where A_{ta} is the total maize area (hectares or ha) in the MLN-affected year. The economic valuation of maize production loss is calculated as: $Q_1 \times$ producers' price of maize (USD/ton) in the MLN-affected year.

13.2.3 Maize Yield Prediction: Specifying the Autoregressive Integrated Moving Average (ARIMA) Estimation Process

To predict the maize yield $\left(\overline{\overline{y}}_e\right)$ in Kenya, DR Congo, and Tanzania, this study employed univariate time-series analysis applying the autoregressive integrated moving average (ARIMA) estimation method developed by Box and Jenkins (1976). Symbolically,

$$(yield)_t = \beta_0 + \sum_{i=1}^{p} \beta_i (yield)_{t-1} + \sum_{j=1}^{q} \alpha_i u_{t-j} + u_t$$

where yield is the actual maize yield (ton/ha) in year $t(= 1961–2020)$, p is the number of lags of the dependent variable (maize yield), q is the number of lags of the error term u_t, and t is the year (t = 1961–2020).

To apply the ARIMA method, a series must be stationary. To check the stationarity, the augmented Dickey-Fuller test procedure was applied. The unit root test statistics result is presented in Table 13.1. In the case of Kenya and Tanzania, a simple natural log of the yield turned the series stationary. In the case of the maize yield data for DR Congo, the first difference of the natural log form of the maize yield variable rejects the null hypothesis of the presence of the unit root in the data, making the data stationary.

We tabulated and graphed autocorrelations and partial autocorrelations to determine the number of lags (p) of the dependent variable and the number of lags (q) of the error term. The model that provided better prediction power for Kenya was ARIMA (1, 0, 4); ARIMA (2, 1, 1) for DR Congo; and ARIMA (1, 0, 3) for Tanzania.

Table 13.1 Augmented Dickey-Fuller test for unit root (H0: Random walk without drift, $d = 0$)

Sampled countries	Kenya	DR Congo	Tanzania
Dependent variable	ln (maize yield)	d2.ln (maize yield)	ln (maize yield)
Constant	0.14*** (0.04)	0.002 (0.003)	0.07* (0.04)
ln (yield)$_{t-1}$	−0.32*** (0.09)		−0.31*** (0.09)
d.ln (yield)		−1.23*** (0.13)	
No. of observations	59	58	59
Z(t)	−3.34**	−9.50***	−3.27**
MacKinnon approximate p-value for *Z(t)*	0.01	0.00	0.02
Dickey-Fuller critical value of *Z(t)* 5%	−2.92	−2.92	−2.92

Note Values in parentheses are standard errors. *, **, and *** indicate significance at 10%, 5%, and 1% level, respectively

13.3 Descriptive Findings

The temporal changes in maize area (million ha), production (million tons), yield (tons/ha), and net export (export–import, '000 tons) in the sampled countries are shown in Table 13.2. The yearly maize consumption per capita (in kg) and the daily dietary energy intake from maize in the sampled countries are also presented.

In Kenya, maize is the major staple food and a major source of livelihood for millions of smallholder farmers. Over the years, the maize area and maize production have consistently increased in Kenya, as illustrated in Table 13.2. However, maize yield in Kenya oscillated between 1.2 and 1.8 tons/ha during 1961–2020. Therefore, the growth in maize production has mainly come from area expansion than a productivity gain. Interestingly, although maize is the major staple food of Kenya, the consumption of maize has been showing a declining trend. In 1961, the yearly per capita maize consumption in Kenya was 112 kg, which supplied 972 kcal of the daily dietary energy per person, 43% of the total daily calorie intake of a person in Kenya (1,149 kcal). In 2019, the yearly per capita maize consumption reduced to 74 kg, equivalent to 642 kcal dietary energy or 29% of the total dietary energy intake (2,205 kcal). Despite a declining trend in per capita maize consumption, the maize yield of Kenya failed to increase because the increase in aggregate demand stemmed from the increase in population. Consequently, the net maize import of Kenya has increased over the years. In 1961, the net maize import of Kenya was 103 thousand tons, which has increased to 260 thousand tons in 2019. In 2010, the year before the MLN infestation, the maize yield was 1.73 tons/ha, whereas in 2011, when the MLN emerged, maize yield was 1.58 tons/ha. In a report, the Government of Kenya recognized that the MLN outbreak is a major threat to achieving self-sufficiency in the country's maize production (Government of Kenya 2019).

In DR Congo, maize is the second major staple food after cassava. As shown in Table 13.2, maize area (million ha) and production in the country have increased during 1961–2020. Over the years, the maize area and maize production have consistently increased in DR Congo. However, like Kenya, maize yield in DR Congo also stagnated at less than 0.80 tons/ha for a long time. As a result, the growth in maize production has mainly come from area expansion than a productivity gain. Also, the per capita maize consumption in DR Congo has shown a declining trend. In 2011, the yearly per capita maize consumption in DR Congo was 24.1 kg, equivalent to 221 kcal dietary energy per person and more than 11% of the daily total calorie intake (1,920 kcal) of a person in DR Congo. In 2019, yearly per capita maize consumption was reduced to less than 21 kg, equivalent to 190 kcal dietary energy or nearly 10% of a person's total dietary energy intake (1,913 kcal) in DR Congo. Despite a declining trend in per capita maize consumption, the domestic maize production of DR Congo failed to increase since the increase in demand stems from the increase in population. Consequently, the net maize import of DR Congo has increased over the years. In 2011, the net maize import of DR Congo was 64 thousand tons, which has increased to 121 thousand tons in 2019. The MLN emerged in DR Congo in 2013.

Table 13.2 Temporal changes in maize area (million ha), production (million tons), and yield (tons/ha) in the sampled countries, 1961–2019 (FAOSTAT 2022a)

Country	Year	Area (million ha)	Production (million tons)	Yield (ton/ha)	Export–Import ('000 tons)	Consumption (yearly per capita per kg)	Daily kcal
Kenya	1961	0.75	0.94	1.25	−103	112	972 (43)
	1971	1.15	1.40	1.22	−29	109	953 (41)
	1981	1.12	1.77	1.58	−76	115	997 (44)
	1991	1.31	2.40	1.83	21	88	763 (38)
	2001	1.64	2.79	1.70	−318	85	740 (36)
	2011	2.13	3.38	1.58	−299	87	757 (35)
	2019	2.29	3.58	1.56	−260	73.7	642 (29)
	2020	2.19	3.79	1.73	–	–	–
DR Congo	1961	0.54	0.37	0.69	–	–	–
	1971	0.61	0.44	0.72	–	–	–
	1981	0.76	0.64	0.83	–	–	–
	1991	1.26	1.02	0.81	–	–	–
	2001	1.46	1.17	0.80			
	2011	2.43	1.89	0.78	−64	24.1	221 (11.5)
	2013	2.55	1.98	0.78	−44	24.6	226 (12.0)
	2019	2.77	2.14	0.78	−121	20.7	190 (9.9)
	2020	2.74	2.11	0.77	–	–	–
Tanzania	1961	0.79	0.59	0.75	−47	50.4	451 (25.8)
	1971	0.98	0.72	0.73	4	46.8	419 (24.9)
	1981	1.35	1.84	1.36	−155	84.0	751 (34.2)
	1991	1.84	2.33	1.26	5	76.9	687 (30.8)
	2001	0.85	2.65	3.14	−65	68.6	613 (30.2)

(continued)

Table 13.2 (continued)

Country	Year	Area (million ha)	Production (million tons)	Yield (ton/ha)	Export–Import (‘000 tons)	Consumption (yearly per capita per kg)	Daily kcal
	2011	3.29	4.43	1.32	−12	57.7	516 (22.8)
	2012	4.12	5.10	1.24	160	61.1	516 (23.8)
	2019	3.43	5.65	1.65	184	55.9	500 (21.1)
	2020	4.2	6.71	1.60	–	–	–

In terms of yearly per capita consumption, maize (56 kg per capita per year) is the second major staple food after cassava (92 kg per capita per year) in Tanzania, but in terms of the daily dietary energy intake per capita, maize is the major staple food (500 kcal daily per capita). As Table 13.2 illustrates, maize area and maize production have consistently increased over the years. Maize yield, however, initially increased and then declined drastically. In 1961, the maize yield in Tanzania was 0.75 tons/ha, increasing to 3.14 tons/ha in 2001. However, after that, the maize yield in Tanzania decreased significantly. In 2020, maize yield was 1.60 tons/ha. In terms of net trade (export–import), Tanzania emerged as a net exporter of maize. In 2019, the country exported 184 thousand tons of maize. MLN-affected the maize fields in Tanzania in 2012. In 2011, the year before the MLN invasion, maize yield was 1.32 tons/ha, whereas in 2012, when MLN emerged, maize yield was 1.24 tons/ha. This reduction in maize yield in 2012 is mainly due to MLN.

13.4 Major Findings: Quantifying the Economic Loss of MLN Outbreaks

Estimated functions explaining maize yield prediction in Kenya, DR Congo, and Tanzania applying the ARIMA estimation process are presented in Table 13.3. The model’s fitness was checked by examining the white-noise property of the error term and the Eigenvalue stability conditions for both AR (autoregressive) and MA (moving average). Table 13.3 also shows that the estimated functions explaining maize yield in the sampled countries are statistically stable and are good fits.

The actual maize yield in the three countries during 1961–2020 and the predicted yield applying the Box-Jenkins method after the ARIMA estimation process for 1961–2030 are shown in Figs. 13.2, 13.3, and 13.4. The parallel movement of the actual maize yield trend and the predicted maize yield in the sampled countries indicates the strength of the prediction process used in this study.

The model estimated that the expected maize yield in Kenya in 2011, when MLN first emerged in the country, was 1.79 tons/ha, and the actual maize yield was 1.58

Table 13.3 Estimated functions applying the ARIMA estimation process explaining maize yield in the sampled countries (Author's estimation)

	Kenya	DR Congo	Tanzania
	ln (maize yield)	d.ln (maize yield)	ln (maize yield)
Constant	0.40*** (0.11)	0.0020 (0.00)	9.37*** (0.23)
ARMA			
AR			
ln (maize yield)$_{t-1}$	0.94*** (0.07)		0.94*** (0.10)
d.ln (maize yield)$_{t-1}$		−1.15*** (0.17)	
d.ln (maize yield)$_{t-2}$		−0.29 (0.18)	
MA			
u_{t-1}	−0.19 (0.14)	1.00 (56.27)	−0.53* (0.31)
u_{t-2}	−0.75*** (0.12)		0.16 (0.23)
u_{t-3}	0.23* (0.13)		−0.18 (0.19)
u_{t-4}	0.22* (0.13)		
Sigma			
Constant	0.10*** (0.01)	0.024 (0.67)	0.25*** (0.02)
Observations	60	59	60
Log-likelihood	51.47	136.0	−1.95
Wald chi^2 (5)	221.7	158.1	386.21
Prob < chi^2	0.00	0.00	0.00
Portmanteau test for white noise			
Portmanteau (Q) statistic	18.7	16.3	19.27
Prob < chi^2 (28)	0.91	0.95	0.89
Eigenvalue stability condition			
AR parameters satisfy stability condition	Yes	Yes	Yes
MA parameters satisfy the invertibility condition	Yes	Yes	Yes

tons/ha (Table 13.4). Thus, the per ha loss in maize yield was 211 kg. As the total maize area in 2011 was 2.13 million ha, the total maize production loss is estimated at more than 442 thousand tons. In 2011, the producer's price of maize in Kenya was USD 281/ton. Thus, the loss in maize production in Kenya in 2011 is estimated at USD 124.2 million. This finding is lower than the findings of De Groote et al. (2016), who estimated a loss of 0.5 million tons of maize worth USD 187 million in Kenya due to MLN.

The model estimated for DR Congo (Table 13.4) shows that the expected maize yield in 2013, when MLN emerged in the country for the first time, was 0.784 ton/ha, while the actual maize yield in the same year was 0.779 ton/ha. Thus, the per hectare loss in maize yield in DR Congo was calculated at 4.62 kg. As the total maize area

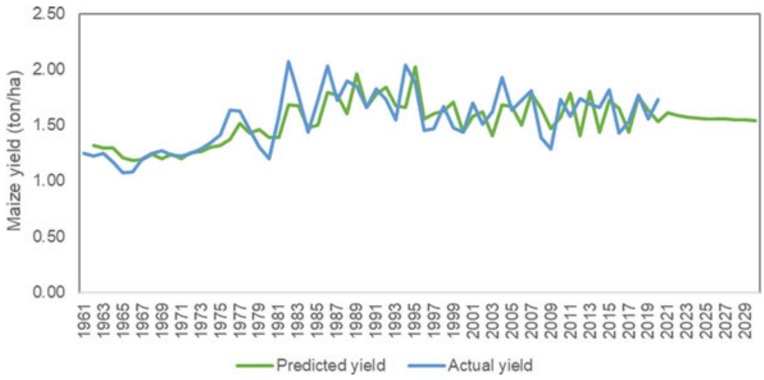

Fig. 13.2 Predicted (1962–2030) and actual (1961–2020) maize yield in Kenya

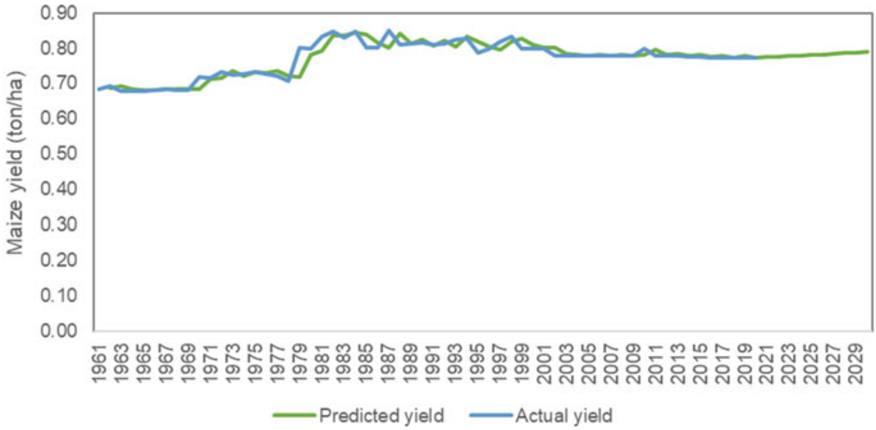

Fig. 13.3 Predicted (1962–2030) and actual (1961–2020) maize yield in DR Congo

was 2.50 million ha, the total maize production loss in 2013 is calculated at more than 11.6 thousand tons. In 2013, the maize export price of DR Congo was USD 84.8/ton,[1] with the loss in maize production estimated at USD 0.98 million.

The model estimated for Tanzania (Table 13.4) shows that the expected maize yield in 2012, when MLN first emerged in the country, was 1.40 tons/ha, and the actual maize yield in the same year was 1.24 tons/ha. Thus, the per hectare loss in maize yield for Tanzania was calculated at 162 kg. As the total maize area in Tanzania in 2012 was 4.10 million ha, the total maize production loss in 2012 is calculated at more than 663 thousand tons. In 2012, the producer's price of maize in Tanzania was USD 163/ton, with the loss in maize production estimated at USD 108.1 million.

[1] Producer's price of maize for DR Congo in 2013 was not available in FAOSTAT. In 2013 DR Congo reportedly exported 224 tons of maize worth USD 84.8/ton. In quantifying the production loss for DR Congo, this study used the maize price of USD 84.8/ton.

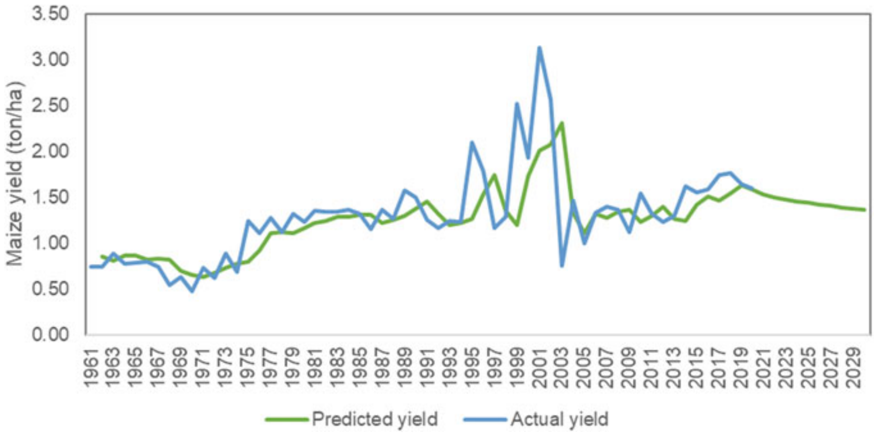

Fig. 13.4 Predicted (1962–2030) and actual (1961–2020) maize yield in Tanzania

It must be mentioned here that this study only considered the direct loss in maize production due to the MLN outbreak in the sampled countries. In reality, because of MLN, many smallholder farmers were forced to stop maize cultivation partially or completely or were forced to switch to other crops. Such involuntarily transition in cropping pattern is a deviation from the Marshallian net utility maximization or Pareto optimality condition. However, this study did not consider market loss due to involuntary transition in cropping patterns in the sampled countries.

13.5 Conclusion and Policy Implications

While it is imperative to supply more food, the emergence, re-emergence, and the global spread of lethal pests and diseases of crops have generated credible threats to sustainable crop production systems. A successful minimization of crop losses due to pests and disease infestations can significantly contribute to global food security. Developing and scaling out improved agronomic practices and resistant and resilient crop varieties are imperative to minimize crop losses due to pests and diseases. For this, strong financial support for research and development (R&D) from the donor communities is necessary. However, to convince donor communities, evidence-based cases must be presented. Using the MLN outbreak in Africa, this study quantified the economic loss in maize production due to the MLN outbreak in Kenya, DR Congo, and Tanzania.

Historically, MLN was long confined to the Americas. For the first time in history, in 2011, MLN was first reported in southwestern Kenya (Wangai et al. 2012), and by 2013, this lethal maize disease had spread to all maize-cultivating areas of Kenya (CIMMYT 2022b). In DR Congo, MLN emerged in 2013, and in 2012 MLN emerged in Tanzania.

Table 13.4 Quantifying loss in maize production due to MLN outbreak in the sampled countries. (Sources: FAOSTAT 2022b[a], c[b])

Country	Predicted maize yield	Actual yield in the MLN-affected year	Maize area in the MLN-affected year (A_0) (million ha)	Yield loss (kg/ha)	Total production loss ('000 tons) $Q_l = \Delta Y \times A_0$	Producers' price of maize in the MLN-affected year (USD/ton)[a]	Monetary value (million USD) of the total lost production ($Q_l \times P_r$)
Kenya	1.79	1.58	2.13	211	442.1	281	124.2
DR Congo	0.784	0.779	2.50	4.62	11.56	84.82[b]	0.98
Tanzania	1.40	1.24	4.10	162	663.1	163	108.1

This study estimated that the losses in maize production in Kenya and Tanzania are significantly large. In Kenya in 2014, 26.2% of the children under five years old were stunted; in 2019, 13.4% of adult males and 8.9% of adult females were underweight (Development Initiatives 2021d). In DR Congo in 2017, 41.8% of the children under five were stunted; and in 2019, 17.8% of adult males and 12.3% of adult females were underweight (Development Initiatives 2021b). In Tanzania in 2018, 31.8% of the children under five were stunted; and in 2019, 11.5% of adult males and 9.0% of adult females were underweight (Development Initiatives 2021c). The emergence of MLN and the loss in maize production due to MLN have created further havoc on these three countries' already precarious food security situation.

This study is a call for action to fight MLN in Africa. This study strongly suggests short- and long-term effective strategies to eliminate the MLN threat in Africa. In the short-run, assured investment is needed in R&D to fully understand the disease dynamics in the African setting, actively observe its emergence and re-emergence in the regions, and develop and scale-out effective practices to control the spread and crop damage. Since the disease is new in Africa, it is important to develop awareness among the farmers about this lethal disease. For example, as MLN is mainly a seed-borne disease, the movement of seeds from infected areas must be strictly controlled (Boddupalli et al. 2020). In addition, crop rotation and diversification, seed treatment with fungicides, and foliar sprays can be useful in the short-run to control MLN (Boddupalli et al. 2020). It is imperative to develop and deploy resistant maize varieties to fight MLN successfully in the long-run. Importantly, the International Maize and Wheat Improvement Center (CIMMYT) in Mexico has already developed 18 MLN-tolerant maize varieties and deployed them in Kenya, Uganda, and Tanzania (Boddupalli et al. 2020). Among the 18 MLN-tolerant varieties, 14 varieties are second-generation seeds with higher yield potentials and more tolerant to MLN. A study demonstrated that scaling out of MLN-tolerant maize varieties can generate economic benefits of USD 195–678 million in Kenya and USD 245–756 million in Ethiopia (Marenya et al. 2018). This study thus strongly urges external support to scale-out MNL-tolerant maize varieties in the affected countries on an emergency basis since the usual process of seed dissemination takes a relatively long time (Mottaleb et al. 2019).

Recollections of Professor Keijiro Otsuka

Otsuka sensei was my class teacher, mentor, philosopher, and guide. I learned many things from him, including how to write the introductory paragraph of a research article. I still remember the example he presented in the class explaining the tragedy of the commons. He taught us that it is important to go to the field, see things, and talk to stakeholders to understand an issue's complexity and relate it with the existing theories. As a student of Otsuka sensei, I know that he has never taken a day off on Saturday in his career, and every morning he starts his day by reading a new article. He demonstrates that there is no substitute for hard work and dedication to become successful in anyone's field. Being a student of Otsuka sensei, it is my immense pleasure and honor to be part of the Festschrift celebrating his glorious lifetime achievements.

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Chapter 14
Sustainable Green Growth in Agriculture: The Role of Regional Cooperation

Kazi Arif Uz Zaman and Kaliappa Kalirajan

Abstract Due to the continuous need to attain food security for the growing population, resource exploitation in the agriculture sector is evident. Hence, both production growth and sustainability have become key policy dilemmas. This paper examines the prospective roles of regional cooperation in attaining sustainable green growth in the agricultural production process. To formulate the Green Growth Index for Agriculture (GGIA), 16 South-through-East Asian countries were considered. The result implies that if the countries could work under a regional cooperation bloc, on average, they can exploit the untapped potential production of 33.8% without deploying any additional resources. Analysis for emission-management reveals that if the countries could work under a regional cooperation bloc, on average, its agriculture emission-management efficiency would be 45%. According to the GGIA, China, Japan, and South Korea have the highest overall efficiency, while Cambodia, Lao PDR, and Thailand have the lowest in this region.

14.1 Introduction

To reinforce an effective green growth policy in agriculture, it is important to focus on maximizing production using a given level of inputs and technology and minimizing emissions resulting from the same level of inputs. The contemporary literature highlights the impact of climate change and environmental degradation on agricultural production (Nelson et al. 2009; ADB 2013; IPCC 2014; Lipper et al. 2014; Kaur and Kaur 2016). However, the way agricultural production (process) impacts emission, environmental degradation, and subsequent climatic change is rarely examined.

This study contributes to this gap in the literature by analyzing how the agricultural production process affects the environment through emissions while focusing

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on how countries under a regional cooperation framework can work together to best manage emission containment to attain the goal of sustainable green growth in agriculture. Specifically, this chapter examines the countries' current state of emission-management efficiency and subsequently derives the impact of regional cooperation in achieving green growth in agriculture by reducing emissions and environmental degradation. For empirical analysis, 16 South-through-East Asian (StEA is used throughout the paper to represent the regional bloc) are considered.

The next section explains the methodology and model specifications. Results and findings are presented in Sect. 14.3. A composite indicator for combining agricultural production and emission-management efficiencies is explained in Sect. 14.4. Concluding remarks and policy implications are given in Sect. 14.5.

14.2 Methodology and Data

14.2.1 Methodology

This study uses the well-established stochastic frontier production function analysis (SFPFA), which facilitates the calculation of production and emission-management efficiencies.[1] This study uses the technical inefficiency effects model for using the panel data proposed by Battese and Coelli (1995). The basic model is designed as shown in Eq. (14.1).

Maximizing

$$\begin{aligned} \ln output_{i,t} = \beta_0 &+ \beta_1 \ln land_{i,t} + \beta_2 \ln labor_{i,t} + \beta_3 \ln capital_{i,t} \\ &+ \beta_4 \ln fertilizer_{i,t} + \beta_5 \ln energy_{i,t} + \beta_6 \ln FDI_{i,t} \\ &+ time - U_{i,t} + V_{i,t} \end{aligned} \quad (14.1)$$

$i = 1, 2, 3, \ldots\ldots\ldots\ldots, k$ (for each country)
$t = 1, 2, 3, \ldots\ldots\ldots\ldots, T$ (for each year)

Here, *output* refers to the aggregated agriculture output, while *land* refers to a country's total arable land. *Labor* and *capital* denote the total labor (in number) and capital (in USD) deployed in agriculture. *Fertilizer* and *energy* refer to the amount of fertilizer and energy consumed in agriculture production. *FDI* denotes the cumulative foreign direct investment (FDI) inflow since 2000 in the country's agriculture sector. FDI inflow is used as a proxy for technological progress. *Time* is incorporated to capture the time trend in agriculture production. Subscripts i and t represent the ith country and time, respectively. $U_{i,t}$ denotes the single-sided non-negative error term for the combined effects of inefficiency, on which complete information is not available. $V_{i,t}$ refers to the normal statistical error term, which captures the effect of

[1] For more details on the SFPFA methodology and empirical analyses, particularly using both primary and secondary data from the Asian region, see Kalirajan and Shand (1994), among others.

inadvertently omitted variables. The ratio of the actual output to the estimated frontier potential output is defined as the technical efficiency or production management efficiency for the concerned country for the particular year.

To understand sustainable green growth in agriculture, we need to comprehend the interrelationship among inputs, output, and emissions. Primarily, inputs (such as land, labor, capital, fertilizer, energy, and technology) maximize agricultural production. Nevertheless, striving for higher production may also instigate the deployment of more input resources, resulting in higher emissions. Thus, examining the emission-management efficiency resulting from the same inputs is imperative.

The basic emission-management efficiency model should target the minimization of emissions from agricultural inputs and activities. The model is designed as shown in Eq. (14.2).

Minimizing

$$\begin{aligned} \ln Emission_{i,t} = {} & \beta_0 + \beta_1 \ln Land_{i,t} + \beta_2 \ln Labor_{i,t} + \beta_3 \ln Capital_{i,t} \\ & + \beta_4 \ln Fertilizer_{i,t} + \ln Energy_{i,t} + \beta_6 \ln FDI_{i,t} \\ & + time + U_{i,t} + V_{i,t} \end{aligned} \tag{14.2}$$

$i = 1, 2, 3, \ldots\ldots\ldots\ldots, k$ (for each country)

$t = 1, 2, 3, \ldots\ldots\ldots\ldots, T$ (for each year)

Here, *emission* refers to the aggregated emissions (of all greenhouse gases [GHG], including CO_2, methane [CH_4], and nitrous oxide [N_2O]) produced in the different agricultural activities. The other variables (i.e., land, labor, capital, fertilizer, energy, FDI, time, and error terms) have been defined earlier. The estimated frontier potential minimum emission ratio to the actual emission is defined as the emission-management efficiency for the concerned country for the particular year. For the most emission-efficient country, the ratio will be 1, and greater than 1 indicates emission inefficiency.

The software FRONTIER 4.1 was used to perform the estimation with the maximum likelihood method as introduced by Coelli (1996). The country-specific production and emission-management efficiencies were calculated based on the methods suggested to estimate the stochastic production and cost frontiers.

14.2.2 Description of the Data

The data on aggregated agriculture production (in million USD), aggregated agriculture emission (in gigagram carbon dioxide equivalent [CO_2e]), arable land (in thousand hectares), capital (in million USD), fertilizer (in kilogram [kg]), energy consumption in agriculture (in terajoule), and FDI inflows in agriculture (in million USD) are extracted from the database of the Food and Agriculture Organization of the United Nations (FAO). Labor (in thousand) data was collected from the Asian Development Bank's (ADB) *Key Development Indicators* (various years).

Data were collected for the 2000–2013 period for all StEA countries except Bhutan, Brunei, and the Maldives, for which a complete set of data are not available. Along with these three countries, Singapore was also removed from further analysis because of its low-scale agriculture emission. In aggregate, these four countries emit only 0.03% of the total agricultural emission of the region; hence, skipping these countries from the analysis would not have a substantial influence on the agricultural policy implication.

14.3 Results and Findings

14.3.1 Estimations of Production Efficiency of the Countries

The agricultural production efficiency of the countries for the 2000–2013 period is presented in Table 14.1. It reveals that China has the highest production efficiency at 94.7%. Japan, Vietnam, and South Korea follow China with 91.1, 90.6, and 85.1%. Thailand, on the contrary, has the lowest efficiency at 36.5%. Cambodia, Lao PDR, and Nepal are the other least-efficient countries, with efficiency levels of 36.5%, 46.1%, and 49.8%, respectively. Among the other large-scale producers, India has a production efficiency of 65.2%, and Indonesia has 58.4%.

Table 14.1 Country-wise production management efficiency in agricultural production, 2000–2013

Country	Production management efficiency (%)
Bangladesh	71.1
Cambodia	46.1
China	94.7
India	65.2
Indonesia	58.4
Japan	91.1
Lao PDR	49.8
Malaysia	65.6
Myanmar	84.1
Nepal	52.6
Pakistan	61.4
Philippines	73.4
South Korea	85.1
Sri Lanka	75.7
Thailand	36.5
Vietnam	90.6

14.3.2 Regional Cooperation

The impact of regional cooperation was estimated by considering the StEA as a single bloc. Inputs and output variables of all the countries were summed up to get the aggregated level of inputs and output for the whole region. This single bloc is then put into the model, and its efficiency was calculated by the maximum likelihood estimation by comparing the entities with regard to the best-practice performer. The estimation reveals that this regional bloc's overall production management efficiency is 83.7%. It implies that if the countries could work under a regional cooperation bloc, on average, their agriculture production efficiency would be 83.7%. Since most of the large agriculture producers, such as China, Japan, and South Korea, have much higher efficiencies in production, the overall weighted efficiency of the StEA region remains relatively higher. It also means that the regional cooperation bloc can work together to further increase its production toward the untapped frontier potential production of 16.3% without deploying any additional resources (i.e., inputs).

To understand the link between enhanced production management efficiency and emission reduction potential, this study uses the calculation as shown in Table 14.2.

With x amount of aggregated input, the regional bloc can produce y output. Since emission or environmental degradation results from using inputs in the agriculture production process, let's assume that x amount of aggregated input leads toward an aggregated emission of m. With a further increase of efficiency by 16.3%, x amount of aggregated input will produce 116.3y amount of aggregated output, but the amount of aggregated emission will stay at m. Hence, to produce the agricultural output at the current level with this higher level of production management efficiency, the emission level may be reduced to $m/1.163$ or 86.0% of its current emission level. Therefore, the production management efficiency increase of the production process may save up to 14.0% of its current emission level, considering that the production level remains at its current level.

14.3.2.1 Synergy Effect for Potential Gap Reduction

The synergy effect claims that the combined action of a group of countries (i.e., regional cooperation) should bring added benefits over the sum of an individual country's actions. Hence, it is important to calculate the synergy effect in any regional cooperation framework to understand the impact of combined action.

Table 14.2 Estimation of the link between optimal production efficiency and emission reduction

Scenario	Input	Output	Emission
Actual scenario	x	y	m
Frontier potential production efficiency scenario	x	1.163y	m
New level of emission (with current production level and potential efficiency)	0.86x	y	0.86 m

Table 14.3 Synergy effect measure (i.e., the impact of regional cooperation) to close the potential gaps

Year	Sum of individual gaps	Gap as a unitary bloc	Impact of cooperation
2000	131.21	105.03	20.0
2001	145.91	117.39	19.5
2002	154.70	124.81	19.3
2003	114.92	80.94	29.6
2004	135.03	97.23	28.0
2005	127.60	81.37	36.2
2006	155.19	110.48	28.8
2007	132.79	75.64	43.0
2008	128.91	66.95	48.1
2009	147.43	86.81	41.1
2010	165.42	95.73	42.1
2011	169.73	100.47	40.8
2012	174.43	106.52	38.9
2013	172.26	103.18	40.1
Average			34.0

For this purpose, gaps in frontier potential agricultural productions (i.e., frontier potential production minus actual production) are calculated separately for all 16 countries. Then the model considered the whole regional bloc (StEA) as a single entity and calculated the gap for that whole bloc. As Table 14.3 shows, the gap in the potential agricultural production of the StEA (as a single bloc) is smaller than the sum of all 16 countries' gaps. The calculation, thus, supports the synergy effect phenomenon. To quantify the impact of regional cooperation, the differences between those gaps from the potential (the sum of individual country's gaps minus the whole bloc's gap) are measured as percentages of the gap without cooperation. Hence, the synergy effect of the regional bloc is calculated as:

$$\begin{aligned} &Impact\ of\ regional\ bloc\ (synergy\ effect) \\ &= \frac{(Gap\ without\ forming\ regional\ bloc - Gap\ as\ a\ regional\ bloc)}{Gap\ without\ forming\ regional\ bloc} = \\ &= \frac{(sum\ of\ gaps\ from\ potential\ of\ each\ country - gap\ from\ potential\ for\ StEA)}{sum\ of\ gaps\ from\ potential\ of\ each\ country} \end{aligned}$$

Table 14.3 reveals that the synergy effect, on average, is 34%

14.3.3 Estimations of the Emission-Management Efficiency of the Countries

The emission-management efficiency of the countries for the 2000–2013 period is shown in Table 14.4. It depicts that China has the highest emission-management efficiency at 70.4%. Thailand, Malaysia, and Sri Lanka follow China with 60.3%, 58.7%, and 54.3% efficiency. India and Indonesia have 42.8% and 53.3% emission-management efficiencies, respectively. Myanmar, Lao, and Cambodia are the three least-efficient countries, with efficiency levels of 30.5%, 32.2%, and 34.0%, respectively.

14.3.3.1 Impact of Regional Cooperation

A similar approach as described earlier is adopted to measure the impact of regional cooperation on the aggregated emission-management efficiency, which considers the StEA as a single bloc. Inputs and output variables of all the countries are summed up to get the aggregated level of inputs and output for the whole region. This single bloc is then put into the model, and its efficiency was calculated using the maximum likelihood estimation by comparing the entities with regard to the best-practice performer. The estimation reveals that the overall technical efficiency of this regional bloc for emission containment is 52.6%. It implies that if the countries could work under a

Table 14.4 Country-wise emission-management efficiency in agricultural production (2000–2013)

Country	Emission-management efficiency
Bangladesh	40.7
Cambodia	34.0
China	70.4
India	42.8
Indonesia	53.3
Japan	49.4
Lao PDR	32.2
Malaysia	58.7
Myanmar	30.5
Nepal	42.7
Pakistan	38.6
Philippines	40.9
South Korea	51.5
Sri Lanka	54.3
Thailand	60.3
Vietnam	42.2

Table 14.5 Estimation of the link between optimal emission-management efficiency and potential production level

Scenario	Input	Output	Emission
Actual scenario	x	y	m
Potential efficiency in emission-management	x	y	0.526 m
New level of production (with current emission level and potential efficiency)	1.90x	1.90y	m

regional cooperation bloc, on average, their agriculture emission-management efficiency would be 52.6%. It also refers that if the regional cooperation bloc can work together with the given set of inputs, the region can further contain (i.e., decrease) the agricultural emission by 47.4% from the current level.

This study uses the following calculation to understand the link between the potential emission-management efficiency and the potential production level, as shown in Table 14.5.

With x amount of aggregated input, the regional bloc can produce y output and m level of emission. Now for the potential efficiency in emission containment, with the given set of inputs, emissions can be further reduced by 47.4% from the current level. Therefore, the optimal emission level with the given input (x) and given production level (y) would be $(1 - 0.474)m$ or 0.526 m.

Now, assume that the StEA region adopts the potential emission-management efficiency practices. If at that efficiency level, it wants to remain at the current emission level (m), it would, in turn, allow the aggregated input level to (1/0.526) x (i.e., 1.90x). Since x level of input produces y level of output, the new level of input (i.e., 1.90x) would produce a 1.90y level of output. Therefore, the potential production management efficiency in the emission-management process may further enhance the production level by 90% from its current level, considering it allows emissions to remain at the current level.

14.4 Green Growth Index in Agriculture (GGIA): A Composite Indicator

For an effective green growth policy in agriculture, a country should simultaneously focus on growing its production and lowering production-related emissions. This becomes plausible by attaining higher efficiency both in production and emissions management. In reality, some countries may have higher production management efficiency owing to better use of inputs to maximize production, while some countries may have high efficiency in managing emissions. Hence, a combined index needs to be prepared to know the resultant efficiency toward attaining a green growth policy. Saltelli (2007) mentions that a composite indicator is easier for general interpretation and more useful in evaluating performance than following several separate indicators' trends. It is rational to argue that a composite indicator (or combined index) always helps initiate the discussion and motivate the common interest.

Though the formulation of a composite indicator seems to follow the mathematical or computational models, the essence and justification for it depend on the intended purpose, peer acceptance, and the craftsmanship of the modeler (Rosen 1991). The Organisation for Economic Co-operation and Development (OECD 2008) handbook identifies two key steps (i.e., multivariate analysis and normalization) as essential steps for aggregation. Multivariate analysis requires that the structure of the dataset is investigated and its suitability for combination be assessed. Since this study attempts to combine two factors, both efficiency terms, and for the same set of 16 countries, it is plausible to combine. Normalization is also attained since both efficiencies are estimated based on best practices as the benchmark. Yet, the key discussion for an aggregation technique remains toward the arbitrary weighting process (Sharpe 2004). This study reveals that both agriculture production management efficiency and emission-management efficiency are equally significant for attaining sustainable green growth in agriculture. It also shows strong linkages between the optimal production efficiency with emission reduction and optimal emission-management efficiency with increasing production. Hence, equal weights were considered for the aggregation technique to concurrently emphasize the countries' production and emission-management efficiencies.

The next question is whether the additive (linear aggregation) or multiplicative (geometric aggregation) technique is suitable for this study. In fact, a country with lower scores would prefer an additive aggregation technique over the multiplicative. However, it also means that multiplicative aggregation would set greater incentives to address the limiting factors more intensely for the low-score country as it would give it a better chance of improving its position in the ranking (Munda and Nardo 2005). The multiplicative aggregation technique was considered to emphasize improving the countries' performance. The GGIA is thus proposed as follows:

$$\text{GGIA} = \sqrt{\text{Production efficiency} \times \text{Emission} - \text{management efficiency}}$$

Based on 2000–2013 average efficiencies, GGIA was calculated (Table 14.6). China (82%), Japan (67%), and South Korea (66%) have the highest GGIA. Cambodia (40%), Lao PDR (40%), and Thailand (47%), on the contrary, have the lowest GGIAs. The whole of the StEA region has a GGIA of 66%.

14.5 Concluding Remarks and Policy Implications

14.5.1 Concluding Remarks

An ever-growing population and the climate change phenomenon have compelled producers to exploit the resources in agriculture production even faster. This study

Table 14.6 Countries' overall performance regarding production efficiency, emission-management efficiency, and GGIA

Country	Production efficiency (%)	Emission-management efficiency (%)	GGIA (%)
Bangladesh	71	41	54
Cambodia	46	34	40
China	95	70	82
India	65	43	53
Indonesia	58	53	56
Japan	91	49	67
Lao PDR	50	32	40
Malaysia	66	59	62
Myanmar	84	31	51
Nepal	53	43	47
Pakistan	61	39	49
Philippines	73	41	55
South Korea	85	52	66
Sri Lanka	76	54	64
Thailand	37	60	47
Vietnam	91	42	62
StEA	84	53	66

examined regional cooperation's prospective roles in attaining sustainable green growth by enhancing countries' production management and emission efficiencies.

This study adopted the stochastic frontier model to estimate the production management efficiency and emission efficiency levels of 16 countries. The empirical results reveal that China has the highest production management efficiency. Japan, Vietnam, and South Korea follow China, while Thailand, Cambodia, Lao PDR, and Nepal are the least-efficient countries in terms of agriculture production management among the StEA countries. The estimation reveals that this chosen regional bloc's overall production management efficiency is 83.7%, implying that it can work together to further increase the region's agriculture production by 16.3% toward untapped potential production without deploying any additional resources. Estimating the link between potential production efficiency and emission reduction reveals that under the fully-efficient scenario, an increase in the production management efficiency may reduce 14.0% of emissions from its current level, considering the production level remains the same. The synergy effect calculation also revealed that the StEA countries could have improved their production closer to the potential had they worked under a common regional cooperation bloc than working separately.

This study also examined the countries' current state of emission-management efficiency and subsequently derived the impact of regional cooperation in achieving green growth in agriculture by reducing emissions and environmental degradation.

Empirical results revealed China had the highest emission-management efficiency (70.4%), while Myanmar had the lowest (30.5%). The results further show that the overall emission efficiency in controlling emissions from agriculture is 52.6%. It also emphasizes that if the regional cooperation bloc can work together with the given set of inputs, the region can further decrease emissions from agriculture by 47.4% from the current level. The calculation also shows that regional cooperation has a positive synergy effect on emissions management for the StEA countries.

A combined index had to be prepared from each country's production management and emission-management efficiency to understand the resultant efficiency toward attaining green growth. In this regard, the multiplicative (geometric aggregation) technique was used to generate the GGIA. The calculation showed that China, Japan, and South Korea have the highest GGIA while Cambodia, Lao PDR, and Thailand have the lowest. The GGIA of the StEA region as one bloc was 66%.

14.5.2 Policy Implications

The analysis presented in this study has several policy implications for strengthening sustainable green growth in the agriculture sector of StEA countries. Information on the production and emission-management efficiencies can help countries have a comprehensive idea about their respective strengths and challenges, which can help them improve their efficiencies. From a regional cooperation perspective, a policy framework based on the analysis would provide wide-ranging tools to manage intra-regional demand and supply of foods more efficiently while complying with the measures necessary for the transition toward low-emission agriculture systems. Obviously, under a regional cooperation framework, countries with higher efficiency in production management should produce more so that resources within the regional bloc are efficiently managed. Higher production under the regional cooperation framework is feasible by accelerating technology transfer, knowledge sharing, and capacity building between high-efficient and low-efficient countries. Institutional settings at the regional level should be strengthened to constantly monitor the level of progress and disseminate adequate policy, rules, and technical support to all member countries. Creating a common fund to finance agricultural green growth projects may also play an important role. In this context, the role of multinational financial institutions like the Asian Development Bank (ADB), Asian Infrastructure Investment Bank, and the World Bank is crucial. Easing trade restrictions on agricultural production inputs may also facilitate efficient production among the countries (Kalirajan and Anbumozhi 2014).

Recollections of Professor Keijiro Otsuka

Keijiro Otsuka, fondly known as 'Kei' among his friends, has always been very keen to introduce 'innovation' in terms of methodology and empirical discussions in his research. He believes in primary data collection and face-to-face interviews with stakeholders. He enumerates clearly the basic sources of economic issues through this approach, which helped him arrive at appropriate models to provide feasible solutions.

I have never seen him with a ‘long face’ when I worked with him from 2001 to 2009 in FASID/GRIPS. He was always cheerful and encouraged his students and colleagues to make a significant contribution to the literature. In this context, Kei has been a ‘nitty–gritty’ researcher and a ‘tactful taskmaster,’ which I learned when we coedited three books and two special editions of *Developing Economies* (2006) and the *Journal of Agricultural and Development Economics* (2005).

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Part III
Transformation of the Rural Economy

Chapter 15
Facilitating Inclusive Use of ICTs in Rural China

Jikun Huang, Lanlan Su, and Xinyu Liu

Abstract The usage of information and communication technologies (ICTs) is increasingly becoming an important driving force for transforming the rural economy in China. Using a unique nationally-representative household survey dataset in 2015–2019, this study documents the overall trends of internet access, computer and smartphone usage, and e-commerce adoption in rural China and examines the main factors affecting farmers' adoption of major ICTs. The results show that the increase in usage of ICTs has been impressive. Empirical analyses suggest that human capital, resource endowment, ICT infrastructure, and neighborhood influence are the main determinants of households' or individuals' adoption of ICTs. However, a digital divide has emerged across regions and among farmers. This study concludes with several policy implications for fostering rapid and inclusive usage of ICTs in rural areas in the coming digital era.

15.1 Introduction

Information and communication technologies (ICTs) have spread globally, but there is a large gap between developed and developing countries. According to 2018 data reported by the International Telecommunication Union (ITU 2018), globally, about 58% of households had internet access at home, almost half of all households had at least one computer, and 76% of the population owned at least one mobile phone. However, the percentages of households with internet access (85%) and a computer (83%) and individuals owning a mobile phone (92%) in developed countries were much higher than the corresponding numbers (47% for internet access, 36% for having a computer, and 73% for owning a mobile phone) in developing countries (ITU 2018). Furthermore, there is also a large gap between rural and urban areas in

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developing countries in terms of ICT diffusion (Nakasone et al. 2014; Deichmann et al. 2016).

China has also experienced a rapid expansion in ICTs and has made great efforts to reduce the gap between rural and urban areas since the early 2000s. Nationally, the internet penetration increased from 16% in 2007 to 70% in 2020. The number of internet users increased from 210 to 989 million, and mobile phone subscriptions rose from 50 to 986 million over the same period (CNNIC 2021). In 2007, the rural internet penetration rate was only 7%, much lower than the 26% urban internet penetration rate. By 2020, while the internet penetration rate (80%) in urban areas was about three times that in 2007, it was eight times in rural areas (56%) over the same period. Facilitating rural ICT development was included for the first time in the Five-Year Plan for the National Economic and Social Development (or the Tenth Five-Year Plan) that was released in 2001. After that, the central and local governments have increased investment in rural ICT infrastructure, broadband village construction, capacity building and training, and policy support for rural e-commerce (Ministry of Agriculture and Rural Affairs 2020).

Driven by the significant increase in internet penetration, e-commerce has also developed rapidly in China. For example, the value of online sales in rural areas rose from CNY 353 billion in 2015 to CNY 1,800 billion in 2020, accounting for about 15% of the national online retail value in 2020 (Ministry of Commerce 2021). In terms of agricultural products, the online retail value reached CNY 398 billion in 2019. Moreover, the Taobao Village model (with a total yearly turnover larger than CNY 10 million on the Taobao platform from operating 100 live online stores and 10% of local households running online stores) that started in 2009 had 5,425 villages in 2020 (AliResearch 2020). Although the share of Taobao Villages in 2020 was less than 1% of total villages (690,000 villages) in China, this share is expected to increase significantly in the future, given its rapid growth.

In the literature on the adoption of ICTs by rural households, there has been an increasing number of empirical studies based on household surveys in many countries. These studies show that human capital, household resources (e.g., access to land and credit, etc.), and local ICT infrastructure are major factors affecting farmers' adoption of ICTs (Aker and Mbiti 2010; Kikulwe et al. 2014; Ma et al. 2018) and e-commerce (Kabango and Asa 2015; Li et al. 2021; Liu et al. 2021). However, there are also concerns about potential inequality due to the uneven spread of ICTs (Guo and Chen 2011; Hartje and Hübler 2017; Leng et al. 2020; Liu et al. 2020; Li et al. 2021) across regions and among the population.

The overall goal of this study is to further examine the major factors affecting rural households' adoption of major ICTs in China. While this is similar to many existing studies, we contribute to the literature mainly in two areas. First, we use a unique dataset on ICT adoption from the primary household surveys (2015–2019) with nationally representative samples in rural China. Second, we pay particular attention to the inequality of ICT adoptions across regions and households within the same village. The results of this study have important policy implications for fostering inclusive usage of ICTs and e-commerce, not only in China but also in other developing countries.

The rest of this paper is organized as follows: Sect. 15.2 introduces the household survey datasets and documents the development trends of major ICTs and e-commerce in rural China. Sect. 15.3 describes the main factors that likely affect the adoption of major ICTs. Sect. 15.4 discusses the empirical models and estimation strategies used in this study, and Sect. 15.5 presents the estimation results. The last section concludes with several policy implications.

15.2 Data

15.2.1 Sampling Approach

To ensure that samples represent rural households in major agricultural production regions in China, we combined three household surveys that used stratified random sampling in ten provinces (Datasets 1a, 1b, and 1c) to form a nationally representative sample (Dataset 1). Dataset 1a covers Zhejiang, Hubei, Guangdong, Shaanxi, Sichuan, and Jiangxi provinces with survey data from 2015 to 2019. Dataset 1b covers Liaoning and Hebei provinces with survey data from 2015 to 2019. Dataset 1c covers Henan and Shandong provinces with survey data in 2015 and 2016. The locations of each surveyed county in the ten provinces are presented in Fig. 15.1.

Datasets 1a and 1b used the same stratified random sampling approach. In each of these eight provinces, all counties were arranged in descending order of gross value of industrial output (GVIO) per capita, then divided evenly into five groups in all provinces, except Jiangxi, which had 12 groups due to more research funding from this province. One county was randomly selected from each group (12 counties in Jiangxi and five counties in each of the other seven provinces). The same procedure was also applied to select two townships from each county based on GVIO per capita, except in Jiangxi, where three townships per county were selected. In each sampled township, one administrative village was randomly selected. Within each village, 20 households (but ten households in Jiangxi) were randomly selected. A total sample of 2,480 households (1,400 $= 20 \times 1 \times 2 \times 5 \times 7$ in the seven provinces and 1,080 $= 10 \times 3 \times 3 \times 12$ in Jiangxi Province) were selected for the survey. The first wave of the survey was conducted in early 2017 with data from 2015 and 2016; the second wave for the same households was conducted at the end of 2019 with data from 2017–2019. In this study, a total of 2,526 households (1,451 in the seven provinces and 1,075 in Jiangxi Province) were actually surveyed. The slightly higher number in the actual survey sample than the designed sample is due to replacing several new households in 2019 for households surveyed in 2017 but could not be followed up in 2019.

Dataset 1c from Henan and Shandong also used a stratified random sampling approach but was based on the area of cultivated farmland per capita instead of GVIO. We ranked all counties' areas of cultivated land per capita in descending order, then all counties were divided evenly into three groups. One county was

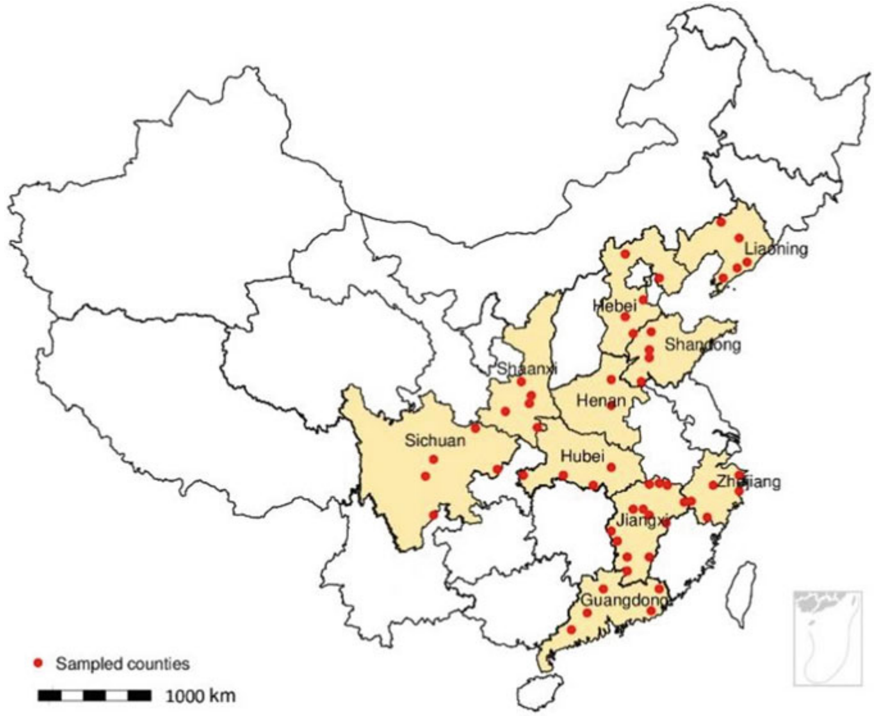

Fig. 15.1 Nationally representative surveys in ten provinces

randomly selected from each group. In each county, two townships were selected using the same procedures, which was also applied to select two villages from each township. Within each sampled village, ten households were randomly selected. A total of 240 households ($10 \times 2 \times 2 \times 3 \times 2$) were surveyed in 2017 for data from 2015 and 2016. Only one household did not complete the survey.

In all surveys, face-to-face interviews were conducted for each village and household. The survey mainly collected information on demographics, internet access, use of computers and smartphones, and agricultural production and marketing. Additionally, village leaders were interviewed to collect information on the infrastructure of ICTs in the village.

Because the surveyed samples differ among provinces, particularly between Jiangxi and the other seven provinces, and over time due to both follow-up and additional new samples, it was necessary to use a sample weight system for generating the whole sample mean and in the regression analysis. Specifically, for the statistics and regression analysis at the household level, the sample weights were calculated based on the number of households surveyed each year in each province. For the statistics and regression analysis at the individual level, the sample weights were calculated based on the number of individuals surveyed each year in each province.

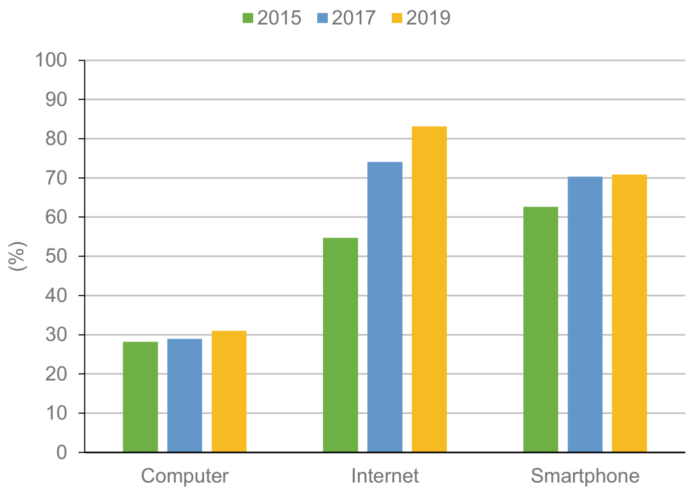

Fig. 15.2 Adoption of three major ICTs by rural households or individuals (2015–2019)

15.3 Adoption of Major ICTs by Rural Households and Individuals

Although there are many ICTs, the main ones used by rural households are internet access, computers, and smartphones. ICT application in e-commerce to sell agricultural products was also examined. Figure 15.2 shows the adoption of the three major ICTs in rural China from 2015 to 2019. Among the three ICTs, the percentage of households with internet access increased faster than households with a computer and individuals with smartphones. By 2019, the percentage of households with computers and access to the internet reached 30% and 83%, respectively; and the percentage of individuals with smartphones reached 71%. Our survey results are consistent with the statistics (measured for the whole population) reported by the China Internet Network Information Center (CNNIC 2021) if the internet and smartphone use in our data were also measured based on household population rather than households or individuals at least 16 years old.[1]

Figure 15.3 shows the adoption of three major ICTs by province from 2015 to 2019. While the adoption rates for all three ICTs had increased in nearly all provinces over time, the level of adoption of computers and internet access differ among the provinces. The percentage of individuals using smartphones did not vary significantly among the provinces.

Households with computers and internet access have increased over time, although this varied among the provinces. For example, even by 2019, less than one-third of rural households had a computer in Hebei, Liaoning, Jiangxi, Guangdong, Sichuan, and Shaanxi, indicating that there is still much room for the diffusion of computers

[1] The working age starts at 16 years according to the Labor Law in China.

Fig. 15.3 Adoption of three major ICTs by province in rural China, 2015–2019

in rural China. A slight decline in the number of households with a computer in Zhejiang and Hubei provinces in 2017 is due to adjusting the samples of these two provinces in the second round of surveys. In terms of internet access, the statistics show that its penetration rates in all surveyed provinces were close to or more than 70% in 2019. The growth rates in Hebei, Guangdong, and Liaoning provinces were relatively higher than those of other sampled provinces from 2015 to 2019.

Despite its rapid development, our survey data show that e-commerce is still not a common marketing channel for farmers to sell their products. In 2015, less than 1% of farmers had sold their products online. By 2019, although the number was more than double, only about 2% of them sold their products through e-commerce. When we asked farmers their most important reason for not using e-commence, about 67% responded that they lacked functional e-commerce skills. About 30% said they did not have storage facilities to keep their produce fresh. The rest said they lacked packaging and marketing skills and noted the high logistics cost. Due to the limited number of observations of farmers using e-commerce in our sample, this paper does not empirically analyze the factors affecting e-commerce adoption in rural China.

15.4 Variables and Descriptive Statistics

In general, variables reflecting the characteristics of individuals, villages, and households are used to explore the major factors that may affect farmers' ICT adoption. The definitions of all variables are shown in Table 15.1.

By comparing official statistics and our data presented in Tables 15.2 and 15.3, we confirm that our samples are representative of the national statistics in rural China. These include the household head's age, gender, education, farm size, and household size (NBSC 2020). According to official statistics, rural nonfarm labor was 41.5% in 2019 (NBSC 2020). Our data show that the percentage of individuals (at least 16 years old) who had nonfarm jobs was 42% in 2019 (Table 15.3).

Our surveyed villages seem to have better infrastructure. Nearly 20% of the sampled villages had at least one business office established by China Mobile, China Unicom, or China Telecom, the three major providers of mobile communication services in rural China. More importantly, the surveyed villages have achieved universal coverage of mobile phone services and broadband internet since 2016.

Table 15.2 shows the descriptive results of ICT adoption at the household level. Generally, there are significant differences in the observed characteristics between adopters and non-adopters of computers and the internet. On average, household heads who adopt the computer and the internet are younger, with more years of schooling, and have work experience in nonfarm sectors. Also, households with more family members, especially members who engage in non-agricultural jobs and cultivate more farmland, show a higher proportion of adopting it. Moreover, the villages' infrastructure and ICT adoption in their neighborhoods positively correlate with the households' adoption of the computer and internet.

Table 15.1 Definitions of all variables used in this study

Variables	Definition
ICTs adoption	
Computer	1 if the household has a computer, 0 otherwise
Internet	1 if the household can access the internet, 0 otherwise
Smartphone	1 if the individual (at least 16 years old) has a smartphone, 0 otherwise
Household head or individual characteristics	
Age	Age of household head or individual (years)
Education	Years of education (years)
Gender	1 if male, 0 otherwise
Nonfarm	1 if engaged in a nonfarm job, 0 otherwise
Household characteristics	
Others_nonfarm	Number of household members engaged in nonfarm jobs, excluding the household head or individuals at least 16 years old
Farm size	Area of cultivated land of the household (hectares)
Household size	Number of household members
Village characteristics	
Neighbor computer	Percentage of sampled households owning computers in the same village (%)
Neighbor internet	Percentage of sampled households with access to the internet in the same village (%)
Neighbor smartphone	Percentage of sampled individuals (at least 16 years old) owning smartphones in the same village (%)
Telecom	1 if there is at least one business office established by China Mobile or China Unicom, or China Telecom in the village, 0 otherwise

Table 15.3 shows the differences in the characteristics between smartphone adopters and non-adopters. Similar findings are shown in Table 15.2 on using computers and accessing the internet by household. There are significant differences in all characteristics (except the existence of a telecom operator) between smartphone adopters and non-adopters. Specifically, individuals with a smartphone are younger, better educated, and employed in nonfarm sectors than those without smartphones. Meanwhile, individuals with more family members engaging in nonfarm jobs and more land also tend to have smartphones. Moreover, the neighborhood effect is a potential enabling factor for individuals' usage of smartphones.

15.5 Model Specification and Estimation

A household's or an individual's adoption occurs when the expected utility of using ICTs (U_{1i}) is greater than the utility without using ICTs (U_{0i}) (i.e., $U_{1i} - U_{0i} > 0$).

Table 15.2 Descriptive statistics on computer and internet adoption at the household level

Variables	Mean	Computer (m = 0.28, SD = 0.45)			Internet (m = 0.74, SD = 0.44)		
Household head characteristics		Yes	No	*T*-test	Yes	No	*T*-test
Age	56.28	53.08	57.53	– 4.45***	54.82	60.56	– 5.74***
Education	6.79	7.86	6.37	1.49***	7.10	5.85	1.25***
Gender	0.98	0.99	0.98	0.01***	0.99	0.97	0.02***
Nonfarm	0.30	0.44	0.25	0.19***	0.36	0.12	0.24***
Household characteristics							
Others_nonfarm	0.92	0.95	0.61	0.34***	0.93	0.35	0.58***
Farm size	0.33	0.37	0.29	0.08***	0.35	0.30	0.05*
Household size	4.25	4.27	3.58	0.69***	4.86	3.29	1.57***
Village characteristics							
Neighbor computer	31.01	43.25	25.66	17.59***	32.03	26.35	5.68***
Neighbor internet	75.78	79.56	74.17	5.39***	81.04	60.01	21.03***
Neighbor smartphone	68.72	71.92	66.82	5.10***	70.12	62.77	7.35***
Telecom	0.20	0.23	0.18	0.05***	0.20	0.18	0.02

Note n = 13,570; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 15.3 Descriptive statistics of smartphone usage at the individual level

		Smartphone (m = 0.70, SD = 0.46)		
Variables	Mean	Yes	No	*T*-test
Individual characteristics				
Age	45.62	39.55	59.77	–20.22***
Education	7.55	8.67	4.92	3.75***
Gender	0.52	0.55	0.46	0.09***
Nonfarm	0.42	0.56	0.09	0.47***
Household characteristics				
Others_nonfarm	0.92	1.06	0.59	0.47***
Farm size	0.33	0.34	0.31	0.03***
Household size	4.25	4.36	4.00	0.36***
Village characteristics				
Neighbor computer	31.01	32.27	28.06	4.21***
Neighbor internet	75.78	77.49	71.79	5.70***
Neighbor smartphone	68.72	70.65	64.21	6.44***
Telecom	0.20	0.21	0.18	0.03

Note n = 45,933; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

The difference between the utility with and without ICT adoption may be denoted as a latent variable ICT_i^*, so that $ICT_i^* > 0$ indicates that the utility of ICT adoption exceeds the utility without adoption. While the utility difference cannot be directly observed, a household's or individual's propensity to adopt ICTs can be expressed in a linearized form as follows:

$$ICT_{ikt}^* = \beta_1 I_{it} + \beta_2 L_{it-1} + \beta_3 V_{it-1} + \varepsilon_{it} \tag{15.1}$$

$$ICT_{ikt} = 1[ICT_{ikt}^* \geq 0] \tag{15.2}$$

where ICT_{ikt} represents the ith household or individual which adopts the kth *ICT* ($k = 1$ or 2 or 3, representing computer use or access to the internet or having a smartphone) in year t. I_{it} is a vector of the household head characteristics when $k = 1$ or 2, and the individual characteristics when $k = 3$; the characteristics of the household head or individual include age, education, and gender. $L_{it\text{-}1}$ is a vector of the nonfarm job of the household head or individual and the household's characteristics in one-year lagged form. The household characteristics include the number of household members engaging in nonfarm jobs, farm size, and household size. $V_{it\text{-}1}$ is a vector of village characteristics in one-year lagged form, including the percentages of households having computers, access to the internet, and whether a telecom office operates in the village. 1[•] is an indicator function, denoting $ICT_{ikt} = 1$ if $ICT_{ikt}^* \geq 0$; otherwise, $ICT_{ikt} = 0$. $\beta_1, \beta_2, and \beta_3$ are the vectors of parameters to be estimated. ε_{it} is a random error term, which is assumed to be normally distributed.

The logit model estimates the above equations with and without the village fixed effect and with and without year dummies. The village fixed effect estimation can control for all time-invariant factors that may affect ICT adoption, and year dummies can control yearly specific impact. To correct the potential estimation bias caused by the different sample sizes among different provinces and over time, the sample weights adjusted by the observations of each province in each year are used in all regressions.

15.6 Empirical Results

Table 15.4 presents the estimation results based on a logit model on whether households have computer and internet access. To check the robustness of estimation results, two alternative specifications considering the year effect and the village fixed effect are estimated: column 2 and column 5 consider the year effect (a dummy for each year), and column 3 and column 6 consider both year effect and the village fixed effect. Generally, the results are consistent among the three estimations. In the rest of the discussion, we will focus on the estimation results in column 3 and column 6.

The estimation results provide strong evidence of the digital divide in age and education. The estimated parameters for the household head's age and education are

Table 15.4 Estimation results of households with computers and access to the internet

	Computer			Access to the Internet		
	(1)	(2)	(3)	(4)	(5)	(6)
Household head characteristics						
Age_{it}	– 0.007*** (0.001)	– 0.007*** (0.001)	– 0.009*** (0.001)	– 0.006*** (0.001)	– 0.007*** (0.001)	– 0.007*** (0.001)
$Education_{it}$	0.012*** (0.002)	0.012*** (0.002)	0.014*** (0.003)	0.009*** (0.001)	0.008*** (0.001)	0.009*** (0.001)
$Gender_{it}$	– 0.102 (0.104)	– 0.104 (0.103)	– 0.118 (0.116)	– 0.009 (0.010)	– 0.012 (0.010)	– 0.014 (0.010)
$Nonfarm_{it-1}$	– 0.033 (0.033)	– 0.037 (0.034)	– 0.048 (0.042)	0.032 (0.019)	0.019 (0.019)	0.016 (0.019)
Household characteristics						
$Others\_nonfarm_{it-1}$	0.040*** (0.005)	0.042*** (0.005)	0.042*** (0.004)	0.050*** (0.003)	0.051*** (0.003)	0.064*** (0.003)
Farm $size_{it-1}$	0.033*** (0.006)	0.033*** (0.006)	0.035*** (0.008)	0.019*** (0.003)	0.017*** (0.002)	0.035*** (0.005)
Household $size_{it-1}$	0.005 (0.005)	0.005 (0.005)	0.017** (0.007)	0.021*** (0.004)	0.022*** (0.004)	0.018*** (0.005)
Village characteristics						
Neighbor $computer_{it-1}$	0.007*** (0.000)	0.008*** (0.000)	0.004*** (0.000)	– 0.000 (0.000)	– 0.000 (0.000)	0.002*** (0.000)
Neighbor $internet_{it-1}$	0.000 (0.000)	– 0.000 (0.000)	0.001 (0.000)	0.006*** (0.000)	0.006*** (0.000)	0.004*** (0.000)
$Telecom_{it-1}$	0.008 (0.017)	0.006 (0.016)	0.003 (0.008)	0.015** (0.005)	0.015** (0.005)	0.038*** (0.010)
Village fixed effect	No	No	Yes	No	No	Yes
Year dummies	No	Yes	Yes	No	Yes	Yes

Note n = 13,570; estimated parameters are marginal effects, standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

statistically significant ($p < 0.01$) for all alternative specifications (row 1 and row 2 in Table 15.4). A one-year increase in the household head's age reduces the probability of households using computers by 0.9% (column 3) and accessing the internet by 0.7% (column 6). One year more of schooling of a household head increases the probability of the household using a computer by 1.4% and access to the internet by 0.9%. These results are consistent with previous findings that younger and higher educated farmers are more likely to adopt ICTs (e.g., Aker and Mbiti 2010; Al-Hassan et al. 2013; Leng et al. 2020).

Table 15.4 also shows that nonfarm employment, farm size, and household size significantly affect the use of computers and the internet by rural households. Nonfarm employment positively affects the use of ICTs (row 5) which can be attributed to the benefits stemming from nonfarm employment, such as improving human capital, enhancing income, and extension of social network (Ma et al. 2018). However, it is interesting to note that the nonfarm employment of the household head does not affect the household's use of the computer and internet (row 4). This may reveal that a rural household's use of the computer and internet is mainly influenced by their children. Additionally, households with more cultivated land are more likely to have computer and internet access. This may be because farmers operating more land have a stronger motivation to improve the efficiency of agricultural production through good use of ICTs (Aker 2011), or they can afford to buy computers and get access to the internet more (Kabango and Asa 2015).

The estimated parameters show that the intensity of using the computer (or internet) by the other households in the village has a significant positive effect on the household's use of the computer (or internet) (rows 8 and 9). These results provide strong evidence for the existence of neighborhood effects and social learning relating to the adoption of ICTs among rural households. Finally, the effect of the presence of a telecom office on households' access to the internet is significantly positive. This indicates that the mobile infrastructure in the villages lays the foundation for the diffusion of the internet in rural areas.

Table 15.5 reports the estimation results of individuals who had smartphones. Similar to the findings of households' usage of the computer and internet, age and education of individuals, nonfarm employment of other family members, farm size of the household, and percentage of farmers who have computers and smartphones within the whole village all have a significant effect on individuals' smartphone use. In addition, the differences between males' and females' smartphone use and those with and without nonfarm experience were also confirmed.

Specifically, on average, the probability of males using smartphones is 5.6% higher than that of females (row 3). Compared to those who do not engage in nonfarm jobs, employment in nonfarm sectors leads to an 8%–9% increase in using smartphones (row 4).

Table 15.5 Estimation results of individuals with smartphones

	(1)	(2)	(3)
Individual characteristics			
Age_{it}	– 0.011*** (0.000)	– 0.011*** (0.000)	– 0.012*** (0.000)
$Education_{it}$	0.015*** (0.001)	0.014*** (0.001)	0.015*** (0.001)
$Gender_{it}$	0.054*** (0.008)	0.055*** (0.008)	0.056*** (0.008)
$Nonfarm_{it-1}$	0.096*** (0.002)	0.089*** (0.002)	0.080*** (0.002)
Household characteristics			
$Others\_nonfarm_{it-1}$	0.006* (0.003)	0.007** (0.003)	0.015*** (0.004)
Farm $size_{it-1}$	0.008*** (0.002)	0.009*** (0.001)	0.010*** (0.002)
Household $size_{it-1}$	– 0.006* (0.003)	– 0.006* (0.003)	– 0.008 (0.005)
Village characteristics			
Neighbor $computer_{it-1}$	0.000 (0.000)	0.000 (0.000)	0.001** (0.000)
Neighbor $smartphone_{it-1}$	0.005*** (0.000)	0.005*** (0.000)	0.005*** (0.000)
$Telecom_{it-1}$	0.014*** (0.004)	0.013*** (0.004)	0.008** (0.003)
Village fixed effect	No	No	Yes
Year dummies	No	Yes	Yes

Note n = 45,933; estimated parameters are marginal effects, standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

15.7 Concluding Remarks

Using a nationally-representative household survey dataset covering 2015–2019, we document the trends of ICT usage in the past five years in rural China, empirically test the main factors affecting farmers' usage of ICTs, and discuss the inequality issues of digital technology adoption in rural China.

The results show that, even though the increase in ICT adoption has been impressive, there is still plenty of room for ICT penetration (particularly computers) in rural China. While e-commerce is emerging and clustering in some economically-developed regions, the average adoption of e-commerce for rural households in China is still very limited. Thus, a digital divide has emerged in rural China.

The econometrical results suggest that human capital (e.g., age, education); resource endowment (e.g., farm size and nonfarm employment); ICT infrastructure; and neighborhood influence are the main determinants explaining a household's or individual's adoption of ICTs.

The results of this study have several policy implications. First, while the spread of ICTs and e-commerce has been rapid and is expected to reshape agriculture and rural development in the future, a more inclusive development strategy should be pursued now. Digital technology can be driven by market forces and further accelerate the diffusion of ICTs in rural areas in the future. Still, without the policies and investment to support those left behind in using digital technology, new inequality will occur in rural areas in the digital era. Second, more support should be provided to disadvantaged rural households and farmers through skills training, social network improvement, farm size expansion of the smallholders, and other capacity-building programs. Particular attention should be given to the older and less educated farmers and those in the less developed regions. Last but not least, investment in ICT infrastructure, enhancement of postharvest facilities, and improvement in logistics for e-commerce in rural, particularly in less developed rural areas, are essential to advance equality in the course of ICT diffusion.

Recollections of Professor Keijiro Otsuka

It is my great honor to participate in this Festschrift to recognize Professor Keijiro Otsuka's contribution to development economics. I first met him in 1989 when I was a PhD student at the International Rice Research Institute. Since then, we have closely kept in touch through various academic activities and conferences. He has also served as an Academic Advisory Committee Member of the China Center for Agricultural Policy (CCAP) and has provided constant support for our research programs since CCAP was launched in 1995. His works on the adoption and impacts of agricultural technology in developing countries have significantly contributed to our understanding of the roles of technology and policy in agricultural development. Thus, I decided to write this paper on facilitating the inclusive use of ICT in rural China, one of the major areas I have worked on recently.

– *Jikun Huang.*

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Chapter 16
EdTech for Equity in China: Can Technology Improve Teaching for Millions of Rural Students?

Cody Abbey, Ma Yue, Guirong Li, Prashant Loyalka, and Scott Rozelle

Abstract Despite major advancements in China's K-12 educational outcomes over the past several decades, large regional inequities in academic achievement still exist, a proximal cause of which are gaps in teaching quality. Although conventional approaches to improving teaching quality for disadvantaged populations have overall been unsuccessful in China (i.e., student relocation to better-resourced urban schools, attracting high-quality teachers to low-resource rural schools, and rural teacher training), technology-assisted instruction may play a role in bridging these gaps. This paper explores why conventional approaches to improving teaching have not been effective in rural China and then describes the potential applications of technology-assisted instruction based on the small but growing body of empirical literature evaluating such interventions in other low- and middle-income countries. The paper concludes that while other (non-tech) interventions have thus far been ineffective at raising teaching quality, China may be uniquely positioned to harness technology-assisted instruction due to a favorable ecosystem for the scaling of EdTech in rural areas, though much more experimental research is necessary to assess which approaches and technologies are most cost-effective and how to best scale them.

16.1 Introduction

Previous literature suggests subpar teaching is a primary reason why rural Chinese students lag behind academically. In this paper, we initiate an investigation into the potential of educational technology (EdTech) to increase teaching quality in rural China. First, we discuss why improvements in conventional teaching approaches in remote schools are infeasible in China's context, referring to past research. We

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then explore the capacity of technology-assisted instruction to improve academic performance by examining previous empirical analyses and discussing why China might have especially favorable conditions for implementing technology-assisted instruction at scale compared to most other low- and middle-income countries. This paper lays the foundation for a long-term research investigation into whether EdTech can narrow China's education gap.

16.2 Why Poor Teaching is Widening China's Education Gap

In recent decades, as China's economy has grown exponentially, China's education system has achieved a number of notable successes. The adult literacy rate increased from 66% in 1982 to 97% in 2019 (UNESCO 2019a). Students from large cities in China have performed among the best on international standardized evaluations, such as the Organisation for Economic Co-operation and Development's (OECD) Program for International Student Assessment (PISA). In fact, on the 2012 PISA, students from Shanghai, China, outperformed students from 64 other countries in all subject areas tested (OECD 2014). Overall school access has also increased dramatically over the past decades, as nearly all (99%) of China's children—both urban and rural—are finishing primary school, and all children are entitled to nine years of free schooling (which includes primary and lower secondary school in China) (Chung and Mason 2012). Since 2005, the share of youth attending upper secondary school (grades 10–12) has also increased rapidly (Bai et al. 2019).

Despite these accomplishments, large disparities in academic performance still exist between China's urban and rural youth. Gaps in school performance between China's urban and rural children emerge as early as primary school (Zhang et al. 2015) and have been shown to exist not only in the national aggregate but also at the provincial level (Xiang et al. 2019). Differences in achievement on international assessments make these gaps even more apparent. While Shanghai students have performed among the top in the world on standardized tests, students from lower-income, inland, and predominately rural provinces have performed among the lowest (Gao et al. 2017). This is worrisome as rural children make up approximately 70% of China's school-aged population (National Bureau of Statistics 2020).

As a result of academic performance disparities, there are significant differences in educational attainment between students across urban–rural and regional boundaries. For example, only 60% of students from poor counties in Ningxia Province take the high school entrance exam, while almost 100% of students from non-poor counties do (Loyalka et al. 2017). Without sufficient years of quality education, rural students may not be able to develop the human capital needed to succeed in the knowledge economy (Wang et al. 2018).

Research in recent years has shown many reasons why rural students in China struggle in school. For example, despite substantial improvements over the past few decades, schooling facilities in rural areas are still worse than in urban areas (Wang et al. 2017; Yang et al. 2013). Urban parents usually have attained a higher level of education and have more time and ability to help their children with their studies (Huang and Du 2007). Average incomes in urban areas are more than 2.5 times higher than those in rural areas, so urban families also have more resources to invest in their children's education (NBS 2020). Furthermore, health problems among rural students negatively impact their academic performance. Specifically, studies have shown that, at least over the past decade, conditions such as anemia (Li et al. 2018), intestinal worms (Liu et al. 2017), and uncorrected visual acuity (Ma et al. 2014; Nie et al. 2018) negatively affect the performance of students in rural schools.

Among the most important factors driving low student performance may be the poor quality of teaching received by rural children. The close relationship between teacher quality and student outcomes has been demonstrated in numerous studies in the international literature (Boyd et al. 2008; Kane et al. 2006; Sanders and Rivers 1996; Goe 2007; Rice 2003; Rockoff 2004; Hanushek 2011). In China, as well, research has demonstrated the importance of teacher quality for student learning (Chu et al. 2015; Park and Hannum 2001; Zhang et al. 2018) and the poor quality of teaching in rural areas (Niu 2009; Liu and Onwuegbuzie 2012; Zhang and Campbell 2015; Chung and Mason 2012).

While teacher quality is key in any effort to enhance student performance, the literature has shown that the teaching received by rural students in China lags far behind that received by urban students. This raises several questions: What are conventional ways—approaches tried in other contexts—to resolve a school system's teaching quality problem? Have these ways worked in rural China, and why or why not? If not, are there alternative ways of teaching rural students with the assistance of technology that has worked in other contexts, and would these be viable approaches in rural China?

The overall goal of this paper is to seek out answers to these questions. First, we will review common approaches to improving teaching quality for disadvantaged student populations and discuss why they may not work in China's context. Second, we will explore the existing international literature for the potential roles of EdTech in addressing this gap.

To meet these objectives, we will use the following strategy. First, we will examine the existing literature on three different strategies that educators in other nations (and China) have used to address the needs of rural students and provide evidence for why such approaches have not been universally effective in rural China. Second, we will explore analyses of the potential of the newly-emerging EdTech sector to improve student outcomes, hypothesizing why large-scale adoption in low-resource areas of developing countries is rare and why China may be uniquely advantaged to harness EdTech for improving instructional quality at scale.

16.3 Traditional Ways to Improve Teaching: Can They Work in Rural China?

How then can China improve the quality of teaching for rural students? In theory, three traditional solutions have been used internationally that China could implement, but due to structural and political barriers, they are either not feasible or have been tried and failed. These three traditional solutions are (1) to allow children to migrate to urban areas to access better schooling; (2) to attract well-trained, well-educated urban teachers to rural schools; and (3) to raise the quality of rural teachers through teacher training or professional development programs.

16.3.1 Rural–Urban Migration

In some countries, the easiest solution is for children in low-resource school districts to migrate to more developed areas to access higher-quality education (Echazarra and Radinger 2019; Crowley 2003; Deluca and Rosenblatt 2010). In China, however, moving rural students to city schools to access higher-quality teaching is not feasible for most rural families. Of course, as in other countries, those who wish to move to cities for their children's education often face financial barriers due to the huge urban–rural income gaps that exist in China. However, even for those who can afford urban housing and living costs, rural families face administrative restrictions in the household registration, or *hukou,* system. Under the hukou system, a person's access to social services—including public education—is tied to their hukou registration (which is inherited at birth). As a result, those children with rural hukous have historically been unable to legally enroll in urban primary schools (Chan and Buckingham 2008). Although policy shifts at the national level in recent years have mandated that local authorities provide free education to rural migrant students, schools in some—especially larger—cities continue to impose an array of difficult-to-fulfill administrative and academic requirements that can prevent migrant students from attending at all (UNESCO 2019b).

16.3.2 Teacher Relocation

With rural children unable to access the higher-quality educational resources of urban areas, another approach to reducing educational disparities between urban and rural areas could be to attract high-quality teachers from urban areas to rural schools (Roberts 2004; Harmon 2001; Hudson and Hudson 2008; McEwan 1999; Cobbold 2006). Starting in 2007, due to a perceived shortage of the supply of high-quality teachers in rural areas, China's Free Teacher Education (FTE) program offered qualified students at six of the top normal universities in different parts of China a package of financial benefits, which included tuition exemption for a degree in teaching, free accommodation, and a monthly stipend (MOE 2007, 2018). While ambitious, according to the literature, the FTE program has so far failed in its key goal of attracting teaching majors at high-quality universities to work in rural schools after graduation, partially due to negative attitudes of FTE students toward the subpar working conditions, remote locations, and lower pay compared to urban teacher positions (Fu and Fu 2012; Shang 2017; Zhou 2010; Li et al. 2011; Shang and Yu 2018; Wang and Gao 2013; MOE 2005, 2006; He and Wang 2016; Li 2010). Although recent adjustments to the policy have attempted to address some of these issues, such as by shortening the mandatory period of service (MOE 2018), so far, it is too early to tell whether such revisions will improve outcomes.

16.3.3 Teacher Training

Considering the restrictions barring the enrollment of students in urban schools and the reluctance of urban teachers to move to rural areas, a third approach to improving educational outcomes for rural students is teacher training programs. Initiatives to train teachers have been implemented elsewhere to varying degrees of success (Yoon et al. 2007; Gersten et al. 2014; McEwan 2015; Popova et al. 2018), while in China, the literature generally indicates null impacts on learning. In one study of Beijing migrant schools by Zhang et al. (2013), the researchers conducted a randomized controlled trial (RCT) that measured the impact of an intensive, short-term in-service teacher training program on teacher performance and student achievement. The results displayed no significant program impact on either teachers' pedagogical practices or students' test scores. In another province-wide study of rural schools in central China, Loyalka et al. (2019) evaluated the effectiveness of the National Teacher Training Program (NTTP), ultimately finding no impacts on student academic performance or teaching approaches. The results of Loyalka et al. (2019) were basically supported by Lu et al. (2019), who also evaluated the impacts of the NTTP and concluded that the program may have even negatively impacted the performance of students on a standardized math test—at least in the short-run. The overly theoretical content and rote delivery methods of the programs, the busy schedules, and poor baseline content knowledge among teachers were all reasons cited for the lack of impact.

In conclusion, the three traditional approaches to improve teaching quality have not been successful thus far in rural China. First, barriers with historical foundations in a discriminatory residence registration system have prevented children from rural areas from attending higher-quality public schools in cities. Second, policy initiatives to bring new graduates to rural areas have failed to do so despite employing a host of incentives and contractual obligations. Finally, small-scale, independently-run, and nationwide, government-run professional development programs have not been able to improve the pedagogy of rural teachers for a number of reasons, in particular, the lack of emphasis on content and techniques easily applied to the classroom and misalignment with teachers' baseline knowledge and schedules. In light of these challenges, we now turn attention to a fourth approach that has only become practical in recent years: using new technologies to enhance teaching quality in rural China and, in turn, systematically raise student academic performance.

16.4 The Potential of EdTech to Improve Teaching and Achieve Equity

With rural children unable to migrate to cities for better education, urban teachers unlikely to move to rural areas, and mediocre returns (if any) on the attempted teacher training programs, are there other options for improving teaching quality in rural China? In recent years, one opportunity that has arisen is using new internet- and mobile-based technologies to improve the educational experience. This section provides relevant background on EdTech in general and describes different types of EdTech that could be potentially used as alternative solutions to poor teaching in remote, rural schools, focusing specifically on technologies for improving classroom teaching.

16.4.1 Introduction to EdTech

EdTech can be broadly defined to include all technologies used in education. This comprises hardware, software, internet connectivity components, and the content delivered through these platforms (J-PAL 2019; Bulman and Fairlie 2016). While there are many goals and uses of EdTech, studies in the economics of education generally focus on how technology may or may not impact academic outcomes in major subject areas, such as math or language.

One unifying theme in the evaluation of EdTech effectiveness is that the use of technology is placed in the context of educational production functions commonly discussed in the economics literature. Investment in computer hardware, software, and connectivity may offset other inputs that affect student achievement in the context of the household and the school. Likewise, time spent using computers offsets other educational or recreational activities. Carefully considering how technology use complements or crowds out other investments is crucial to conducting a cost/benefit analysis of introducing new technologies in education and understanding whether EdTech will serve to narrow or exacerbate educational disparities.

Several past reviews of EdTech have categorized EdTech innovations into different modes or approaches, each of which attempts to intervene in a different part of the learning process (Bulman and Fairlie 2016; Escueta et al. 2017, 2020; Rodriguez-Segura 2020). The primary modes with some evidence of effectiveness include software packages that allow students to engage in self-led learning in specific subjects (computer-assisted learning); technology-enabled behavioral interventions, such as text-messaging campaigns that aim to provide teachers, parents, or students with information or incentives; and technologies that aim to directly support teacher pedagogy. In line with the scope of the current study, we will focus on this third category of EdTech interventions ('technology-assisted instruction'), particularly those that can enhance and transform classroom instruction in K-12 education.

16.4.2 Types of Technology-Assisted Instruction

Nowadays, in places that have achieved broad access to hardware and internet connectivity, there are a wide variety of digital resources available to teachers that can be used to improve classroom pedagogy. Because EdTech tools and approaches are so wide and varied, to identify those that can be helpful in specific settings to address specific problems, it is important to understand both the functions of different EdTech tools and carefully identify strategies for using them that can most effectively improve student performance.

Previous scholarship has sought to identify different frameworks to better understand the functions of these tools. One recent framework, the substitution augmentation modification redefinition (SAMR) model, developed by Dr. Ruben Puentedura, divides classroom technology integration into four different categories: (1) substitution, (2) augmentation, (3) modification, and (4) redefinition. These categories differ mainly in the degree to which they alter the educational process. For example, while those technological tools that 'substitute' or 'augment' merely enhance existing tasks (for example, by improving the efficiency of grading or the efficacy of feedback), technologies that 'modify' or 'redefine' can fundamentally transform existing tasks to create previously inconceivable ones (e.g., allowing students to learn a foreign language by communicating with native speakers over the internet) (Puentedura 2014).

Of the many forms of technology-assisted instruction, remote instruction (also often referred to as 'distance learning' or 'long-distance learning') has become one of the major foci of research since the 1980s. Remote instruction uses physical technology and educational processes to give access to students when they are removed from the source of instruction and resources by either space or time (Cavanaugh 2001). Beginning in the 1990s, it became increasingly common for distance learning to be conducted online instead of on radio or television (Means et al. 2009).

Remote instruction conducted online can be further split into two types: asynchronous and synchronous (Wicks 2010; Hrastinski 2008). Asynchronous online learning is separated by time. The teacher(s) and the student(s) are able to operate separately, as they do not need to be online at the same time. In this form of learning, students can watch pre-recorded videos of the distance teacher and communicate with the teacher via email and discussion boards. The obvious advantage of asynchronous online learning is removing the need to operate simultaneously. However, this also raises the concern that the student may lack direct or sustained communication with a teacher and fellow students, reducing their feeling of belonging to a learning community. Such communities are essential for collaboration and learning (Hrastinski 2008).

On the other hand, synchronous online learning requires the teacher(s) and the student(s) to be online simultaneously, interacting in real-time. It commonly utilizes media, such as live video and chat. While this ensures that teachers and students can engage in more direct communication closer to traditional face-to-face (F2F) instruction, an obvious practical drawback is the need to be online simultaneously (Chen et al. 2005).

Nowadays, different types of online learning are being blended together with F2F approaches to transform the teaching and learning process. One example of this is the flipped classroom. This model received its name for reversing the traditional educational process that required students to attend an F2F lecture in the classroom (the group setting) and then practice what they learned at home (the individual setting). Instead, the flipped classroom model requires students to view an asynchronous lecture video at home before attending class. Then, in the classroom, students work in groups to practice and master the material while the teacher is free to walk around the room and provide guidance (Delgado et al. 2015). In recent years, the flipped classroom model has received extensive attention in the media and scholarly communities (Tucker 2012; Gilboy et al. 2015; Strelan et al. 2020).

16.4.3 Evidence of Impacts on Academic Performance in High-Income Countries

Does EdTech work inside or outside the classroom to improve students' academic performance? Even more than a decade ago, there was already a large body of literature examining the relationship between technology-assisted instruction and student performance (Cavanaugh 2001; Bernard et al. 2004; Zhao et al. 2005; Means et al. 2009), though findings from the body of technology-assisted instruction research before the turn of the century appear to be largely inconclusive (Trucano 2005). Beginning in the '00 s, a more rigorous body of research gradually began to emerge with the goal of evaluating the effectiveness of EdTech, with some modest evidence of its benefits. Two of the meta-analyses that specifically looked at K-12 education in this period, Cheung and Slavin (2013), found some evidence of a small positive effect (+0.15–0.16 SD) on reading and math achievement in comparison to traditional instruction. Like Trucano (2005), however, they acknowledged that more rigorous studies often had smaller and less significant effect sizes. Escueta et al. (2020) reviewed the literature on online courses and found that while purely online instruction has resulted in worse learner outcomes than F2F instruction, blended instruction can potentially match the effectiveness of F2F instruction. However, an important caveat is that the literature they reviewed almost entirely focused on online courses for college students. Recent evidence of learning losses during school closures in the COVID-19 pandemic generally supports the view that purely online instruction delivered to students at home is not as effective as F2F or blended instruction in school for K-12 students (Engzell et al. 2020; Kuhfeld et al. 2020), though these were not rigorous evaluations of specific in-school interventions.

Overall, the body of literature that has formed on this topic in developed countries does not provide convincing evidence about whether technology integrated into the classroom impacts student performance. This is partially due to inadequacies in most previous studies' experimental and methodological designs, making it difficult to rely on their results. Another concern is that most research has focused on post-secondary education, which is not necessarily applicable to the K-12 environment. Even when looking past these limitations, there is no consistent trend among past meta-analyses regarding whether technology-assisted instruction is more effective than traditional classroom learning. At the very most, there may be some evidence that blended learning has more promise than pure online learning (Zhao et al. 2005; Means et al. 2009; Escueta et al. 2017). In addition, for those studies that do report positive impacts, it is often difficult to ascertain whether this was due to increased instructional time or the technology itself. In a rapidly developing sector such as EdTech, the existing body of literature will need to be frequently built upon to keep up-to-date with the most current technologies.

16.4.4 Previous Research in Low-Resource Contexts of Low- and Middle-Income Countries

Provided that there is an effective model available for implementing and scaling technology-assisted instruction, it might potentially improve educational outcomes for students in isolated, poorly-resourced areas. For instance, with remote instruction, neither the students nor the teachers are required to physically relocate while still matching skilled educators with the students who need them the most. Although these interventions may not have had consistent positive impacts in high-resource settings, it is possible that in poorly-resourced schools, the teaching and academic performance are low to such a degree that EdTech could make a significant difference in outcomes. Many studies in the international literature have raised the possibility of EdTech's potential in this regard (Hannum et al. 2009; Sattar 2007; Sundeen and Sundeen 2017; Barker and Hall 1994; Sharma 2003; World Bank 2021).

In recent years, the evidence base of technology-assisted instruction's effectiveness in low-resource contexts is growing, though still nascent. Rodriguez-Segura (2020) reviewed the literature on EdTech effectiveness in developing countries and found two studies that evaluated synchronous remote instruction delivered via satellite in rural areas, including one at-scale experiment in India involving over 2,000 schools (Naik et al. 2020) and another large-scale experiment in Ghana in 77 schools (Johnston and Ksoll 2017). Both RCTs found evidence of effectiveness for improving student learning outcomes compared to normal F2F instruction. Although the authors of the Ghana study noted that the program was quite costly, especially concerning upfront fixed costs (including installing the satellite dishes and equipment in the schools), Naik et al. (2020) reported that in India, when implemented at scale, the program was highly cost-effective (with an additional cost of USD 16.7 per year). There has also been some evidence of the effectiveness of using pre-recorded (asynchronous) lectures in the classrooms of low-resource areas in both Mexico (Borghesan and Vasey 2021) and Pakistan (Beg et al. 2019). The few large-scale evaluations of technology-assisted instruction in China have thus far employed primarily quasi-experimental designs (Bianchi et al. 2020; Clark et al. 2021), and randomized experiments will be necessary to understand which approaches are most cost-effective in China's rural areas.

16.4.5 Challenges to the Scaling of EdTech in Low-To-Middle-Income Countries (LMICs) and China's Unique Potential

Considering the positive effects of these past interventions and the need for higher-quality teaching in most low-resource areas, why have there been relatively few efforts to investigate and scale the use of technology-assisted instruction in low-resource areas of most LMICs? As alluded to in Johnston and Ksoll (2017), a major reason is that many developing countries still do not have the necessary information technology (IT) infrastructure. Although the required computer-to-student ratio for remote instruction is relatively low compared to other interventions like computer-assisted learning, the purchasing of the equipment and cost of installation (in addition to satellite technology or broadband internet, as well as software maintenance) may still be too high in some contexts (Sundeen and Sundeen 2017). Other factors that may hinder the implementation and scaling of EdTech include a lack of relevant education policy and vision set by the government, an insufficient supply of EdTech products and services in the market, and low levels of human capacity (e.g., educators, NGOs, and on-the-ground leadership that can implement the interventions and ensure that they are sustainable) (Omidyar 2019).

China, however, may be an exception to the limitations described above. Over the past several decades, the country has made substantial investments into the IT infrastructure of schools to equip the large majority of classrooms (including in rural areas) with computers, projectors, and internet access (CNNIC 2018; Bianchi et al. 2020). This is partially thanks to China's ambitious policy agenda, which has highlighted EdTech as an integral part of its strategy to improve learning for the millions of students in rural areas that receive poor teaching (Zhao and Gan 2017; MOE 2019) and which has become further emphasized following school closures during the COVID-19 pandemic (MOE 2021). China is also home to some of the largest EdTech companies in the world, and in 2019 private investment in the EdTech market surpassed USD 4.4 billion (Omidyar 2019). Many NGOs and corporate social responsibility departments of companies have experimented with the use of remote instruction in rural schools, and the government is now piloting the use of the dual-teacher model (in which a high-quality remote teacher cooperates with a local classroom teacher to deliver instruction) in provinces like Zhejiang (Xinhua News 2019). Finally, although China has had difficulty attracting high-quality teachers to rural areas, it does not generally face the barrier of teacher absenteeism like in India (Duflo et al. 2012) and South Africa (Bipath and Naidoo 2021), thus enabling it to have adequate levels of human capacity to implement EdTech in schools (as long as adequate training is provided).

For these reasons, it appears that China has a favorable ecosystem to facilitate the scaling of EdTech interventions, though rigorous experimental research will first be necessary to establish a roadmap for the future. Just as prior RCTs have pointed to the effectiveness of supplementary computer-assisted learning in rural China for remedial tutoring (Mo et al. 2015), there is a need for rigorous experimental research to evaluate the effectiveness of technology-assisted instruction. To understand how technology-assisted learning can be implemented most sustainably to improve learning, the goals of such a research agenda should include measuring which approaches are most cost-effective over time, exploring what levels of intervention intensity (i.e., minutes per day) lead to the greatest impacts and how these interventions should be integrated into classroom instruction (i.e., supplement or substitute existing learning inputs), how impacts may vary across different regions and student characteristics, and how the effects of these interventions on student outcomes (including outcomes related to both academic performance and social-emotional development) can best be monitored from year to year.

16.5 Conclusion

By drawing from the existing academic literature, reports from the public and private sectors, and independently acquired data from the field, we have explored the potential of using technology-assisted instruction to improve teaching in China's rural areas. Like in other contexts, teaching quality is a major determinant of children's schooling outcomes in China, and regional disparities in teaching quality are a proximal cause of the urban–rural educational achievement gap. As traditional methods to improve teaching—including student migration to the cities, attracting quality teachers to rural areas, and teacher training—appear to have fallen short in China, a significant role for technology may exist. Although a small but growing body of evidence indicates the effectiveness of technology-assisted remote instruction (particularly high-quality live-streamed or pre-recorded remote instruction delivered in class during the school day), most developing countries have yet to harness such technologies to provide quality education to disadvantaged learners at scale. There is reason to believe that China is uniquely positioned to successfully implement and scale up technology-assisted interventions due to its adequate infrastructure in rural areas, ambitious policy initiatives, and large EdTech market. Although China appears well-positioned to scale technology solutions to address problems of equity in education throughout the country, more rigorous experiments will first be necessary to understand which approaches are most effective for reaching the tens of millions of students in rural schools.

Recollections of Professor Keijiro Otsuka

I was first introduced to Keijiro Otsuka, who I know simply as Kei, by my Cornell Ph.D. advisor Randy Barker when Kei was at the International Rice Research Institute. He and his group at that time then introduced me to Jikun Huang, who was also a PhD student, and the foundation of my career was established. Over time, Kei and I met often … in Japan, in the US, and in meetings around the world. We have met and worked as collaborators, colleagues, and friends. The breadth of his work is amazing. He is one of those rare scholars who can work on many different areas of economic development during his career and make an impact in all of them. I am proud to be able to participate in Kei's Festschrift. Congratulations to you, Kei! – *Scott Rozelle.*

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Chapter 17
Mobile Revolution and Rural Development

Tomoya Matsumoto and Ggombe Kasim Munyegera

Abstract Mobile phones have spread rapidly over the last two decades and are now being used even in rural areas of low-income countries, where the poor are concentrated. The number of mobile phone subscriptions per 100 people in the Sub-Saharan Africa region went from 1.7 in 2000 to 82.4 in 2018, meaning that mobile phones have spread to almost all regions and all social classes. The widespread use of mobile phones has made it possible to deliver voice and text information to remote areas at a low cost and has also triggered a variety of services using mobile phones as a platform. Particularly in Sub-Saharan Africa, electronic payment services on mobile phones or 'mobile money' rapidly spread and changed people's lives. This significant change involves not only the urban wealthy but also the rural farmers who previously had little access to financial services. This essay summarizes the findings from the authors' recent research on the impact of the mobile revolution on the lives of rural residents in developing economies.

17.1 Introduction

The African continent, where the world's poorest countries are concentrated, has experienced the rapid spread of mobile phones over the past two decades. According to the World Development Indicators published by the World Bank, mobile phone subscriptions per 100 people in Sub-Saharan Africa have increased from 1.7 in 2000 to 93.6 in 2020. This significant change implies that mobile phones are rapidly penetrating almost every region and social class.

The widespread use of mobile phones has made it possible to deliver voice and text information cheaply, remotely, and instantly, and triggered the emergence of various services using mobile phones as a platform. In particular, mobile money services

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and electronic payment services using mobile phones have been spreading quickly in Sub-Saharan Africa and changing people's lives. This change affects the wealthy in the cities and smallholder farmers in remote areas who have minimal access to traditional financial services. Mobile money enables many more rural residents in developing countries to remit and receive money, make deposits, and borrow cheaply and conveniently.

Most people in Sub-Saharan African countries have been left in financial exclusion, having very limited access to formal financial services provided by banks and other financial institutions. This is due to, among other constraints, high transaction costs, including fees for opening and maintaining accounts and the transportation cost to avail of the service. Under such circumstances, rural residents cannot save and invest effectively or borrow at low-interest rates. As a result, they have limited risk-coping measures and, hence, temporary shocks, such as bad weather or illness, often negatively and severely affect their livelihood and sometimes force them to sell their productive assets or discontinue educational investment for their children. Such disinvestment has a long-term negative influence on people's welfare. Consequently, people lose the chance to escape from the poverty trap. So, financial exclusion is one of the causes of chronic poverty. However, the dissemination of mobile phones and the accompanying development of new information and financial services, the 'mobile revolution,' has dramatically changed the situation.

This essay will report on the recent development of mobile phone networks and related services and their consequences, mainly focusing on the authors' empirical research in developing countries.

17.2 Rapid Dissemination of Mobile Phones in Africa

As researchers on rural economies in Sub-Saharan African countries, we have witnessed dramatic changes in the social and economic environment in the last two decades. The most significant change that we observed could be the development of mobile phone networks and the widespread use of mobile phones. Currently, mobile phone networks have covered almost all areas of human activity. Indeed, our research sites in rural communities in East Africa are mostly covered. We can communicate with the village leaders and other informants in advance to make an appointment or update the local information. In the past, there was no way to contact village leaders without visiting their villages, and we often failed to meet the persons of interest in the target villages. With mobile phones, fieldwork has become much easier and more efficient than before.

The authors have been working on a research project constructing longitudinal household survey data in three East African countries (Kenya, Uganda, and Ethiopia), known as the Research on Poverty, Environment, and Agricultural Technology (RePEAT) project.[1] The project focuses on rural residents in those three countries

[1] Yamano et al. (2011) describe the details of the RePEAT project.

and covers the period of the mobile revolution in the last two decades. According to the RePEAT data, Kenya has the highest mobile phone ownership rate (i.e., the percentage of households where at least one family member owns a mobile phone), which increased from 13% in 2004 to 93% in 2012 and up to 99% in 2018 among our sample households in rural communities. In Uganda, the rate increased from 4% in 2003, 73% in 2012, and 95% in 2015. In Ethiopia, although it is a little behind the curve, the rate increased significantly from 0% in 2004 to 48% in 2014. The speed at which mobile phones have been spreading shows how great the benefits of mobile phones are.

17.3 Mobile Phone Penetration and Its Influence on Markets

Improved access to information infrastructure in wider areas, including rural villages, has led to significant changes in the patterns of agricultural production and marketing behavior of smallholder farmers. When information can be exchanged at a low cost, transaction costs for buying and selling agricultural products shrink, and producers in remote areas, who previously could not profit from trading, have started participating in market transactions, implying expansion of the market economy through the mobile phone network. Muto and Yamano (2009), a study using the RePEAT data of the Ugandan survey, found that farmers in remote areas, who had been engaged in almost subsistence farming, started selling their products through markets where the mobile network coverage expanded. They started selling more particularly perishable agricultural products, such as bananas. Through fieldwork, we also observed that small-scale farmers in Kenya have begun producing new commodity crops, such as fruits, vegetables, and fresh flowers, for urban supermarkets and exports, which would not be possible without reducing transaction costs because of mobile phone communication with traders.

The expansion of mobile networks broadens the market economy to more remote areas by reducing transaction costs and integrating neighboring regions' fragmented local markets. When markets in the different regions are separated due to high transaction costs, commodity prices are determined by each region's supply and demand conditions. However, as they are integrated, the supply and demand conditions in the larger integrated market determine commodity prices. Thus, market integration reduces price fluctuations. In addition, mismatches between supply and demand that cause unsold goods or shortages will be reduced.[2] Therefore, market integration is generally desirable for both producers and consumers because they lead to more efficient resource allocation and reduce the risk of price fluctuations.

[2] Jensen (2007) and Aker (2010) clearly show that the market integration of local markets through mobile network expansion reduces commodity price fluctuation and eliminates price disparities between localities in India and Niger, respectively.

Moreover, market integration through improved information flow by mobile network development is strengthened by improving logistics through transportation infrastructure. As the transportation infrastructure has considerably improved in many Sub-Saharan countries (Kiprono and Matsumoto 2018), the gain from the information infrastructure improvement would be more prominent. This dramatic change in markets has been happening in many Sub-Saharan African countries through the mobile revolution.

17.4 Variety of Services Using Mobile Phones as a Platform

Mobile phones are used as a tool for communication and as a receiver for various services. Public organizations have offered support, and private companies have offered commercial services using the short message service (SMS). In the health sector, several healthcare-related SMS services are provided. For instance, in Kenya, Malawi, and South Africa, those infected with HIV/AIDS get SMS messages indicating the type and timing of their retroviral therapy medication. The Babyl platform allows patients to register, book appointments, and receive prescriptions and examination results via mobile phone in Rwanda.[3] In agriculture, information service companies provide subscribers the price information of agricultural products in the market and agricultural technical guidance via SMS (Aker and Mbiti 2010).

Mobile money is the most revolutionary service among those using mobile phones as a platform.[4] This electronic payment service allows users to exchange money with individuals on mobile phones without having an account at a financial institution. Indeed, even those without a mobile money account can send and receive money via shared phones. Interestingly, Sub-Saharan Africa is the region where mobile money is most prevalent globally. In 2014, 12% of adults in Sub-Saharan Africa had a mobile money account, whereas only 2% did on the world average. Moreover, mobile money account owners in Sub-Saharan Africa have grown to 21% by 2017. Nearly half reported owning a mobile money account but no other financial institution account (Demirgü-Kunt et al. 2018). Among Sub-Saharan countries, Kenya is the most advanced in terms of mobile money users, where 73% of adults have a mobile money account. Uganda and Zimbabwe follow, where about 50% of adults had an account in 2017.

In Kenya, Safaricom, the biggest mobile network operator (MNO), launched its mobile money service in March 2007. M-Pesa (M stands for mobile, Pesa for money in Swahili) quickly spread nationwide as a means of depositing and transferring money, owing to its low transaction fees and the convenience of making monetary transactions with simple operations on mobile phones. Other MNOs followed suit,

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[3] The detail is given in the following URL: https://rdb.rw/government-of-rwanda-babyl-partner-to-provide-digital-healthcare-to-all-rwandans/.

[4] Jack and Suri (2013) and Suri and Jack (2016) empirically identified the positive mobile money impacts on risk coping and poverty reduction in Kenya.

and there have been multiple companies offering mobile money in Kenya, although M-Pesa has been overwhelmingly dominant.

An account can be opened in a matter of minutes at M-Pesa outlet counters in town, free of charge, by bringing your ID card. Users can also make deposits and withdrawals there (or at automated teller machines or ATMs, but only in urban areas). Once users deposit a positive balance on their accounts, they can make money transfers easily and quickly by operating a simple app embedded in the memory of the mobile phone SIM (subscriber identity module) card. They have to enter the recipient's phone number, the amount of money to be transferred, and the PIN. When completing a transaction, they immediately receive a confirmation SMS on their phone, indicating the amount sent and the remaining balance. This process is so secure that it is indeed rare to lose money either by the customer or the clerk at the outlet. Furthermore, users need to present their photo identification at the mobile money outlet counter to withdraw cash from their account. So even if their mobile phone is stolen or lost, there is little risk of money on the account being withdrawn by someone else. Thus, many people use their mobile money accounts to protect their money. For instance, long-distance travelers deposit cash into their mobile money account before departure to avoid carrying cash while traveling and reduce possible theft risks. In general, people have very high trust in mobile money services. From a gender perspective, mobile money often provides a safe platform for women to save their money privately without spousal interference. This increases their confidence to save and increases their access to financial services.

17.5 Spread of Mobile Money in Rural Economies

The rapid spread of mobile money in rural Kenya in a short period is due to the improved accessibility of such services through the enrichment of mobile communication and financial infrastructure and has a lot to do with the lifestyle of the rural residents. Many rural residents in Kenya are smallholder farmers engaging in settled agriculture. Since they own only small parcels for farming, it is common to send their family members, typically adult males, to towns and cities for earnings during off-farming seasons, while the remaining adults take care of their house and children.[5] For such migrant workers, mobile money has become indispensable as a means of remittances to families at home. Before the advent of mobile money services, the only ways to send money home were wire transfers handled at post offices or hand-carried by acquaintances or the migrants themselves when they returned home. Although there used to be high risks of remittance money being lost and stolen, such risks have been eliminated by mobile money services. High demand for a remittance measure

[5] According to the RePEAT Kenya survey in 2012, the average landholding is 1.6 ha, and the proportion of households with at least one migrant worker is 0.59 (Kiprono and Matsumoto 2018; Mugizi and Matsumoto 2020).

and lack of alternative financial channels can explain the dramatically rapid dissemination of mobile money in Sub-Saharan Africa and South Asia, while penetration has been modest or slow in other parts of the world. Indeed, the RePEAT survey in Kenya, representing the rural population, shows the rapid dissemination of mobile money; 43% of farm households had already used mobile money by 2009. The figure increased to 72% in 2012.

Although a step behind Kenya, Uganda also has experienced the rapid dissemination of mobile money since the first mobile money service was launched in March 2009. Several followers started mobile money services, but currently, two MNOs have dominantly operated the service due to severe market competition. Mobile money users in Uganda have been rapidly and steadily increasing, which has been observed even in rural areas. According to the RePEAT survey in Uganda, representing the rural population, the proportion of households using mobile money was almost zero in 2007, increasing to 38% in 2012, and 70% in 2015.

17.6 New Services Using Mobile Money

Mobile money has become more and more popular. It has begun to be used for many other purposes besides peer-to-peer (P2P) money transfer. For example, many schools in Kenya and Uganda have accepted mobile money payments for school fees. In the past, parents of students generally had to go to the school before each school term/semester to make payments in cash. While many elementary schools are located nearby, secondary schools are often located in distant locations. So, parents can save a considerable amount of time and money by making mobile phone payments. In addition, the accounting process has been eased for the schools by receiving the fees in mobile money, which indeed is associated with greater transparency. An increasing number of people have been paying their utility bills with mobile money.

New loan and insurance products using mobile money have been designed and developed. Some digital loan products are offered by MNOs partnered with commercial banks, sometimes called 'mobile banking loans,' while others are done by fintech firms that develop lending platforms (called 'digital loan apps' or 'mobile loan apps') connecting borrowers with lenders and distributing loans via mobile money. As individuals open and use mobile money accounts, MNOs accumulate their history of transaction records, creating credit information for individuals. Such accumulated information and its analysis enable individuals who lacked credit history and were excluded from formal credit markets in the past to access digital loan products. At the same time, these new financial products also create new business opportunities. According to the 2021 FinAccess household survey in Kenya, representing individuals aged 16 and above, 9.3% of the population uses the credit from mobile banking loans in 2021, which is the highest share among formal loans, whereas 3.4% use credit from savings and credit cooperative organizations (SACCOs, which are local, member-based financial organizations), and 2.9% use bank loans.[6]

A new type of agricultural insurance called Kilimo Salama (meaning 'safe farming' in Swahili) was offered as a trial product to small-scale farmers in Kenya in 2011. It was indexed insurance, which covered input cost for crop production when excess rain or drought would occur, and used precipitation information from the nearest rainfall monitoring station to determine the payment of insurance claims. Thus, it did not need an inspection of the crop damage incurred by policyholders. Hence, it could be provided at a low insurance premium. In addition, the use of mobile money for claim payments further reduced costs. It made the insurance available even to small-scale farmers, who had been most vulnerable to weather risks and excluded from the market in the past. Index insurance products have drawn considerable attention since they cause less adverse selection and moral hazard than traditional insurance products. That is because insurance payments of index insurance are determined by the level of the objectively observed index rather than the actual damage reported by policyholders. Despite the high potential welfare gain for policyholders from the new insurance product reducing their weather risks, the trial has not been scaled out, as far as we know. Although the service provider did not report the details, low demand for the insurance product may be the reason for termination. Fukumori et al. (2022) examined the determinants of the product's take-up and found that a better understanding of the insurance product enhances take-up. Low demand for the index insurance products has been reported in some cases. The basis risk, or weak correlation between the index and the actual loss incurred by policyholders, has attracted attention as a factor in lowering demand (Hill et al. 2019; Janzen and Carter 2019).

Mobile phone dissemination and the associated development of mobile financial services have significantly influenced aid organizations. They may fundamentally alter humanitarian and development assistance measures in the near future. For example, a pilot program in Niger distributed emergency relief funds using mobile money to residents in the areas suffering severe weather shock damage (Aker et al. 2016). Typically, relief supplies are procured in-kind outside, distributed to aid disaster areas, and provided to victims. There are several issues causing inefficiency in the implementation of such aid programs. First, the diversion or elite capture of relief supplies often occurs and reduces the amount of supplies delivered to victims. Second, the delivery of supplies is delayed. Third, relief supplies from the outside could crowd out local suppliers and distributors. However, the direct remittance of aid to the victims in the affected areas via mobile money will greatly reduce implementation costs and improve the efficiency of aid programs. In addition, potential crowding out could be averted by business opportunities created by local business entities to sell their commodities via the platform. Furthermore, the physical and mental burden on the victims will be reduced as they will not have to travel far and wait in long

[6] The most common credit sources are shopkeepers and family/friends/neighbors, used by 28% and 16% of the population, respectively. The database can be accessed via the following URL: https://www.centralbank.go.ke/2021/12/17/full-2021-finaccess-household-survey-dataset/.

lines to receive relief supplies. There is also the advantage that each recipient can purchase the commodities they want according to their own circumstances.

More and more humanitarian fund transfer programs utilizing mobile money have been implemented recently for those severely suffering from natural disasters in Haiti, Afghan refugees in Pakistan, and refugees and returnees in Rwanda. The GSM Association (GSMA 2017) reported the outcome and lessons from such assistance programs and found that disbursing aid funds has the high potential to benefit recipients with timely payment, humanitarian organizations with increased traceability and efficient delivery, and mobile money providers with more customers. The full potential can be utilized where the mobile money ecosystem exists; that is, recipients have a mobile phone and a mobile money account, mobile money agents are located near recipients and keep enough liquidity, and merchants accept mobile money payments. Londoño-Vélez and Querubín (2022) evaluated a program distributing an unconditional cash transfer of about USD 19 to 1 million poor households during the COVID-19 pandemic and found that the program had a significantly positive but modest impact on the households' well-being. Through the program, Columbia achieved rapid dissemination of mobile money. Benerjee et al. (2020) examined the effects of universal basic income in Kenya during the pandemic and found a significant but modest improvement in the well-being of the recipients.

Governments have also engaged in the development of mobile money payment systems proactively. Besides their policy and regulatory roles, government institutions in many African countries have increased the range of public services offered via digital platforms, including digitizing public services (e.g., birth certificates and national IDs) and payment via digital platforms like mobile money. Electronic declaration and digital payment of taxes in Uganda, Rwanda, and other countries are examples of such efforts by revenue authorities. As a result, taxpayers benefit from increased efficiency and reduced time and cost of tax payment. At the same time, the revenue authorities benefit from reduced incidence of tax evasion and delayed payments, and greater domestic resource mobilization.

17.6.1 Mobile Money's Impact on People's Livelihood in Developing Countries

Observing dramatic changes in the financial environment in developing countries after the emergence of mobile money services, a growing body of academic literature has evaluated the influence of access to mobile money on people's livelihood in developing countries. In this section, we want to share the findings mainly from our research on mobile money and its impact on the livelihood of rural societies in developing countries.

17.6.2 Welfare Impact of Mobile Money

We investigated the impact of access to mobile money on household welfare measured by per capita consumption using the 2009 and 2012 waves of the RePEAT panel data in Uganda (Munyegera and Matsumoto 2016). The study covered a period from the onset of mobile money services in the country when almost nobody used mobile money to the transition stage when about 40% of households started using it. To identify the causal effect of access to mobile money, we utilized the panel structure of the household data tracking the same households during the period of rapid dissemination of mobile money in rural Uganda. Using a combination of household fixed effects, instrumental variables, and propensity score matching methods, we controlled for possible selection biases caused by unobserved factors that simultaneously affect mobile money adoption and outcome variables. Then, we found a positive and significant effect of mobile money access on real per capita consumption. The mechanism of this impact is the facilitation of remittances. Our preferred estimates indicated that households with at least one mobile money subscriber are 20 percentage points more likely to receive remittances from their members in towns and cities. As a result, the total annual value of the remittances they received was 33% higher than their non-user counterparts. We attribute this impact to reducing the transaction, transport, and time costs associated with mobile phone-based financial transactions. This study suggests significant welfare benefits of access to affordable financial services, which might go afield in reducing poverty and vulnerability, especially among the rural poor.

We also found that mobile money use increases the likelihood of saving and borrowing, besides receiving remittances (Munyegera and Matsumoto 2017). The corresponding amounts of each service are also significantly higher among mobile money user households relative to their non-user counterparts. The results imply that developing and enhancing access to and usage of pro-poor financial products could be a first step to achieving greater financial inclusion.

17.6.3 Healthcare Access and Mobile Money

Cash flow through mobile money eases the credit constraint on rural households and, hence, it is expected to positively affect several aspects of their lives, other than consumption. For example, many expectant mothers in developing countries do not receive adequate care during pregnancy due to financial constraints. If such hurdles in accessing healthcare can be overcome, it will reduce maternal and newborn mortality. Using the RePEAT data, Egami and Matsumoto (2020) looked at the impact of mobile money on access to health services, particularly maternal healthcare, in rural Uganda. They hypothesized that mobile money adoption would motivate rural Ugandan women to receive antenatal care. Utilizing a unique panel dataset covering the period of mobile money dissemination, they applied community- and mother-fixed effects models with heterogeneity analysis to examine the impact of mobile money adoption on access to maternal healthcare services. They found suggestive evidence that mobile money adoption positively affected the take-up of antenatal care. Heterogeneity analysis indicated that mobile money benefited geographically challenged households by easing their liquidity constraint as they faced a higher cost of traveling to distant health facilities. This study suggests that promoting financial inclusion by means of mobile money motivates women in rural and remote areas to make antenatal care visits.

17.6.4 Educational Investment and Mobile Money

The Uganda RePEAT data shows that health shocks are rampant in rural households and negatively correlate with economic activity and educational investment. For example, those who reported fever episodes and chronic diseases could not engage in income-earning activities for 7 days and 12 days, respectively, on average. They also experienced a significant income loss, which appeared to be associated with low educational investment among households with school-age children. Tabetando and Matsumoto (2020) examined the impact of mobile money adoption on rural households' educational investment, particularly when they face health shocks. They found that mobile money user households mitigated the negative impact of health shocks on per-child educational expenses by having an increased remittance receipt. They also found that mobile money user households received remittances from more senders than non-user households. It implies that the user households are financially connected to a larger family and social network, which can function as insurance when facing unexpected adverse events.

17.7 Conclusion: Rural Development and Financial Inclusion Through Mobile Technology

In the COVID-19 pandemic, the significance of mobile money services has been reconfirmed, particularly in the regions where people have limited access to traditional financial services. Mobile money has been used to disburse aid funds by humanitarian organizations and remittances between family and friend networks, which mitigated the most harmful consequences of the negative shocks. The biggest potential beneficiaries of mobile technologies are rural residents in developing countries. A part of this potential has been realized, and we have had the chance to witness several aspects of the impressive change in rural societies in Kenya and Uganda. Although Sub-Saharan African countries still have a lot of poverty-related challenges, many of them have developed mobile communication and financial infrastructure, and more people have been involved in this dramatic change and have had better access to financial services. There is no doubt that private businesses will be booming corresponding to this mobile revolution, coupled with improvements in transportation infrastructure after the pandemic. We strongly believe that the light of hope is gradually shining on the future of Africa. It is fascinating and fortunate for us to have the opportunity to observe this dramatic change in the mobile and financial environment closely as a researcher during this period of major transformation in Africa. This was made possible by the generosity and constant guidance of Professor Otsuka. With the hope that the era of Africa will come, we would like to continue observing what is happening on the continent.

Recollections of Professor Keijiro Otsuka

I first met Professor Otsuka in 1996 when I began my master's program at Tokyo Metropolitan University and took his class. In his class, students prepared answers to end-of-chapter questions from a microeconomics textbook in English and submitted them every week, which the professor corrected. Being new to economics and writing in English, I almost cried as I completed the homework each time. Sometimes I couldn't submit by the deadline, so I sent it by fax. The submitted essays were always filled with red ink and many comments: "This sentence doesn't make sense," "There is a leap in logic," among many others. I remember how happy I was on the rare occasions when I received a "well done" comment. To my surprise, Professor Otsuka is still as passionate about his research as he was then. I was very fortunate to have met him and received training from him at the beginning of my academic career, which is the biggest treasure in my life.

—Tomoya Matsumoto.

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Chapter 18
Transformation of Rice-Growing Villages in the Philippines

Jonna P. Estudillo

Abstract Rice-growing villages that look dormant under the shadow of mango trees have undergone a major transformation in their economies. Such transformation is accompanied by household income growth and poverty reduction. The first objective of this chapter is to describe the drivers of economic transformation in four villages (Kei's villages) in the Philippines from simple rice-dependent economies to more complex ones characterized by diverse sources of livelihood. The drivers of these economic transformations are population pressure, new rice technology, land reform, investments in human capital, urbanization and commercialization, and infrastructure. The second objective is to explore the strategic processes that accompany such transformation, such as rising productivity of rice farming, production of high-value crops, and rising incidence of nonfarm work within the local economy and migration to local towns, big cities, and overseas, among the younger generation. An important finding is that in the course of transformation, participation in the nonfarm labor market and migration are the main pathways in moving out of poverty for the children of poor landless farmers.

18.1 Introduction

Economic transformation is widely observed to have been accompanied by rapid household income growth and poverty reduction. Economic transformation is the shift of the focus of economic activities away from agriculture to industry and services. This essay presents a picture of the economic transformation of four rice-growing villages in the Philippines (Kei's villages). Professor Keijiro Otsuka practiced what Professor Yujiro Hayami fondly called 'pedestrian economics,' which is the art of studying the fabric of the rural economy by walking around the villages and interviewing households. Kei did several rounds of surveys in the villages for nearly two decades since Cristina C. David initiated the first one in 1985.

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Kei's villages that look dormant under the shadow of mango trees have undergone a major transformation in their economies. Such transformation is accompanied by household income growth and poverty reduction. The first objective of this essay is to describe the drivers of economic transformation in Kei's villages from a simple rice-dependent economy to a more complex one characterized by diverse sources of livelihood. These drivers are population pressure, new rice technology, land reform, urbanization and commercialization, and infrastructure. The second objective is to explore the strategic processes that accompany such transformation, such as rising productivity of rice farming; production of high-value crops; rising incidence of nonfarm work among the younger generation within the local economy; and migration to local towns, big cities, and overseas. An important finding is that in the course of transformation, participation in the nonfarm labor market and migration are the main pathways in moving out of poverty for poor landless children of farmers.

Section 18.2 of this essay describes the villages and Sect. 18.3 identifies the drivers of transformation. Section 18.4 describes the strategic processes accompanying the transformation, and Sect. 18.5 documents income growth and poverty reduction. Finally, Sect. 18.6 is the concluding remarks.

18.2 Description of the Study Villages

Two of Kei's study villages are located in Central Luzon (CL) (CL1 represents irrigated ecosystem, CL2 represents the lowland rainfed ecosystem), and two are located on Panay island (P) (P1 represents irrigated ecosystem, and P2 represents the upland).[1] Surveys were done in 1985 consisting of a randomly selected subsample of households in four villages. In 1993, 1997, and 2001, censuses of all households in the three villages (CL2, P1, and P2) were done. Mahabub Hossain, with funding from the International Rice Research Institute (IRRI), conducted the 1993, 1997, and 2001 surveys. Kei undertook surveys in the four villages in 2004 and 2008. Our descriptive tables show data from 1985 (the first survey) and 2008 (the last survey) when data are available for the four villages. In 1985, we had a total of 323 households and 1,330 in 2008. Households were grouped into two categories: (1) farmer households consisting of owner cultivators, leaseholders, and share tenants, and (2) landless households consisting of casual agricultural workers and non-agricultural households. Household grouping was based on the occupation of the household head.

[1] These villages were randomly selected from an extensive survey of 50 villages representing irrigated and lowland production environments in Luzon and Panay Island.

18.3 Drivers of Transformation

18.3.1 Population Pressure

Population pressure means a high growth rate of the labor force on a closed land frontier. One indication of population pressure is the increase in the proportion of landless households. The proportion of landless households rose more rapidly in the irrigated villages of CL1 and P1 because of the presence of greater employment opportunities in rice farming in irrigated ecosystems that attract migrant poor households. Average farm holding declined in all villages and more visibly in CL1. The increasing scarcity of farmland is expected to lead to impoverishment because farming is an important source of income.

18.3.2 New Rice Technology

Kei's villages are characterized by a high rate of adoption of modern rice varieties as early as 1985 in CL1, CL2, and P1 because of their favorable production environments. CL1 and P1 are fully irrigated, while CL2 is favorable lowland, which became fully irrigated by the Casecnan irrigation system in 2008. Adoption in P2 was low in 1985 because it is in the upland, but then adoption rose to 100% in 2008 because of the release of new modern varieties (MVs) that can thrive in upland conditions.

18.3.3 Land Reform and Investments in Human Capital

The 1972 Philippine land reform program converted share tenants into leaseholders or amortizing owners, who received the Certificate of Land Transfer (CLT) title. Upon completion of the amortization fees, the CLT titleholders were conferred the Emancipation Patent (EP), a certificate of full ownership. The EP title is acceptable in outright land sales or as collateral for loans. Leasehold rent and amortization fees were set at a fixed rate during the program implementation. Rice yields since then rose because of the Green Revolution, so there was a divergence between the market rental value and actual land rent, or amortization fees (were created) (Otsuka 1991).

Pawning emerged for land under leasehold, CLT title, and EP. This is particularly observed in the irrigated villages of CL1 and P1, where rice yields rose considerably due to the diffusion of high-yielding varieties. Under the pawning arrangement, the farmer surrenders his land in exchange for money from a moneylender. The farmer usually becomes a share tenant of the moneylender on his own land until the farmer can pay off his loan.

Indeed, the pawning of land began in 1975, soon after the implementation of the land reform in the study villages in 1974. The proportion of area acquired by the respondents under pawning arrangements has since risen over time in Central Luzon. This can be traced to the rise in the pawning of land under the newly-acquired EP titles. Land reform was transformative because pawning revenues were used to finance children's schooling, particularly tertiary schooling, and to finance the fixed cost of overseas migration (Estudillo et al. 2009). According to our village informants, farmers who pawned out their lands to finance schooling and overseas migration could repay their loans in less than five years to resume self-cultivation. The more educated children are then engaged in nonfarm work within the Philippines or migrate overseas, thereby diversifying household sources of income. Nonfarm work and migration then serve as important household risk coping mechanisms to buffer the uncertainty of agricultural income. As shown in Table 19.1, the younger generation who obtained higher levels of schooling are those who are engaged in nonfarm work and overseas migration.

18.3.4 Urbanization and Commercialization

Kei's villages experienced the wave of urbanization through the expansion of local towns, small cities, and big cities. CL1 and CL2 saw the creation of new villages nearby and within the jurisdiction of the city of Muñoz because of population growth. There was also the expansion of Cabanatuan City and San Jose, which are nearby cities, in terms of labor-intensive industries, including garments and food manufacturing. The expansion and rehabilitation of the North Luzon Expressways made it easy for workers in CL1 and CL2 to get employed in Manila. P1 benefited from the booming local economy of Pototan City and Iloilo City, which are fairly accessible to P1 via jeepney. In P2, villagers could find work in downtown Igbaras and Iloilo City primarily because of the newly-rehabilitated bridge that connects P2 to Igbaras town proper. Cable TV and internet connections expanded, bringing new ideas and values that transformed the traditional beliefs and norms in the villages.

In terms of commercialization, I witnessed the emergence of contract farming in okra production before the construction of the Casecnan irrigation system in CL2. Under this contract farming, the contractor provides all the inputs, such as seeds, fertilizer, and technology, while the farmer provides land and labor. Landless workers were employed in okra production, which decreased unemployment during slack periods in rice production.

18.3.5 Infrastructure

Kei's villages experienced improvements in economic infrastructure, such as electricity, roads, bridges, and irrigation. The proportion of households with access to electricity in 2008 was 90% in CL1, 83% in CL2, 86% in P1, and 92% in P2.

There have been improvements in road length and quality since the first survey in 1985. Village roads were extended in remote areas within the village, while existing roads were upgraded from soil to asphalt in CL1, CL2, and P2. Being close to Iloilo City, P1 has had good quality roads since the 1980s. CL2 and P2 used to be isolated from the town proper by a river. A bridge was constructed in CL2 in 1992 and in P2 in 1995, making it convenient for the farmers to market their products and for others to work downtown and in nearby towns and cities. More importantly, children in CL2 and P2 were able to continue their schooling beyond the fourth grade. Before the bridge, primary schools in CL2 and P2 offered curriculum up to the fourth grade only. With the construction of the bridges in the two villages, school enrollment in high school rose remarkably in CL2 and P2.

CL2 used to be rainfed, while some farmers invested in portable water pumps to produce high-value crops, such as watermelon, onions, and other vegetables during the dry season. CL2 became fully irrigated in 2008 with the opening of the Casecnan irrigation system. Farmers can now plant rice in the dry season, increasing the cropping intensity and total rice production per year.

18.4 Strategic Processes that Accompany the Transformation

18.4.1 Increasing Productivity of Rice Farming, High-Value Crops, and Livestock

Rice yield rose because of the adoption of MVs and higher fertilizer application in all villages. There was an increase in total rice production in the four villages, partly because of yield increase and partly because of the adoption of shorter-duration MVs that enable farmers to have 2–3 crops per year. There was also an increase in the revenue from rice production because of the increase in rice prices due to the 2007–08 food crises. The spread of new rice technology is transformative because it enables farmers to secure food and allocate resources to children's health and schooling. Otsuka et al. (2009) found that the increase in income from rice production was spent on children's education, who, upon completing schoolwork, decided to work in the nonfarm sector in the locality or move to local towns, big cities, and overseas, and send remittances. The increase in nonfarm income was the major source of household income increase and poverty reduction.

The importance of rice income has declined due to the rice sector's stagnant rice yield and declining employment opportunities because of the diffusion of labor-saving technologies. Production of high-value crops and livestock has become more common: the share of nonrice income among children living in the study villages was 19%, which is higher than the 15% share of rice income. So, it seems the economic importance of rice farming vis-à-vis other crops has declined in the traditional rice-growing villages.

18.4.2 Nonfarm Work and Migration[2]

Here I discuss how poverty has declined over generations in Kei's villages, as noted in the main findings of Estudillo et al. (2014). The most important strategy to halt the transmission of poverty from parents to children is for the younger generation to take advantage of new economic opportunities within the villages' rural nonfarm economy or move out to explore job markets beyond the villages in local towns, big cities, and even overseas. Parents' income has come mainly from agricultural sources, while children's income has come largely from nonfarm sources. Initially, poverty was higher among landless households. Children from poor landless households could find their way out of poverty by acquiring more education, participating in the rural nonfarm labor market, and migrating to local towns, big cities, and overseas. Migrant children have higher total income coming mainly from nonfarm income.

To explore whether poverty has been transmitted from parents to children, it is necessary to have socioeconomic information on pairs of parents and children spanning at least two generations. Kei and I compiled information on three generations of members belonging to the same household in the four villages. Information from the first generation (G1), consisting of respondents' parents, was taken from the 1985 survey conducted by IRRI. Data for the second-generation (G2) members, consisting of the respondents and their siblings, were taken from the 1989 survey conducted by Quisumbing (1994).

Kei and I constructed a specially designed questionnaire intended for personal in-house interviews of the third generation (G3), consisting of the daughters and sons of the respondents (G2). There were 3,218 respondents' children that were reported in the original 1985 survey. We were able to trace the whereabouts of nearly half of them (1,516 children). We gave in-house interviews to 870 out of the 1,516 children (an interview rate of 57%) in their respective current places of residence in 2008. Migrant children tend to cluster in the northern and central parts of the country, where infrastructure is more developed and peace and order are not a problem.

We had a total of 535 individuals in G1; 1,485 individuals in G2; and 1,516 individuals in G3 (1,197 children of farmer households and 319 children of landless households). The tracking rate on the landless households was lower because landless households are geographically more mobile: many of them were not available at the time of the resurvey or were no longer residing in the study villages in 2008 with hardly any information on their whereabouts.

We categorized children into four groups based on their residential addresses at the time of the 2008 resurvey: (1) study villages, (2) local towns, (3) big cities, and (4) overseas.[3] Local towns refer to the *poblacion* (town center) of the study villages, adjacent villages, towns located in the same province, small cities nearby, and cities and towns in other provinces. Big cities include Metro Manila, Metro Cebu, and Baguio.

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[2] Parts of this section draw heavily from Estudillo et al. (2014).

[3] We were able to interview 27 children who were already residing overseas, as it happened that they were visiting the study villages at the time of our survey.

Table 18.1 shows the grouping of G1, G2, and G3 based on the type of job. For G1, we had the following classifications: (1) with a job in agriculture, (2) with a nonfarm job, (3) with an overseas job, and (4) unemployed and others. Almost all male G1 were engaged in agriculture, and almost all female parents were unemployed, mainly housekeepers. G1 were born around 1910, had very little schooling, and owned, on average, less than 1 hectare (ha) of farmland per person. Fathers completed more years of schooling than mothers (3.8 years vs. 3.1 years) and inherited larger areas of farmland (1.1 ha vs. 0.56 ha), indicating a gender bias in the transfer of wealth in favor of males.

For G2, we had the following groupings: (1) with a job in agriculture, (2) with a nonfarm job, (3) with a job in the big cities, (4) with an overseas job, and (5) unemployed and others. G2 were born around 1940, accomplished more than twice their parents' education (6.9 vs. 3.4 years), and inherited about half the size of their parents' farmland (0.39 ha vs. 0.83 ha). Brothers and sisters had about the same level of schooling, in contrast to their parents' generation when females were less favored. Both female G2 and female G3 had become engaged in more diversified occupations, including overseas work.

We categorized G3 based on the parental endowment of farmland: (1) children originating from farmer households and (2) children from landless households. These two groups were further categorized into seven groups based on current residence and occupation: (1) with a job in agriculture in the study villages, (2) with a nonfarm job in the study villages, (3) with a job in agriculture in local towns, (4) with a nonfarm job in local towns, (5) with a job in the big cities, (6) with an overseas job, and (7) unemployed and others.

G3 were born in 1973 (1971–1975), had more than 10 years of schooling (3.3 years more than their parents), and had inherited farmland of less than 0.10 ha. Farmer children completed 0.4 more years of schooling than the landless children—a statistically significant difference ($p < 0.05$). A larger proportion of children from farmer households opted to stay in the study villages. Landless children were geographically more mobile, residing in the big cities, local towns, and overseas.

Children working overseas had the highest income, followed by those in the big cities; children who reside in the study villages had the lowest. Accordingly, poverty incidence and depth of poverty were highest among children living in the villages. That poverty did not exist among overseas children, while less than 10% of migrants in the big cities were poor. Migrant children were deeply engaged in nonfarm work; the largest proportion of their incomes had come from nonfarm income. Surprisingly, even those children who remain in the study villages derived 65% of their income from nonfarm sources, including nonfarm wage income (44%) and remittances and other sources (21%). Rice income has become a much less important source of income for G3, whereas, in contrast, it was the most important source, particularly for farmer households in the G2.

The correlation coefficient of parents' and children's schooling had declined from 0.30 between G1 and G2 to 0.20 between G2 and G3. Children of lowly educated parents tended to catch up with children of highly educated parents in terms of schooling, with male children benefiting more. The correlation coefficient between

Table 18.1 Description of the three generations in the sample (Estudillo et al. 2014, Table 3)

Category	Number	%	Year of birth	Completed years in school	Inherited land (ha)
Parents of respondents (G1)					
With job in agriculture	243	46	1907	3.4	1.14
With nonfarm job	38	7	1909	6.2	0.44
With overseas job	1	0	1910	n/a[a]	n/a[a]
Unemployed and others[b]	253	47	1911	3.1	0.61
All	535	100	1909	3.4	0.83
Respondents and siblings (G2)					
With a job in agriculture	680	46	1940	6.0	0.57
With a nonfarm job	259	17	1943	9.0	0.23
With a job in the big cities	85	6	1944	9.3	0.08
With an overseas job	48	3	1949	10.1	0.51
Unemployed and others	413	28	1940	6.0	0.24
All	1,485	100	1941	6.9	0.39
Children of farmer households (G3)					
With job in agriculture in study villages	287	24	1971	8.8	0.17
With nonfarm job in study villages	202	17	1972	11.0	0.08
With job in agriculture in local towns[c]	45	4	1968	8.7	0.23
With nonfarm job in local towns[c]	76	6	1973	11.9	0.01
With job in the big cities	193	16	1973	11.1	0.03
With overseas job	78	6	1971	12.8	0.01
Unemployed and others	316	27	1972	10.2	0.02
All	1,197	100	1972	10.4	0.07

(continued)

Table 18.1 (continued)

Category	Number	%	Year of birth	Completed years in school	Inherited land (ha)
Children of landless households (G3)					
With a job in agriculture in the study villages	46	14	1972	8.0	0
With nonfarm job in study villages	48	15	1974	10.9	0
With job in agriculture in local towns	11	4	1971	6.8	0
With nonfarm job in local towns	26	8	1974	10.8	0
With a job in the big cities	56	18	1975	10.6	0
With overseas job	35	11	1973	12.9	0
Unemployed and others	97	30	1973	9.4	0
All	319	100	1974	10	0

Notes [a]n/a means data is not available; [b]Includes housekeepers, discouraged workers, retired workers, and people with disability; [c]Includes small cities

parental income and children's income was close to zero. The coefficient of parental income in a regression function of children's income was statistically insignificant with a value of −0.1187. Clearly, parental wealth has become weak in explaining children's economic destiny.

Now we explore whether parental wealth affects children's residential and occupational choices, which, in turn, affect children's income. Education and inherited farmland are the major forms of wealth transfers that could potentially affect children's residential and occupational preferences. For G2, we considered five alternative choices, and for G3, seven choices. Estudillo et al. (2014) performed a multinomial probit function and found that in G2 and G3, education positively and significantly affects the choice of nonfarm work and migration to the cities. For G2, education positively and significantly affects the choice of nonfarm work and migration to the cities. Children with larger inherited farmland are significantly more likely to work in agriculture and significantly less likely to engage in nonfarm work and migrate to the cities.

For G3, the more educated children are more likely to engage in nonfarm work in the village and local towns and migrate to the big cities and overseas: they are less likely to engage in agricultural work in the village and local towns. Like G2, children with larger inherited farmland are more likely to choose farming in villages and local towns.

The main finding is that schooling has enabled G2 and G3 to explore job opportunities in the nonfarm sector in the village and local towns and has prepared them to migrate to big cities and overseas. Inherited farmland remains a decisive factor in choosing farming vis-à-vis other occupations in the village and local towns. Since landless children in G3 obtained schooling levels less than but comparable with that of farmer children, it is reasonable to expect that they are equally likely to explore job opportunities in the nonfarm labor market in the village, local towns, and the big cities. In fact, landless children have a higher propensity to migrate in search of economic opportunities elsewhere outside the village.

For G3, education significantly increases nonfarm household income, whereas the size of inherited farmland significantly increases farm income. Interestingly, inherited farmland does not affect the total household income of G3, which indicates that landless children are not necessarily worse off even if they did not inherit farmland. Education has facilitated the participation of landless children in nonfarm employment and migration to big cities and local towns. These strategies led to increased income, notably earned from nonfarm labor activities. As a result, poverty has declined among landless children, and the income gap between farmers' children and landless children has declined.

18.5 Income Growth and Poverty Reduction

Table 18.2 shows the sources of household income of G2 in 1985 and those of their children (G3) in 2008, classified as coming from farmer or landless households. Sources of household income were the following: (1) rice income, consisting of income from rice production and from off-farm wage activities; (2) nonrice farm income, coming from the production of nonrice crops, livestock, and poultry; (3) nonfarm income, consisting of wage income from nonfarm activities, such as formal and informal salary work and from self-employed activities in trade, transport, and communication; and (4) domestic and foreign remittances. Income data are in purchasing power parity (PPP) at 2005 USD prices.

In 1985, a substantial portion of household income of G2 (76% for farmer households, 49% for landless households) came from agricultural sources, such as the production of rice, nonrice crops, and livestock (Table 18.2). The income of farmer households was about twice the income of landless households. The major sources of disparity were rice and nonrice crop production. Nonfarm income was higher for the landless. And because the landless are land-poor, poverty was higher among the landless (65%) than among the farmer households (42%).[4]

Interestingly, nonfarm income has become the major income source of farmer children (G3)—67% of their income—while it was only 12% of their parents' (G2).

[4] Poverty measures are estimated using the Foster–Greer–Thorbecke index (Foster et al. 1984) with the USD 1.25 per capita per day in purchasing power parity based on private consumption as the poverty line.

Table 18.2 Household income composition of respondents and children in the study villages in the Philippines (annual income at USD PPP 2005)

	Household income of respondents (G2) in 1985	
	Farmer households	Landless households
Rice income	1,104 (58%)	329 (36%)
Nonrice income	342 (18%)	119 (13%)
Nonfarm income	225 (12%)	369 (41%)
Remittances	224 (12%)	91 (10%)
Total income	1,895 (100%)	908 (100%)
Poverty incidence		
Head count ratio (%)	78	94
Poverty gap ratio (%)	48	56
Number of observations	230	65
	Household income of children of respondents (G3) in 2008	
	Married children from farmer households	Married children from landless households
Rice income	610 (8%)	81 (1%)
Nonrice income	757 (9%)	484 (7%)
Nonfarm income	5,452 (67%)	5,372 (81%)
Remittances	1,322 (16%)	691 (11%)
Total income	8,142 (100%)	6,629 (100%)
Poverty incidence		
Head count ratio (%)	24	32
Poverty gap ratio (%)	11	15
Number of observations	527	129
	Single children from farmer households	Single children from landless households
Rice income	772 (12%)	116 (2%)
Nonrice income	545 (8%)	446 (6%)
Nonfarm income	4,144 (62%)	4,963 (71%)
Remittances	1,194 (18%)	1,443 (21%)
Total income	6,656 (100%)	6,970 (100%)

(continued)

Table 18.2 (continued)

	Household income of respondents (G2) in 1985	
	Farmer households	Landless households
Poverty incidence		
Head count ratio (%)	25	11
Poverty gap ratio (%)	13	4
Number of observations	167	43

The income disparity between the farmer and landless households appears to have disappeared in G3, with nonfarm income as the major driver of income growth. Meanwhile, income from rice and nonrice farming remained significantly higher for the farmer children.

The children's and parents' income ratio in the landless category was 7.4 times. In contrast, the corresponding ratio for the farmer was only 4.1, an indication of substantial income growth for the landless children. While children's incomes have largely equalized, poverty incidence among the landless children remained higher, but at a mere 8% points, compared with their parents, in which poverty stood at 23% points higher among the landless class. Landless children who migrated to local towns and big cities increased their income vis-à-vis that of farmer children.

18.6 Concluding Remarks

This chapter identified the drivers of transformation and explored the accompanying strategic processes in Kei's four villages in the Philippines. There was income growth and poverty reduction, and there was no transmission of poverty from parents to children. There was also a decline in income inequality between the rich (farming households) and the poor (landless households). Participation in the nonfarm labor market and migration to local towns and big cities are the main pathways to moving out of poverty for the landless poor. Poverty among the landless poor declined substantially because they have a higher degree of geographical and occupational mobility.

The experience of Kei's villages attests to the power of economic transformation to penetrate the lives and livelihood of rural people. There are no losers in Kei's villages—'the rising tide lifted all boats'—the landless poor benefiting more. It is obvious that to improve the lot of the landless poor, they need more than just the virtue of frugality, initiative, and enterprise. The poor needed education, farmland, infrastructure, and local towns and cities, strategies that increased income, notably income earned from nonfarm labor services, that allowed them to move out of poverty.

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Chapter 19
Structural Transformation and Development Experience from Asian Countries

Yasuyuki Sawada

Abstract Structural transformation is one of the critical drivers of growth and development worldwide. In all countries that achieved development success, agriculture's share of output and employment declined as industry's share grew, followed by 'deindustrialization,' as services became dominant. Also, we observed productivity upgrading from low to high within each of the three sectors. Asia achieved structural transformation at a much faster speed than other developed regions partly because of the continuous deterioration of agricultural terms of trade. At the same time, the manufacturing industry drives Asia's rapid growth because it has a number of essential features, such as a large scope for innovation and technological progress, scale economies, and the creation of better-paying jobs for a broad population. Yet, a few countries in Asia, such as the Philippines, face a critical question: can industrialization be bypassed for development? This chapter approaches these trends and issues by looking at aggregate statistics and long household panel data to discuss the Asian type of 'canonical industrialization' and 'premature deindustrialization

19.1 Structural Transformation in Asia and the Rest of the World

The structural transformation from agriculture to industrialization and then services has been considered the key driver of successful long-term economic development (Lewis 1954; Ranis and Fei 1961; Harris and Todaro 1970; Hayami and Ruttan 1985; Matsuyama 1992; Hayashi and Prescott 2008; Duarte and Restuccia 2010; Bustos et al. 2020; Gollin et al. 2021). Studies on East Asia's development success repeatedly endorse that industrialization and broad structural transformation have been indispensable for low-income economies to undertake the road to high income (ADB 2020).

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In the last five decades, developing countries in Asia have achieved structural transformation successfully. In the 1960s and 1970s, most Asian economies were dominated by subsistence agriculture. Over 60% of Asian labor worked on a farm with low productivity; most Asian exports were simple, labor-intensive products (ADB 2020). A striking feature of economic development in Asia is the fast and continuous decline in agriculture and a corresponding increase in the manufacturing and services sectors' combined output and employment shares. The manufacturing sector's share increases to a certain point. It then declines as the economy shifts from the industrialization stage to a 'deindustrialization' stage. In contrast, the services sector's share continues to increase. As shown in Fig. 19.1, an inverted-U relationship exists between industry shares (in output and employment) and per capita gross domestic product (GDP). Services were already the most significant sector by output and employment for most countries in 1970, rising steadily with income.

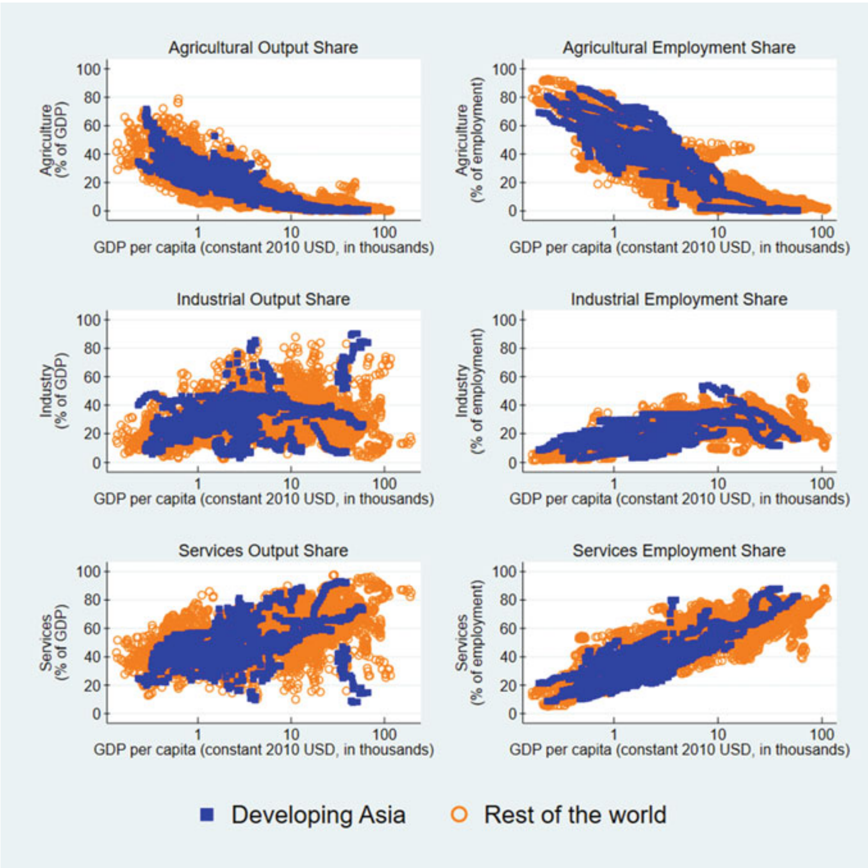

Fig. 19.1 Output and employment structural transformation in Asia and the world, 1970–2018. (Fig. 3.1 in ADB 2020). *Note* GDP = gross domestic product, USD = United States dollar

There are two distinctive features in Asia's structural transformation. First, while the pace of structural change has accelerated in Asia, higher industry shares are seen at lower per capita incomes than before, partly because late starters have the advantage that they can copy those ahead and advance at a quicker pace. Second, unlike the historical pattern of moving from agriculture to industry and then to services, output and employment transformation data show that many countries are directly transitioning from agriculture to services. This is the phenomenon known as 'premature deindustrialization.' Can countries bypass industrialization and growth of the manufacturing sector and leapfrog directly from agriculture-led development to services-led growth? Although the question remains contentious (Rodrik 2016; ADB 2020), the modern micro- and experimental-oriented development economics, which has gone through a 'credibility revolution' radically in the last two decades, is largely silent in answering such a fundamental question (Rosenzweig 2012; Ravallion 2020; Deaton 2020). For example, the dominant approach in development economics does not address long-term issues, such as the Green Revolution and the growth of employment in the manufacturing sector, to reduce poverty in the long-run (Rosenzweig 2012). Put simply, randomized controlled trials (RCTs) cannot provide evidence to identify the key to long-run economic growth (Deaton 2020).

This chapter discusses the core elements of structural transformation in economic development, drawing upon experiences of Asian countries, particularly new micro-level evidence from Asia.

19.2 The Canonical Model of Structural Transformation

Structural change (i.e., the reallocation of labor and broad activities across sectors) contributes to total labor and overall productivity growth. But changes in aggregate productivity also depend on how productivity evolves at the sector levels (i.e., what products are produced and how they are produced). In many Asian economies, the productivity growth within sectors has contributed more to overall productivity growth than the reallocation of labor and other resources into higher productivity sectors (ADB 2020).

Some of the main drivers of successful agriculture development in Asia include technology adoption, product diversification and expansion of the nonfarm economy, policies conducive to agriculture development, and public investments in rural infrastructure. First, technological change since the 1960s in Asia led to significantly improved yields of traditional crops. The Green Revolution, which included introducing new rice and wheat varieties and public investment in irrigation, was coupled with policies on input subsidies to encourage farmers' technology adoption. Second, increasing yields in traditional crops (e.g., rice and wheat) is critical but insufficient for growth, and continued agriculture growth has been partially achieved by structural change within the sector. The expanding demand for livestock and high-value products (which are more labor-intensive than traditional crops) has aided the rapid growth of agriculture in developing Asia. Increasing global trade is a key driver behind these trends. Third, land reforms were introduced to create tenant-owner agriculture and redress inequality of landholdings, although success is limited in some countries. Policies to develop good access to domestic and international markets, combined with technical assistance from processing and marketing firms, were also implemented, supporting the diversification of farmers' high-value crops. Agriculture-related trade agreements and foreign direct investments have likewise included smallholder farmers in global value chains. Finally, in parallel, supportive infrastructure in the countryside has increased job opportunities and raised the chances for the economic mobility of farmers.

Agricultural development in Asia, in turn, supported economy-wide structural transformation. Experiences from the more developed Asian economies have shown strong complementarities between agricultural development and industrialization. Raising agricultural productivity, creating a virtuous cycle of rural economic development beyond food production, and enabling surplus transfers to support industrialization have been the pathways of successful transformation. Inter-sectoral resource flows, especially labor mobility from agriculture to non-agriculture, stimulated an increase in wage to the capital rental price ratio (ADB 2020).

The shift to manufacturing has become an essential component of Asia's development in the context of export-led growth. After World War II, manufacturing goods exports have gone hand-in-hand in explaining Asian development while the structure of production and exports in East Asian economies underwent major changes. This process accelerated, particularly in the 1960s and 1970s, and manufacturing value-added as a share of GDP and manufacturing employment as a share of total employment increased significantly. Japan and other East Asian economies, Southeast Asian economies, and China experienced a major economic transformation as workers moved from being employed in the primary sector in rural areas to cities where manufacturing employment and production increased substantially. This structural change and industrial upgrading occurred sequentially in the Asian countries following the mechanisms described by the 'flying wild geese model.' As the model matures, Asia has been transforming from an inter-industry trade pattern to an intra-industry trade system by strengthening regional production networks and global value chains (ADB 2020).

The development of the services sector is also an essential story of structural change. The role of the services sector has clearly been on the rise, whether viewed in terms of output or employment. The key drivers of Asia's services sector revolution are urbanization, information technology and e-commerce development, globalization, and consequent expansion of business process outsourcing (BPO). However, labor productivity in this sector remains low, which can be attributed to the dominance of traditional activities, such as wholesale and retail trade, hotel and restaurants, real estate, transport, personal services, and public administration. There are thus concerns about weak backward and forward linkages in the services sector. Other distinctive features of the services sector are its massive heterogeneity (low vs. high-productivity subsectors), difficulties in measuring its output, and its highly regulated nature. These features raise questions about the services-led growth model, bypassing industrialization and growth of the manufacturing sector and leapfrogging directly from agriculture-led development to services-led growth, or simply, premature deindustrialization (Rodrik 2016; ADB 2020).

19.3 The Model

Otsuka et al. (2008) used primary data of rural households collected in Asia and Sub-Saharan Africa, spanning nearly two decades or longer, to examine the hypothesis of the two-phase process of economic development and structural transformation. First, in the early stage of economic development, when farming is a dominant source of income, access to land and agricultural technology are the significant determinants of farm household income. Accordingly, there is no incentive to invest in human capital and participate in the nonfarm labor market without substantial productivity improvements in agriculture. Second, as the economy develops with rising agricultural productivity and resulting in deterioration of agricultural terms of trade, the availability of nonfarm jobs increases, emphasizing the importance of human capital, which, in turn, incentivizes rural families to invest in human capital and switch to nonfarm jobs. In this way, an economy moves from being dependent on agriculture as its primary sector to increasingly relying on the secondary and tertiary sectors.

These hypotheses are built on the canonical two-sector model of economic development in which labor reallocation from a low-productivity farm sector to a high-productivity nonfarm sector is the key driver of development. In such modeling, the recent general equilibrium models reveal that it is indispensable to incorporate a preference structure that exhibits Engel's law (i.e., the inverse relationship between a household's income and food expenditure share).[1] To illustrate this feature, we employ the models of Matsuyama (1992, 2007) and Eswaran and Kotwal (1994) to formulate a simple general equilibrium model with the two sectors (i.e., the farm and nonfarm sectors), denoted by F and N, respectively. We postulate that the production functions in these two sectors are well-behaved neoclassical functions (i.e., concave), satisfying the Inada conditions. Then, we can derive the following first-order necessary condition as the equilibrium condition of the labor market:

$$MP_L^N = \frac{P_F}{P_N} MP_L^F \tag{19.1}$$

[1] Generally speaking, we can consider three alternative ways to formalize the preference. The first way is to incorporate the minimum subsistence level of food consumption, (a.k.a. the Stone-Gearly utility function) (Matsuyama 1992, 2007). Second, a hierarchical preference structure formulated by Eswaran and Kotwal (1994) can also exhibit Engel's law. Third, we can incorporate a positive constant term in the consumption of nonfarm goods (Murata 2002; Duarte and Restuccia 2010).

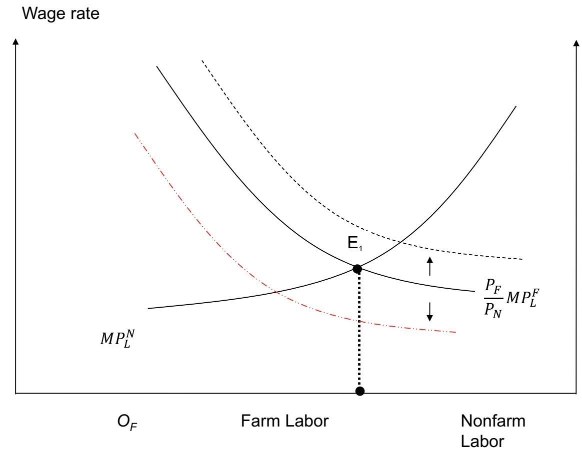

Fig. 19.2 Labor market equilibrium condition

where the marginal productivity of labor in the nonfarm and farm sectors are denoted by ${MP_L}^N$ and ${MP_L}^F$, respectively. P_F and P_N, respectively, are the prices of farm and nonfarm products. In Fig. 19.2, given the equilibrium relative price, we describe the labor market equilibrium condition where O_F is the origin for the farm sector and O_N is that for the nonfarm sector. The length of the horizontal axis in Fig. 19.2 corresponds to the total amount of labor force in the economy. For a closed economy, the domestic goods market equilibrium condition determines the relative price.[2]

Now consider the Green Revolution, which can be incorporated into the model as a case of a positive productivity increase in the farm sector. Then, in Fig. 19.2, the ${MP_L}^F$ locus shifts toward the right from the solid to the dotted curve. This would generate a direct effect of enhancing farm employment. Yet, this is not the only change made by the Green Revolution. At the same time, because of Engel's law, the relative price of farm to nonfarm goods, P_F/P_N(i.e., the terms of trade of agriculture), should decline, thereby shifting the curve to the left (dashed red curve). The total effect on sectoral labor allocation should depend on the relative magnitude of these two opposing effects (i.e., the immediate productivity effect and the price effect). Matsuyama (1992) and Eswaran and Kotwal (1994) show that, under plausible assumptions, the latter effect dominates the former, leading to a labor reallocation from farm to nonfarm sectors after all.

In reality, the long-term decline in real rice prices in the world may be consistent with deteriorations in the farm-nonfarm terms of trade (Fig. 1.3). Such a change in terms of trade is likely to be generated by the Green Revolution, which is represented by a shift of the ${MP_L}^F$ locus toward the left in Fig. 19.2. Theoretically speaking, in a small open economy setting, there will be no price effects, and thus, farm productivity improvements would directly expand the equilibrium share of farm labor. Yet, it would be likely that sufficient growth in nonfarm productivity, additionally shifting the ${MP_L}^N$ locus toward the left, combined with the deterioration of the agricultural

[2] In the case of a small open economy, the relative price is given exogenously.

terms of trade in the world market shown in Fig. 1.3, still helped achieve structural transformation from farm to nonfarm sectors in Asia. The importance of nonfarm productivity growth is much clearer in the case of post-World War II Japan, where high-productivity growth in the nonfarm sector outweighed the productivity improvements in the farm sector (Hayami 1975; Minami 2002). The overall observation of the continuous structural transformation in Asia shown in Fig. 19.1 is consistent with the mechanisms described here.

What are the underlying mechanisms behind such productivity growth, then? We believe that human capital investments are the key to explaining productivity growth in the farm sector and, more importantly, in the nonfarm sector. For developing countries as latecomers, the adoption, imitation, and assimilation of the flows of technical know-how from developed countries, rather than the development of domestic research and development (R&D) sectors, help their nonfarm productivity to catch up to the technological leader. This also suggests the importance of the absorptive capacity of advanced foreign technologies in Asian countries (ADB 2020; Kunieda et al. 2021). The absorptive capacity, with which the gap between the technology frontier and the current level of productivity is filled, should closely depend on the level of human capital (Nelson and Phelps 1966; Keller 2004; Benhabib and Spiegel 2005; Sonobe and Otsuka 2006). Ohkawa and Kohama (1989) discuss that the historical experience of Japan is a typical example of borrowed technology-driven industrialization. Their argument indicates that Asia's success was attributable to its rapid human capital accumulation, by which the absorptive capacity of foreign technology was increased, enabling rapid structural transformation.

19.4 The Case of Laguna Province, Philippines

To capture the long-term dynamics of structural change in-depth, we selected a particular area, Laguna province in the Philippines, located to the south of the capital city Manila. It is the third-largest province in the Philippines, with a population of more than 3 million. Laguna Lake, the largest lake in the Philippines, is located in the center of the province, and agriculture and fishery have long been developed along the lake.

19.4.1 Structural Transformation Seen from the Sky

The map of Laguna province in 1976 and 2016 is shown in Fig. 19.3. The map was based on Landsat satellite images of the NASA Goddard Space Flight Center and the US Geological Survey, in which the area was classified into four categories using a machine learning algorithm. The categories are waterbody (blue), vegetation (green), bare land (orange), and build-up (red). Manila is located to the northwest of the lake and was already developed in 1976, as illustrated by the dominance of the build-ups.

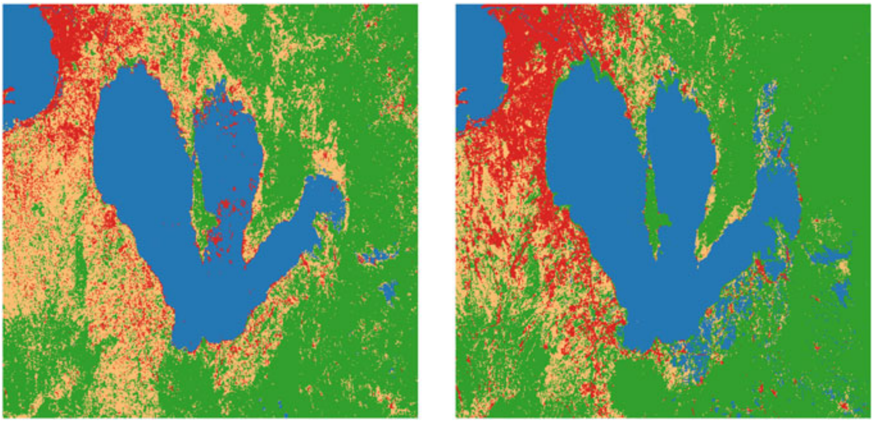

Fig. 19.3 Land use observed by satellite images of Laguna Province in 1976 and 2016. (Kim et al. 2021)

Laguna province is located to the south of Laguna Lake. If we compare the southwest (henceforth, west) and southeast (henceforth, east) sides of the lake, the proportion of build-up in the 1976 image is similar. This suggests that the development was evenly-distributed in Laguna province in the 1970s, giving us suggestive evidence of ‘baseline balance.’

The unique characteristic of Laguna province is that the development has been pretty even until the mid-1970s, and primary industry has been the center of the economy. However, the Southern Luzon Expressway (SLEx) was constructed in 1978, by which the west was connected directly to Manila. This improved connectivity to Manila attracted investments, and several industrial parks were built from the late 1980s until the ‘00s in the west. Due to the expressway and the industrial parks, the west experienced rapid industrial development.

Using the information on land uses obtained from Landsat satellite images in 2016,[3] Fig. 19.3 illustrates changes in land usage. We can observe overall land cover changes from agriculture (vegetation in green and barren in orange) to built-up (red), especially in the west.[4] A series of satellite images show that the proportion of built-up in the west gradually increased over time, whereas the proportion in the east did not change much (Kim et al. 2021).

[3] We constructed land-use data at 269 m × 269 m pixel size from satellite images. While all the images are combined from images during the dry season and wet season, we undertook refinements and quality control of low-resolution images from the old dataset from the 1970s, variations in seasons, and a mechanical failure in the ‘00s.

[4] The Manila to Alabang portion of SLEx was started in 1969 and the Alabang to Calamba part opened in 1978 (Hayami and Kikuchi 2000).

19.4.2 Structural Transformation Seen from the Ground

To further explore micro-level dynamics of structural transformation, we employ another source of information from the ground level (i.e., the Laguna Multipurpose Household Survey), which was designed and initiated by Professors Robert Evenson and Barry M. Popkin with 34 barangays and 576 households in Laguna province in 1975 (Evenson 1980).[5] The panel survey was conducted in 1977, 1982, 1985, 1990, 1992, and 1998 (Ejrnæs and Pörtner 2004).

Since the original data files and respondent lists for the first survey in 1975 were not available, unfortunately, data from 322 households from the 23 barangays surveyed in 1977 were used as baseline information for our tracking survey, which was conducted with all the original respondents as well as their descendants in 2017 (Kim et al. 2021). The survey targeted all individuals in the family trees of the original 322 respondents surveyed in 1977, including information about those who had already passed away at the time of our tracking survey. This unique data allows us to analyze sample individuals' occupation choices in the period of dynamic structural change. The sample obtained from the tracking survey includes 23,650 individuals from 4,992 households in 318 family trees. Almost half of the original households were still located in the same barangay, and nearly two-thirds of them were in the same municipality (including the same barangay). Thus, we were able to reach a 98.7% tracking rate, which is, we believe, a higher rate of recontact than other similar tracking surveys.

Using the tracking dataset, we examined the age-specific distribution of primary lifetime occupations in the west and east separately (Fig. 19.4). While, in both areas, we observed a dramatic decline in the employment share of the agriculture sector over the generations, transformation in sector-specific employment structure from agriculture to traditional services, and manufacturing being more salient in the west than in the east. In the west, the manufacturing sector became the dominant sector over the agriculture sector in the labor market for those below 57-year-old (vertical solid line), replacing the farm sector common for those above 60 years old. The modern services sector dominated the agriculture sector for those below 52 years old (vertical dashed line). These patterns show that the west follows the canonical structural transformation pattern from agriculture to manufacturing and then to (modern) services.

[5] The original 34 sample barangays of the survey were selected by stratified random sampling. Thirteen sample barangays representing (i) lowland rice farming barangay were drawn from earlier survey, named Farm and Home Development Office survey, conducted by UPLB. With regard to the other three categories of barangays, sample barangays were randomly selected from the list of all barangays in each category; six upland barangays, three fishing barangays, and 12 semi-urban barangays. The total of 34 sample barangays are selected to represent the socio-economic condition of entire Laguna province. In each of the 34 barangays, 16 households were randomly selected from the census of barangay households (except 27 households selected in each of the three fishing barangays). With such sampling framework, 576 households were surveyed in the 1975 survey (one household missing).

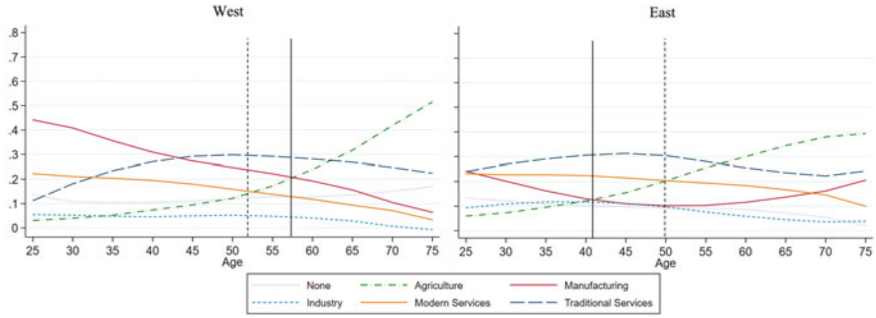

Fig. 19.4 Occupational dynamics in the southwest (west) and southeast (east) sides of Laguna Lake in the Philippines (Kim et al. 2021)

However, traditional services had the highest share among those below 57 years old in the east. The modern services sector dominated the agriculture sector for those below 50 years old (vertical dashed line) and then by the manufacturing sector for those below 41 years old (vertical solid line). The east bypassed manufacturing occupations by transforming its initial agricultural dominance into traditional and modern services occupations. These two figures show the co-existence of the 'canonical structural transformation' in the west and 'premature deindustrialization' in the east. On the one hand, we found that infrastructure development and manufacturing sector investments in the west facilitated occupational transformation from agriculture to manufacturing. On the other hand, with the inaccessibility of manufacturing, the east showed premature deindustrialization, which induced the servicification of occupations.

19.5 Concluding Remarks

Historically, there have been unprecedented structural changes in Asian countries in the last few decades. The share of agriculture has declined sharply, and the shares of industry and services are increasing rapidly. The pattern of structural change, however, has been diversified, even within a country, and not all economies have moved in the same direction and at the same speed. While we still observe that the employment shares in agriculture in Asia are still significant, we also recognize the need to speed up the transition of labor into the more productive manufacturing and service sectors. In addition, these economies will have to industrialize rural areas so that agriculture can catalyze industrial development. Since the agricultural employment capacity has been more or less saturated in Asia, it will be imperative for the manufacturing and service sectors to absorb surplus labor from agriculture.

There are remaining issues that need further investigation in the future. First, there is much room for further examination of the role of the agriculture sector in the region as the sector will remain a significant employer in many Asian economies in the coming decades, particularly in agribusiness and food processing. Moreover, developing modern agriculture and facilitating rural transformation remains a priority for many low- and middle-income Asian economies.

Second, it will be imperative to investigate whether manufacturing remains essential and whether industrialization, in general, cannot be bypassed. While historical analysis indicates that, with few exceptions, countries have been unable to achieve a high-income economy without having a significant manufacturing sector, a dramatic decrease in cross-border communication costs and the 'third unbundling' as posited by Baldwin (2016) may enable a country to absorb a large number of laborers in the service sector and, thus, bypass manufacturing production altogether. Since services will ultimately be the largest sector in both output and employment, low- and middle-income Asian economies need to nurture a more productive services sector to achieve inclusive growth in Asia.

Finally, the low carbon and green growth agenda will be a critical strategic overlay for developing Asia's continuing structural transformation because environmental degradation and climate change threaten the sustainability of Asian development. Asian countries must scale up efforts to protect the environment and act toward climate change mitigation and adaptation while the government and private sector support further structural transformation. Examples include manufacturing and services industries supported by enhanced investments in renewable energy, energy efficiency, sustainable public transport, climate-resilient infrastructure, strengthened framework legislation, safeguard policies, and air and water quality standards.

Recollections of Professor Keijiro Otsuka

I had the chance to meet Professor Kejiro Otsuka for the first time in 1995 when I worked for the International Food Policy Research Institute (IFPRI) as an unpaid summer intern. Considering my situation, Kei kindly offered me a free house-sitting opportunity while his family was away visiting Africa. Since then, we have worked together and have become close friends. In 2008, we coedited a book entitled *Rural Poverty and Income Dynamics in Asia and Africa,* published by Routledge (Otsuka, Estudillo, and Sawada), for which I had a memorable visit to the International Rice Research Institute (IRRI) with him and Jonna as well as Professors Yujiro Hayami and Randy Barker, among others. In the last two decades, Kei has been one of the most influential persons in my academic and non-academic life. I am honored very much to join the Festschrift celebrating his substantial contribution.

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Chapter 20
Mechanization and the Intersectoral Migration of Agricultural Labor

Donald F. Larson and Kevin L. Bloodworth II

Abstract For most countries, the historical path to development includes a sectoral shift of labor from agriculture to other sectors, an inflow of capital to agriculture, and a boost in land productivity. Early in the process of structural transformation, when populations are primarily rural and agrarian, the pace of sectoral migration can appear slow, as births that occur in much larger rural populations nearly match out-migration. As populations become increasingly urban, the dynamics shift, as rural populations experience continued out-migration matched with a declining share of births. This sets the stage for rising wages and labor-saving mechanization in agriculture. In many places, mechanization is associated with economies of scale that encourage a transformation in farm structures toward larger farms. Still, farm structures have been slow to change in Asia and Africa, where most farms are small, limiting potential productivity gains. This chapter uses a cross-country panel of data spanning five decades to examine the relationships among sectoral migration, gaps in sectoral incomes, and mechanization.

20.1 Introduction

In a process repeated in the history of most countries, agrarian economies transform. Central to that process is the reallocation of labor from agriculture to other sectors. In 1975, the geographer David Grigg (1975) noted that agriculture remained the world's most important source of employment, as it had since Neolithic times. This enduring dominant role of agriculture for livelihoods drew people to rural areas where land, water, and climate resources were well suited to agriculture.

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In a lifetime, the way most people work and the places they live have changed dramatically. Grigg estimated that the share of the world's workers employed in agriculture fell from 72 to 62% between 1900 and 1950. Little changed in the developing world; agriculture's share of employment fell from 78 to 73% during the same period. Nearly 70 years later, the International Labor Organization (ILO) estimates that agriculture employed 27% of the world's workers in 2019. The trend has been pervasive and not limited to wealthy countries; among middle- and low-income countries, agriculture's share of employment averaged 32% in 2019 (World Bank 2022).

Closely associated with the movement of labor from agriculture to other sectors has been the movement of people from rural areas to cities and suburbs as the need for workers to live near the fields and pastures they tended gave way to jobs in sectors that benefit from economies of scale and agglomeration (Williamson 1988; Quigley 2008). Between 1950 and 2020, the share of the global population living in rural areas declined from 70 to 40% (UN 2022). The changes were apparent in most countries. In 1950, the United Nations reported that rural populations exceeded the urban population in 75% (151 of 201) of the countries it had data on (UN 2022). By 2020, the number had fallen to 32% (159 of 234). Increasingly, the countries, and places within countries, that remain predominantly rural with high rates of employment in agriculture are poorer. For example, two-thirds of people living in low-income developing countries live in rural areas.

In this chapter, we return to the topic of what determines rates of sectoral migration. We extend a cross-country panel of sectoral income and labor data reported in Larson and Mundlak (1997) to take advantage of national experiences that have occurred in the 25 years since the paper was published. A focus of that paper was to test whether sectoral adjustments in the allocation of labor responded to differences in average-value labor products, as economic theory would suggest. The results supported the notion that they did, as do the findings of this chapter. As explained later, several reasons, including uncertainty and a reluctance to forgo place-specific social capital, could create a wedge between equilibrium labor-product values so that sectoral migration would halt before average incomes in and out of the sector were equal. The Larson-Mundlak estimates revealed evidence of a quantitatively small average-product wedge that was not statistically distinguishable from zero. Our results indicate the same.

Unlike the earlier paper by Larson and Mundlak (1997), we also look at the role played by mechanization. Potentially, imperfections in capital markets could result in less-than-optimal capital-to-labor ratios in rural areas, particularly in agriculture. This could lead to a situation where agricultural labor is substituted for capital made unavailable due to poorly functioning markets. Said differently, capital constraints could preclude otherwise justifiable adoptions of labor-saving mechanization technologies. We find evidence that migration rates speed up as tractor inventories build up, but only when potential regional differences are ignored. Ignoring regional differences has otherwise little impact. This suggests that differences in capital markets or other regional differences may affect mechanization outcomes.

20.2 Background

This chapter is concerned with what determines the restructuring of labor from agriculture to other sectors and its pace. From a macroeconomic perspective, the flow of labor to other sectors, where incomes are higher, is part of an economic growth process that boosts incomes and reduces poverty. So, it is important to understand why the process moves faster in some places than others and why gaps in average sector incomes linger. This chapter is part of a broad literature concerning the links between migration and livelihoods.[1]

Applied studies in this area attempt to explain actions measured at an aggregated level, and related empirical models rely on sector data in countries over time or cross-country panel data. For example, early studies examined the transformation of the British economy during the Industrial Revolution (Williamson 1990); the growth in the US and Japanese economies during the twentieth century (Bellante 1979; Barkley 1990; Minami 1967, 1968; Mundlak and Strauss 1978); and cross-country experiences (Mundlak 1978, 1979; Squire 1981). For early reviews, see Greenwood (1975), Yap (1977), and Molho (1986).

The empirical model is influenced by Sjaastad's (1962) view of migration as an investment in future welfare and Todaro's (1969) observation that migration depends on expected rather than actual wages. Subsequently, a series of empirical models emerged that explained observed migration using wage and, later, income differentials. Still, as Ramsey et al. (2021) point out, early empirical studies were largely empirical constructs that lacked a basis in microeconomic foundations.

Later, the empirical models of aggregate migration indicators would be linked to models of individual choice, building links between theory, household-based empirical studies, and sector studies (Mundlak 1979; Barkley 1990; Larson and Mundlak 1997). Our empirical model is derived from an individual choice model, where migration is motivated by differences in lifetime expected utility, which at the sectoral level is related to sectoral differences in average incomes. We explain the empirical model further in the next section. The conceptual model behind it is derived from a technical annex in Larson and Mundlak (1997). Related studies include Butzer et al. (2002, 2003).

20.3 Applied Model

The empirical model we use is derived from a conceptional model of individual choice in an appendix of Larson and Mundlak (1997). Broadly, the intuition behind the model is that potential sectoral migrants of age g with attributes z compare expected welfare differences between a lifetime employed in agriculture and a lifetime employed in alternative sectors. Age matters, partly because the evaluation occurs over a lifetime,

[1] For insights into the breadth of the literature, see Lucas' (2014) edited handbook.

and also because stocks of skills best suited to one sector or another can accumulate with time. Attitudes toward risk aversion may also shift with time.

Historically, income gaps have been significant, sustained, and easily observed, especially in developing countries, so expected incomes are central to the applied model. We use average incomes rather than wages as our indicator of expected incomes. Measured as sector value-added divided by the size of the labor force, income indirectly accounts for unemployment and provides an averaging across wage differentials within sectors. In our conceptual model, the pool of individuals who conclude that they would be better off seeking employment outside of agriculture grows as income gaps widen.

We use educational attainment, that is, years of schooling, as a measure of portable human capital since greater educational attainment should lower the costs of the new skills needed to do well in a new sector. Alternatively, workers also acquire skills with experience and, as children, may learn from their parents, especially in rural areas. However, these experiential skills are not necessarily transferable to other sectors. This is another reason to expect that younger workers are more likely to migrate since migrating later in life means abandoning greater accumulations of human capital.

Studies based on household and migrant surveys reveal additional factors tied to social capital, which are harder to measure in sectoral labor studies. Some likely work in ways similar to human capital. For example, in choosing to migrate, workers who have become part of a community and whose families may have been part of the community for generations must abandon ties that provide support, solidarity, and informal forms of insurance—costs to migration that increase with age.

Illiquid forms of productive capital, especially smallholder land, which likely accumulates with age, also work to constrain migrants.

Other forms of social capital can work to lower migration costs. A supportive extended family and being rooted in a community can provide a backstop for expected gains from leaving the sector, mitigating potential risks. Moreover, young migrants may be motivated by the potential to improve the lives of their extended family through remittances, and networks are an important form of social capital that can lower migration risks and transaction costs.

Last, empirical migration models must account for existing stocks of sector labor and natural rates of change due to population increase. This is especially important for agriculture because the places most conducive to agriculture are often spatially separate from where non-agricultural jobs are concentrated. Consequently, children born to parents employed in agriculture will more likely develop human and social capital stocks that support livelihoods related to agriculture and face greater obstacles when seeking jobs in non-agricultural sectors than children born to workers in other sectors. Said differently, migration costs are avoided for workers who remain in the places they were born and work using skills they learned growing up; consequently, the initial states of labor allocations matter in models of sectoral migration.

With this as background, our empirical model is written as:

$$m_t = b_0\left[\delta_{t-1} - (1+k)\right]^{b_1} r_{t-1}^{b_2} (1+n_t)^{b_3} z_{t-1}^{b_z} + u_t \tag{20.1}$$

where

$m = M/L_a$ is the ratio of migrants (M) to agricultural labor (L_a);

$\delta = w_n/w_a$ is the ratio of income in non-agriculture (w_n) to that in agriculture (w_a);

r is the ratio of labor in non-agriculture to that in agriculture (L_n/L_a);

n is the rate of labor-force growth; and

z is a vector of additional determinants.

For estimation purposes, the equilibrium point $(1 + k)$ is estimated directly, where $c_0 = (1 + k)$.

The model is structured such that the migration rate increases with the intersectoral income differential, dependent on the labor-force composition and other attributes (z). A key reference point for δ is the equilibrium point at which migration would cease. Under ideal circumstances, it might be reasonable to think that migration from agriculture would stop (an equilibrium point reached) when average incomes in agriculture equaled average incomes out of agriculture; that is when δ= 1. However, as discussed, there are compelling reasons to believe that the equilibrium point is elsewhere. To account for this, an additional parameter, k, is introduced so that the equilibrium point could be reached despite an inequality of average incomes, that is, for values of δ other than 1.

Transaction costs associated with moving from agriculture are numerous and include information barriers, misaligned skills, poorly functioning land markets that make land assets illiquid, location-specific social capital, and uncertainty. For these reasons, an equilibrium point may be reached even when incomes in agriculture remain slightly below non-agriculture, that is, when δ > 1.

Richards and Patterson (1998), Dennis and İşcan (2007), and Önel and Goodwin (2014) suggest that real-options values, which place a premium on waiting due to uncertainty, are important migration costs and therefore help explain lingering sectoral wage or income gaps. On the other hand, Ramsey et al. (2021), using data from Japan and the United States, dispute this assertion and find no empirical support for the complex non-linearities that arise from including option costs in empirical models of sectoral migration.

Recently, Foster and Rosenzweig (2022) have argued that high transaction costs associated with hired labor, together with hurdles to land accumulation in India, create a locally- but not globally-optimal farm size that is small; a condition that precludes potential productivity gains via mechanization. Because mechanization substitutes for labor, the disequilibrium described by Foster and Rosenzweig as "too many small farms" is also a disequilibrium of too many farmers. Potentially, constraints to out-migration may also explain the set of forces that keep farms small in Asia and Africa. Conversely, the successful adoption of mechanization may free labor resources locked in labor-intensive small farms and speed up migration rates.

Evidence elsewhere suggests a range of relationships between mechanization and labor intensity (Otsuka et al. 2016). For example, the adoption of mechanization can be associated with partial substitution of machines for labor where on-farm labor inputs decline, and household labor is split between on- and off-farm employment, muting the transformation of labor markets. See, for example, the transition toward mechanization in the Philippines described by Estudillo and Otsuka (1999). Elsewhere, mechanization is associated with an increase in the size of cultivated farms and labor specialization. For example, Wang et al. (2016) describe how mechanization has been associated with increased average areas cultivated by farmers, increased migration, and a selection process whereby less educated farmers tend to specialize in farming. Still, it is worth pointing out that the disparities in the adoption of mechanization technologies share some similarities with the uneven adoption of Green Revolution technologies in Sub-Saharan Africa, where adoption rates are place-specific (Otsuka and Larson 2012, 2016).

Under ideal conditions, the productivity impacts of mechanization are fully reflected in agricultural wages and the average-value product of agricultural labor. Still, there are good reasons to believe this is not the case, including the effects of constraints on labor markets, land markets, and the well-known constraints on agricultural lending (Yadav and Sharma 2015). For this reason, we also include a measure of mechanization in our analysis.

20.4 Data

For most countries, migration is not directly measured, so it must be inferred from observations on labor. For our purposes, the underlying assumption is that without migration, labor in agriculture and non-agriculture would grow at the same rate as the labor force. Deviations from this are attributed to sectoral migration. In most cases, labor force and population data depend on censuses taken every ten years in most countries. Consequently, we base our calculations of migration on data that are ten years apart. Letting L_T represent total labor, migration from the agricultural sector is given as:

$$M_t = \left[\frac{L_{Tt}}{L_{Tt-10}}\right] L_{at-10} - L_{at} \tag{20.2}$$

Annualized migration rates are calculated as:

$$m_t = \left[\frac{M_{Tt}}{L_{a-10}}\right] \div 10 \tag{20.3}$$

The data in our analysis covers five decades, beginning in 1960 up to 2010. Using various sources, we extended the data reported in Larson and Mundlak (1997). The additional labor data is from the International Labor Organization, as reported in the World Bank Development Indicators (2022). The data on GDP and agricultural share of GDP is also from the World Bank, supplemented with data from the Food and Agriculture Organization of the United Nations (FAO 2022). Data on educational attainment is from Barro and Lee (2013), while additional population data comes

Table 20.1 Sample averages, by decade

Decades	1960s	1970s	1980s	1990s	'00 s
Observations	77	105	108	111	130
Migration	2.01	2.24	2.65	1.47	2.60
Labor growth	2.05	2.48	2.36	2.47	2.39
Ratio of incomes	1.86	2.85	4.20	6.65	15.80
Education, years of schooling	3.50	4.07	5.14	6.19	7.67
Share of population, 15–39	0.37	0.36	0.38	0.39	0.40
Tractors in use, thousands	121.68	129.80	170.01	196.68	197.24

Note Migration rates and labor growth rates are reported as percentage change per year from the beginning to the end of the decade. The remaining statistics are reported at the start of the decade

from the United Nations (2022). To proxy the extent of mechanization, we use data on the stock of tractors in use from FAO (2022).

The original data from Larson and Mundlak (1997) begins in 1950; however, the data on tractors are only available from 1961 to 2008. Using the 1961 data to proxy the beginning inventory value of tractors in 1960, the available data limits our analysis to five decades, starting in 1960 and ending in 2010.

As shown in Table 20.1, the panel is unbalanced, with the number of countries and the composition of countries changing each decade. We have data for 77 countries in our sample for the decade starting in 1960 and 130 countries from 2000 to 2010.

Annualized migration increased through the first three decades, slowed during the tumultuous 1990s, then quickened again in the '00 s. The size of the labor force grew consistently across decades. Consistent with trends in urbanization, the size of the non-agriculture sector relative to agriculture has increased rapidly during the past two decades. Educational attainment steadily increased, and the share of the working-age population under 40 increased slightly. Mechanization rates were already high in most countries in our sample by the 1960s, but gains were made in some places that the cross-country averages obscure.

20.5 Estimation Results

The model given in (Eq. 20.1) is nonlinear because of the inclusion of the wedge parameter k, so we estimated the model using nonlinear least squares, weighted by population. The full model estimates, complete with decade and regional dummies, are given in Table 20.2. Except for the parameter association with stocks of tractors, the estimated parameters are all statistically significant and take on the expected sign.

Of special interest is the equilibrium point parameter, c_0, reported at the top of Table 20.2. The estimate implies that migration halts when the ratio of non-agricultural income to agricultural income reaches 0.97, implying a wedge equal to -0.03. While the estimated parameter, c_0, is statistically different from 0, it is not statistically different from 1, as shown by the test statistic reported near the bottom of the table. Consequently, we cannot reject the notion that migration from agriculture continues until average incomes in and out of agriculture are equal. It is worth noting that when $k = 0$, the nonlinear migration model in (Eq. 20.1) collapses to a nested linear model. This is consistent with the preference of Ramsey et al. (2021) for linear over nonlinear models in their study of Japan and the United States.

The parameter on relative incomes (b_1) shows that migration out of agriculture speeds up as income differences increase. The parameter is slightly lower than the estimated value of 0.36 in Larson and Mundlak (1997). The model shows that migration increases as the labor force grows, but not proportionately. In line with expectations, the estimates show that youth matters; as the share of the working-age population under 40 increases, migration rates increase dramatically. That said, the spread in this demographic category is quite small in our sample, with a standard deviation of 0.03. Consequently, a two standard deviation increase in 'youthfulness' would only increase migration rates by 0.15% per annum.

The results also show that increases in educational attainment also speed up out-migration. At 0.50, the estimate is higher but consistent with Larson and Mundlak's (1997) estimate of 0.29. It is also consistent with the finding that farmers leaving agriculture in China tend to be better educated than those that remain (Wang et al. 2016).

As noted, the estimated parameter on the tractor stocks is statistically indistinguishable from zero and takes the wrong sign. However, this is not true in comparable regressions where regional dummies have been omitted (Table 20.3). Moreover, excluding regional dummy variables does not affect the sign or significance of other parameters. Neither does excluding decade dummies.

Looking closely at the tractor-related results, it is important, at the start, to note that each of the individual time and region dummies are statistically significant and that tests that all regional dummies are equal can be rejected, as can the assertion that all time dummies are equal. Further, it could be that our proxy for mechanization (i.e., FAO's count of tractor stocks) is a poor indicator of the extent of mechanization. Still, our sample rates of mechanization differ significantly relative to other determinants by region and region over time (Table 20.4).[2]

As such, it is plausible that the combination of time and regional dummies adequately sweeps up the effects of mechanization in the context of our cross-country panel. After all, under ideal land, labor, and capital markets, the impacts of investments in mechanization are captured by the value products of labor. Still, while these diminish the likelihood that our estimates are biased and imprecise, it leaves unsettled the degree to which constraints on the adoption of labor-saving technologies, especially mechanization technologies, impact the structural transformation of labor markets and economies.

[2] See Binswanger (1986) for a historical perspective on tractor use in Africa.

Table 20.2 Nonlinear regression results, full model

Parameter	Estimates	t-score	$P > t$
Equilibrium point ($c_0 = 1 + k$)	0.97	4.44	0.00
Parameters on			
Income ratio (b_1)	0.20	3.10	0.00
Labor ratio (b_2)	0.17	4.83	0.00
Labor growth (b_3)	0.50	2.14	0.03
Age (b_4)	2.46	6.29	0.00
Education (b_5)	0.50	5.23	0.00
Tractors (b_6)	−0.02	−1.26	0.21
Dummies			
1960s	0.59	6.04	0.00
1970s	0.28	3.13	0.00
1980s	0.41	6.32	0.00
‘00 s	−0.25	−3.05	0.00
Africa	−2.88	−5.99	0.00
Asia & Oceana	−2.86	−6.11	0.00
Latin America	−2.64	−5.55	0.00
North America & Europe	−2.63	−5.10	0.00
Related tests	Test statistic	$p > F$	
Wedge (k) equals zero	$F(1{,}516) = -0.03$	0.891	
Time dummies are equal	$F(3, 516) = 26.78$	0.000	
Regional dummies are equal	$F(3, 516) = 3.51$	0.015	

Note The model was estimated using Stata 17’s nonlinear least squares estimator

20.5.1 The End of Surplus Labor and the Dual Economy

The gap between incomes in agriculture and other sectors was central to early theories of economic development. The disparity in economic welfare was apparent between the places where households depended on agriculture for their livelihoods and places where they did not, both within and among countries.

Early development theory focused on so-called ‘surplus labor’ locked in agriculture. This gave rise to a class of dual-economy models, where the dynamics of developing economies centered on labor, capital, and technology flows between agriculture and industry. The models were central to early debates about development theory (Lewis 1954; Ranis and Fei 1961; Jorgenson 1961, 1967). Broadly, the models were based on observations that, on average, wages and per capita incomes were lower in agriculture and higher in industry, and the dynamics centered on moving labor

Table 20.3 Nonlinear regression results, with and without regional dummies

Parameter	Estimates	*t*-score	$p > t$	Estimates	*t*-score	$p > t$
Intercept (b_0)	−4.31	−9.30	0.00			
Equilibrium point ($1 + k$)	0.99	4.65	0.00	1.02	14.84	0.00
Parameters on						
Income ratio (b_1)	0.21	3.16	0.00	0.71	6.07	0.00
Labor ratio (b_2)	0.99	4.65	0.00	0.68	14.76	0.00
Labor growth (b_3)	0.18	5.08	0.00	3.50	11.10	0.00
Age (b_4)	0.95	4.01	0.00	3.76	8.68	0.00
Education (b_5)	0.88	2.56	0.01	1.44	8.83	0.00
Tractors (b_6)	0.46	4.26	0.00	2.41	31.76	0.00
Dummies						
1960s				−37.81	−32.25	0.00
1970s				−38.94	−33.78	0.00
1980s				−37.38	−33.52	0.00
‘00 s				−38.00	−33.35	0.00

Notes Tests where the income wedge k equals zero could not be rejected in either alternative version of the model. In the model with neither regional nor decade dummies, the test returned a test score $F(1, 523) = 0.00$, with $p > F = 0.95$. Including regional dummies resulted in $F(1, 519) = 0.09$, with a $p > F = 0.766$. Each decade dummy is significant individually, and a test that the decade dummies were equal to one another yielded an F(4,519) score of 1,586, with $p > F = 0.00$

Table 20.4 Tractors in use divided by the number of workers employed by agriculture (FAO 2022)

Year	Africa	Asia and Oceania	Latin America and Caribbean	North America and Europe	Total
1960	0.004	0.007	0.016	0.214	0.059
1970	0.006	0.041	0.027	0.371	0.096
1980	0.012	0.060	0.035	0.542	0.137
1990	0.015	0.087	0.032	0.720	0.173
2000	0.012	0.088	0.032	0.724	0.220
Total	0.010	0.065	0.029	0.540	0.145

from traditional agriculture. Core debates centered on the extent to which agricultural labor could supply economic growth in other parts of the economy. Dual models of development gave rise to the type of analysis presented here and early explanations of inequality (Todaro 1969; Knight 1976; Robinson 1976; Bourguignon and Morrisson 1998).

The idea that agriculture was a nearly endless source of labor was understandable when the dual model emerged. After all, in the developing world, agriculture employed nearly three-quarters of the labor force in 1950, down only slightly from

77.9% in 1900. Moreover, the number of developing-country workers in agriculture had increased by 44% in that period.

To see this, consider the following decomposition, derived from our earlier definition of migration:

$$\Delta L_a = 1 + n - m \tag{20.4}$$

When migration rates (m) approximate labor-force growth rates (n), changes in the number of agricultural workers are easily obscured, especially when measures of the sector's workforce are inexact (Larson and Mundlak 1997). Our sample showed that differences between the two rates were generally small. Nonetheless, the effects accumulate with sufficient time as the share of labor outside of agriculture grows. At a point, the flows from agriculture become less important than the natural growth within non-agriculture. Specifically, in (Eq. 20.5), the number of migrating workers (M) becomes small relative to the number of workers born into the sector ($L_{nt-1}e^n$).

$$\Delta L_n = L_{nt-1}e^n + M_t \tag{20.5}$$

In 1970, Dixit wrote, "In the long run, one hopes, the dual economy will cease to be dual" (p. 229). As shown in Table 20.5, that time is upon us.

Table 20.5 reports the share of the population living in rural areas, which historically closely follows the share of labor engaged in agriculture. The underlying data is taken from FAO's (2022) historical and projected population numbers. The series runs from 1950 to 2050. The table reports the share of populations living in rural areas by region in 1950 and projected shares for 2050. The table also reports 'inflection years,' which are years in which rural population shares dipped below 50%.

The table shows that most of the world's population (70%) lived in rural areas in 1950 and that most people lived in rural areas until well into the twenty-first century. However, by 2050, nearly 70% of the world's population will not live in rural areas. Harkening back to David Grigg's quote, agriculture's dominant role as an employer, which began in Neolithic times, ended in this century.

Still, the disparities in income that motivated early dualistic models of development remain. In the wealthy countries of North America, Northern Europe, and Oceania, rural population shares had already fallen below 50% by 1950. During the late 1950s and early 1960s, urban majorities had emerged in Central and South America and Eastern and Southern Europe. In contrast, Asia's population remained primarily rural until 2018, and Africa's population is projected to remain primarily rural through 2035. Projections suggest that rural populations will remain in the majority beyond 2050 in Eastern Africa, Melanesia, and Polynesia.

As Menashe-Oren and Bocquier (2021) point out, global urbanization is no longer driven by sectoral migration, and as Taylor et al. (2012) note, the era of farm labor abundance is ending in many places.

Table 20.5 The transformation of rural populations. (FAO 2022 and authors' calculations)

Area	Share 1950	Inflection year	Share 2050
World	0.70	2007	0.32
Africa	0.86	2035	0.42
Eastern Africa	0.95	post-2050	0.55
Middle Africa	0.86	2019	0.33
Northern Africa	0.75	2012	0.35
Southern Africa	0.62	1994	0.22
Western Africa	0.91	2024	0.37
Americas	0.47	pre-1950	0.12
Northern America	0.36	pre-1950	0.11
Central America	0.61	1966	0.17
Caribbean	0.64	1976	0.18
South America	0.57	1959	0.10
Asia	0.83	2018	0.34
Central Asia	n.a	2026	0.37
Eastern Asia	0.82	2007	0.18
Southern Asia	0.84	2044	0.46
Southeastern Asia	0.84	2021	0.34
Western Asia	0.73	1978	0.19
Europe	0.49	pre-1950	0.16
Eastern Europe	0.61	1963	0.20
Northern Europe	0.28	pre-1950	0.11
Southern Europe	0.54	1958	0.18
Western Europe	0.35	pre-1950	0.13
Oceania	0.37	pre-1950	0.28
Australia and New Zealand	0.24	pre-1950	0.09
Melanesia	0.82	post-2050	0.68
Micronesia	0.69	1972	0.24
Polynesia	0.77	Post-2050	0.51

20.6 Conclusions

We extended the dataset used by Larson and Mundlak (1997) and replicated their analysis. We also expanded the analysis to consider the impact of labor-saving mechanization on migration rates. Our analysis covers migration across five decades, beginning in 1960 and ending in 2010.

During that time, the process described conceptually and empirically in Larson and Mundlak (1997) continued. Rates of migration out of agriculture to other sectors proved responsive to income differences. The model suggests that younger and better-educated workers were most likely to leave agriculture. Moreover, the flow of migration was path-dependent and depended on the initial allocation of labor between sectors and labor growth rates.

Despite reasons to believe that transaction costs and imperfect labor markets might cause migration to cease before income gaps between the sectors disappeared, no evidence was found to support the existence of an equilibrium income wedge, a finding also consistent with Larson and Mundlak (1997).

Evidence favoring the notion that the use of labor-saving mechanization technologies was elusive, perhaps due to the limitation in our proxy measure (i.e., national tractor inventories). An alternative explanation is that the heterogeneity in the adoption of mechanization technologies is largely explained by regional differences and that measured impacts of adoption on migration rates are subsumed into measured regional effects. Regardless, further research along the lines of Estudillo and Otsuka (1999), Otsuka et al. (2016), and Wang et al. (2016) is needed to fully understand the constraints on the adoption of mechanization technologies.

More broadly, the inherent dynamics of sectoral migration have played out in a dramatic but predictable way over the last 70 years. Proportionally, small flows of labor out of agriculture into other sectors were at first hard to distinguish from natural rates of population growth, leaving economists to speculate about nearly perfectly elastic supplies of labor originating in agriculture. Over time, the small flows of labor accumulated, and the shift in labor allocations shares accelerated, shifting populations from rural spaces to urban centers.

The structural transformation of labor, away from its long-standing center in agriculture, is nearly complete in many places but continues to play out in others. Still, the broad dynamics driving change are already in place. In all likelihood, the seeds of the next transformation are also in place.

Recollections of Professor Keijiro Otsuka

Gershon Feder introduced me to Kei when I was a researcher at the World Bank. The meeting launched a collaboration resulting in journal articles, book chapters, and two edited volumes on Green Revolution technology adoption in Africa. In addition to having the opportunity to work with Kei, I had the chance to enjoy his company and meet his students over dinners in Washington, Tokyo, and Nairobi. Kei is a prolific and influential researcher, well known to the international community and policymakers. He is energetic and engaging. Importantly, he is a supportive teacher and mentor. He launched and guided a new generation of skilled economists, especially during his stewardship of GRIPS (National Graduate Institute for Policy Studies). I would like to thank the editors for inviting me to contribute to this volume. It is a special honor and pleasure to be part of the Festschrift celebrating Keijiro Otsuka.

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Part IV
Emerging Issues in Agriculture

Chapter 21
Blue Revolution in Asia: The Rise of the Shrimp Sector in Vietnam and the Challenges of Disease Control

Aya Suzuki and Vu Hoang Nam

Abstract The aquaculture sector has grown rapidly over the last two decades, particularly in Asia, providing a larger share of seafood for human consumption than capture fisheries. It has received attention for its contribution to poverty reduction and nutrition improvement for the poor. In this essay, we illustrate the brief history of the development of the aquaculture sector in Asia and present a case of the shrimp sector in Vietnam, one of the largest exporters in the global market in recent years. We show how the sector has developed, particularly in relation to rice production, using nationally-representative household-level data. We then examine a persistent challenge faced by the sector, the frequent occurrence of disease outbreaks, based on our analyses using primary data and randomized controlled trials (RCTs). Specifically, we consider the role of spillovers among farmers and the importance of quantifying unobserved qualities in promoting the adoption of good practices. The effectiveness of digital technology in this area is discussed.

21.1 Introduction[1]

Global fish consumption increased rapidly over the past decades due to rising awareness of healthy diets. The aquaculture sector has contributed to this growing fish demand, providing a higher proportion of total fish consumed than the share supplied by capture fishing in 2018 (FAO 2020; ADB 2021). While fish farming has long been a tradition in many Asian countries, new technologies and farming practices have been introduced to meet the growing demand. Praised as the 'Blue Revolution' in

[1] This chapter draws findings from Suzuki (2021) and Suzuki et al. (2021, 2022). The authors thank Nguyen Thu Giang for her assistance in preparing the data used.

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many Asian countries, this sector is important for development as it can contribute to income generation of smallholder farmers as producers and nutrition improvement of the poor as consumers, and because of its potential impacts on the surrounding environment (Rashid and Zhang 2019; Suzuki 2021).

However, the sector faces one persistent issue: Disease outbreaks. Lafferty et al. (2015) noted that "Aquaculture's history is one of the victories over diseases followed by new challenges" (p. 476). Recent intensification of farming methods to meet the growing demand for fish is also prone to disease outbreaks unless proper practices are in place. As fish vaccinations are not common, farmers tend to use antibiotics, which are prohibited internationally, to prevent the occurrence of such diseases (Lee et al. 2019). Although international and local guidelines for good fish farming practices have been developed, they are not adopted universally in developing countries. Due to the difficulty in managing the wide variation and number of small-scale farmers' farming practices, exported seafood is notorious for the high rejection rates at the ports of developed countries (UNIDO-IDE 2013). Having high rejection rates harms the reputation of the exporting country and affects the volume of its exports. Thus, it is critically important for exporting countries to manage this traceability from the very upstream of the supply chain.

In this chapter, we will illustrate a brief history of the development of shrimp farming in Asian countries based on a literature review and present a case of Vietnam to show the sector's role in the economy, particularly relative to rice production. Then we discuss the challenges of disease outbreaks drawing from our own research. We conclude with some policy recommendations and the way forward for the sector.

21.2 Brief History of Shrimp Farming in Asia

In the 1970s, shrimp were mainly caught in the ocean by trawler vessels (Murai 1988). However, due to the risk of depleting marine resources with this untargeted fishing, many governments placed bans and restrictions on trawling methods in the 1980s. Around the same time, a Taiwanese researcher succeeded in the induced spawning of black tiger shrimp in 1983, which resulted in the rapid growth of shrimp farming in Taiwan (Murai 1988). Taiwan was able to achieve high growth in this sector; this is because it has a long tradition of fish culture, flat coastal land, and appropriate climate. It also had advanced aquaculture technologies, such as mass propagation and disease diagnostics and prevention (Chen and Qiu 2014). Their innovations in shrimp farming technologies were also supported by the foundational works of Japanese researchers and amplified by the strong demand for shrimp imports from Japan (Murai 1988).

Technology developed in Taiwan and Japan spread to other countries in Southeast Asia in the 1980s, and the production of the black tiger species started in Indonesia, the Philippines, and Thailand (Belton and Little 2008; Yi et al. 2018). In the Philippines, the San Miguel Corporation played a key role in converting sugar land to shrimp ponds, responding to the depressed sugar sector. Meanwhile, government support was more apparent in Thailand and Indonesia. The Thai government started supporting the sector in the early 1970s, and the growth in intensive production started in the late 1970s and early 1980s. The Asian Development Bank had a large project on this sector in 1981, and a joint venture between the largest Thai conglomerate, the Charoen Pokphanand Group (CP), and the Japanese conglomerate Mitsubishi was established in 1986 (Hall 2004). In Indonesia, the government promoted shrimp aquaculture after the ban on trawler shipping, which was the major form of shrimp production at that time, and declining oil prices in the export market.

Although the development of shrimp farming was one step forward in reducing the negative impacts on marine resources, in the 1990s, many environmental issues related to aquaculture emerged, such as land subsidence due to pumping too much groundwater, frequent disease outbreaks, destruction of coastal areas, and severe damage to the sector. In the same period, the shrimp sector in all the countries was hit by disease. The Thai shrimp sector was more resilient in that it was able to sustain itself by shifting the major production area from the Gulf of Thailand to the south and applying various farming techniques innovations. Hall (2004) noted that the relative success was mainly due to the following: (1) farmers changing their risky production practices; (2) government support, including investment in infrastructure and the establishment of water treatment centers; and (3) various farming innovations developed in Thailand by both the CP group and small-scale farmers. The CP group operates at every stage of the shrimp supply chain, from hatcheries, feed mills, shrimp ponds, laboratories, research institutes, and marketing stages, and it plays an important role in educating independent small-scale farmers on farming techniques (Goss et al. 2000). Hall (2004) also noted that feed mills in Thailand have incentives to teach farmers good practices as receiving returns on their investment in feed manufacturing takes time. Moreover, small-scale farmers have been actively developing on-farm innovation technologies in Thailand. Conversely, the separation of landowners and farm managers in the Philippines was not conducive to promoting on-farm innovations as it reduced incentives for farmers to be more creative to increase productivity.

The CP group also greatly influenced shrimp farming in other parts of Asia via their subsidiaries or joint ventures in Indonesia, Cambodia, Vietnam, and India. In Indonesia, the response to the disease outbreak by small-scale shrimp farmers was either to move under the control of large-scale corporations or exit production. The government also promoted the relocation of shrimp ponds to other regions through their transmigration programs, which assisted farmers with pond infrastructure and credits. The largest of these corporative complexes became as large as the size of Hong Kong, with 1,600 km of canals and 18,000 ponds (Hall 2004). Indonesia attempted to address this problem by centralizing the water control system.

Environmental issues caused by shrimp farming combined with the depletion of marine resources due to capture fisheries led to the launch of the ‘Code of Conduct for Responsible Fisheries,’ which was endorsed by all the FAO member countries. This code outlines the importance of managing fisheries and aquaculture sustainably, and many technical guidelines and instruments have been developed to realize the principles of the code. Thus, many international organizations joined together to form a consortium to prepare specific guidelines on shrimp farming. After many years of careful research and discussions, the ‘International Principles for Responsible Shrimp Farming’ (FAO et al. 2006) was launched in 2006 and endorsed internationally (Corsin et al. 2008). Further, more detailed guidelines for actual practices that are effective in implementing these principles were developed in many countries (e.g., Vietnam, India, and Thailand) and are referred to as ‘better management practices’ (BMPs) and ‘good aquaculture practices’ (GAPs) (Corsin et al. 2008). These are translated into local languages and disseminated to shrimp farmers via their agricultural extension officers. In addition to these foundational efforts, there have been many international guidelines, standards, and certifications to minimize the adverse effects of shrimp farming on the environment, such as GlobalG.A.P. and certifications by the Aquaculture Stewardship Council (ASC). Many countries have also adopted national certifications in the aquaculture sector. For example, there are three national certification standards in Thailand: GAP, code of conduct, and TAS-7401. The Thai government also requires traceability from hatcheries to the export and registration of shrimp farmers (Suzuki and Nam 2019). Meanwhile, in Vietnam, the government has developed VietGAP, a national standard encompassing various international standards.

Despite all these international efforts to minimize adverse effects, issues associated with sustainable fish farming remain in many countries. First, this may be caused by the diversity of the countries involved in modern aquaculture and the location-specificness of aquaculture, similar to that of agriculture. Second, most of the primary fish farmers in Asia are small-scale farmers operating in ponds less than 1 hectare in size (Hall 2004). Owing to this scale, the number of farmers involved, and the decentralized system involved, controlling all fish farming practices on the ground is extremely difficult. Third, according to Bush et al. (2019), in recent years, the aquaculture sector, which was a ‘south–north’ trade driven by the north lead firms, has transformed itself into a “multi-polarity driven by competing producers, traders, and consumers across, within, and between southern and northern countries” (p. 428). This structure makes it difficult to manage good practices for smallholders as required practices and standards vary across markets.

21.3 Development of the Shrimp Sector in Vietnam

Vietnam was one of the newly-emerging shrimp exporters in the ‘00 s. The country’s rapid growth of shrimp production and exports started when the government issued a decree that allowed farmers to convert their rice farms to shrimp ponds in 2000. This decree was highly appreciated by people in the coastal areas in the south because their rice yields were not as high as in other parts of the country due to the saltiness of their water. Ca Mau, which is located in the southernmost part of the country, produced the largest proportion by volume of farmed shrimp (22%) and farmed fish (4%) in the country in 2018 (General Statistics Office of Vietnam 2020), and the areas for aquaculture ponds and production volume increased after 2000. This was

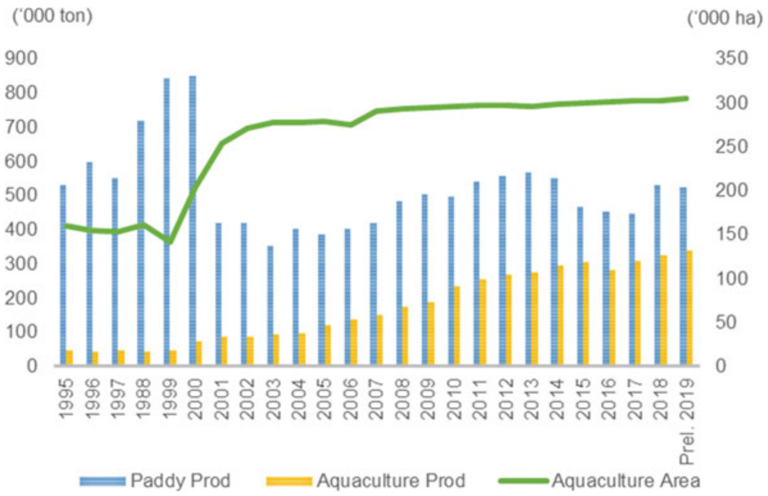

Fig. 21.1 Change in rice and aquaculture production in Ca Mau Province. (General Statistics Office of Vietnam various years)

accompanied by a significant decline in paddy production from the same province (Fig. 21.1).

It was reported that farmers may earn returns ten times more in shrimp farming than those in rice farming (Belton and Little 2008). Figure 21.2 shows that the gross output of product per hectare is higher for the aquaculture surface area than the cultivated area in Vietnam, and the recent growth of the former has been exponential. Black tiger prawn (*Penaeus mondon*), which was originally popular in the area, was cultured up to twice a year, while Vannamei (*Litopenaeus vannamei*), currently the dominant variety, can be cultured up to three times a year as their production cycle is only for three months. Over time, shrimp production in Ca Mau became more intensive, and since 2017, a new farming method known as 'super-intensive' has emerged (Nguyen et al. 2019). The required capital differs across the farming methods adopted. While extensive farming does not require industrial feed, intensive production requires various inputs, such as industrial feeds, aerators, electricity, pumps to remove waste from the pond floor, automatic feeding machines, shade, and water reservoirs. Shrimp needs to be fed 4–5 times a day, and as shrimp are nocturnal, farmers also feed shrimp during the night. Further, farmers need to maintain the water quality in the pond. This high-risk, high-return nature of intensive farming makes it unsuitable for all farmers, even if they have suitable land. In Indonesia, Yi, et al. (2018) provided quantitative evidence that, while there is no barrier to entry for Vannamei shrimp farming, there are barriers to starting intensive farming methods, largely due to capital constraints.

We examined how the development of the shrimp sector took place in relation to rice production based on the Vietnam Household Living Standards Surveys (VHLSS) 2008 and 2018 conducted by the General Statistics Office of Vietnam (Table 21.1).

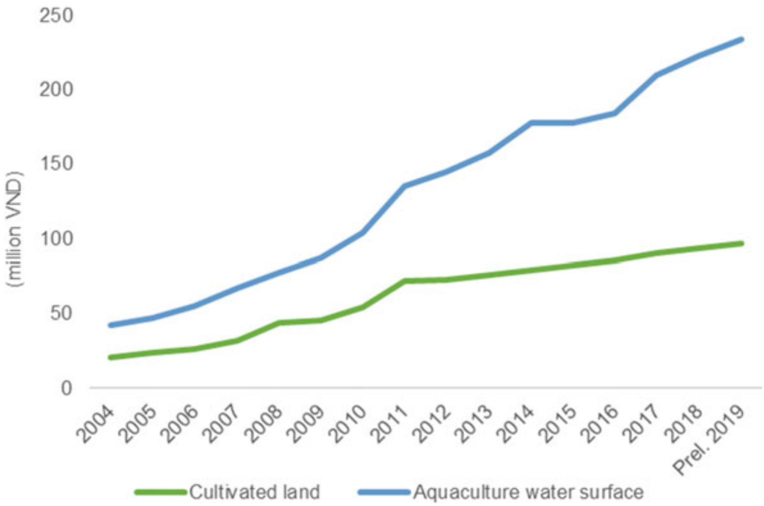

Fig. 21.2 Gross output of product per hectare in Vietnam. (General Statistics Office of Vietnam various years)

Over the decade, the annual income of households increased by 124%. We notice that the area of rice fields declined sharply by 49% and the value of output by 29% over the period, while the production cost increased by 51%, suppressing the profit margin for farmers. However, the profit per square meter (m^2) increased, indicating improved production efficiency.

During the same decade, while the area for aquaculture did not increase much when we examined the nationwide data, the value of aquacultural outputs increased by 186%. The increase in the value of farmed shrimp was particularly large at 268%, while the value of farmed fish increased by 89%. The production costs also rose by 170%, reflecting the introduction of more intensive farming methods, which require more inputs. Even with the increasing production costs, profits from aquaculture also surged at 209%. The increase in the profit per m^2 was insignificant, but it should also be noted that the number of observations for this variable is limited due to missing data.

Per m^2 profit is much larger for aquaculture than for rice production in both years, confirming farmers' comments we received during fieldwork. Another important difference between rice production and aquaculture is the dispersion of the data. The value of output and production costs for aquaculture have much larger standard deviations relative to those of rice production. These reflect various farming methods of aquaculture and their accompanying risks.

Table 21.1 Change in production costs of rice and aquaculture

	2008	2018	%Δ	Diff
	(1)	(2)	(3)	(4)
Annual income per HH (‘000 VND)	66,713 (115,824)	149,743 (164,008)	124.5	0.000***
Rice production				
Area (m^2)	12,813 (23,144)	6,487 (24,217)	−49.4	0.001***
Value of output	30,451 (58,380)	21,741 (89,917)	−28.6	0.030**
Production cost	5,740 (14,667)	8,679 (36,269)	51.2	0.000***
Profit	14,341 (13,708)	13,060 (58,648)	−8.9	0.182
Profit (‘000 VND/m^2)	1.915 (0.617)	2.139 (0.840)	11.7	0.000***
Aquaculture				
Area (m^2)	574.9 (4,900)	587.5 (5,090)	2.2	0.859
Value of output	13,672 (99,495)	39,166 (194,485)	186.5	0.000***
Farmed fish	6,556 (92,833)	12,375 (121,891)	88.8	0.013**
Farmed shrimp	5,975 (33,558)	22,009 (136,945)	268.4	0.000***
Production cost	8,334 (106,651)	22,566 (141,889)	170.8	0.005***
Profit	5,375 (146,771)	16,615 (64,636)	209.1	0.000***
Profit (‘000 VND/m^2)	9.199 (15.201)	16.350 (132.42)	77.7	0.245

Note Computed by authors based on VHLSS 2008 and 2018. Standard deviations are reported in parentheses. *, **, and *** indicate statistical significance at $p < 0.10$, $p < 0.05$, and $p < 0.01$ level. All units are in ‘000 VND unless noted

21.4 Challenges of Disease Outbreak

While the contribution of the shrimp sector is undeniable, it has also faced the issue of disease outbreaks. The common types of disease are acute hepatopancreatic necrosis disease, formerly called the early mortality syndrome, and white spot syndrome. Some diseases are fatal, and farmers may lose all the shrimp harvest. The causes of disease are varied and largely not very well known. The intensification of shrimp farming to meet the rising global demand has increased the density of shrimp stocked and inputs used. Higher density meant greater stress for shrimp. More inputs meant more polluted water due to shrimp waste and uneaten feed. Good management of water quality is essential to maintain the health of shrimp and reduce the likelihood of disease outbreaks.

21.4.1 Spatial Spillovers in Disease Outbreak

One issue that has not received sufficient attention is the role of spillover among farmers. As farmers are connected by waterways, a farmer’s neighbor’s action likely affects the farmer. Water quality is unobservable unless tested frequently, and it is also difficult to monitor farmers' actions all the time. To quantify the effect of spillovers, we considered two channels in which spillovers can affect farmers' outcomes.

First is the physical spillover of pathogens or polluted water across farmers' ponds. The second is the influence of neighbors on the behavior of a farmer, often called peer effects. Recent studies have shown the importance of peer effect in farmers' choice of technology adoption (Conley and Udry 2010). In our case, certain areas may have a higher likelihood of disease because farmers tend to adopt similar, less appropriate farming practices.

Identifying these effects faces the reflection problem posed by Manski (1993). That is, because an individual's outcome tends to be simultaneously determined by his neighbors' outcomes, and an individual tends to choose his own group, decomposing these will be necessary. In this chapter, we show spatial associations among shrimp farmers in their farming practices as well as in the likelihood of disease outbreak. Those interested in further analyses on causal relation should refer to Suzuki et al. (2022).

To examine possible spatial spillovers, we collected primary data from about 600 shrimp farmers in one district in Ca Mau province in Vietnam in 2019, which was also the census survey of shrimp farmers who employed intensive or super-intensive shrimp farming. We explored the possibility of spatial autocorrelation by plotting the global Moran's I (Fig. 21.3). Moran's I was 0.0772 and statistically significant, indicating a positive spatial correlation in the occurrence of disease outbreaks among the shrimp farmers in our field.

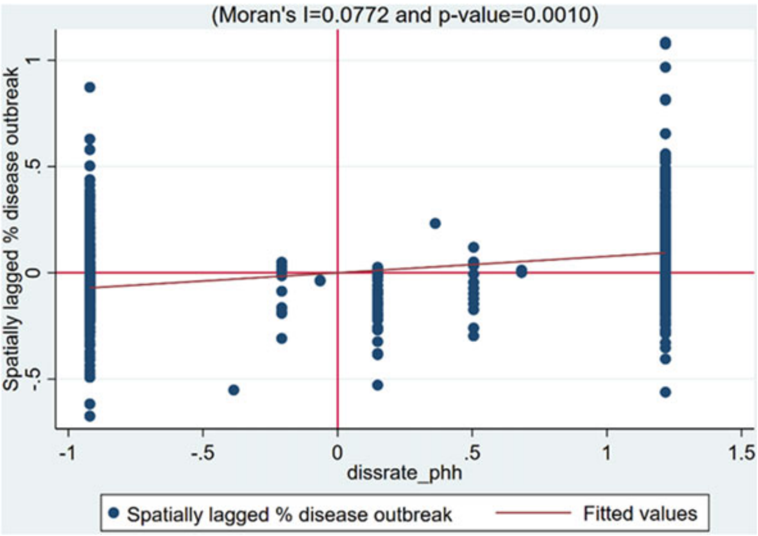

Fig. 21.3 Moran's I plot (Global Moran's I)

To examine more rigorously, we conducted regression analyses. Table 21.2 shows the determinants of farming practices using neighbor's practices as covariates. We find that neighbors' practices are positively and statistically significant in columns (1) and (2), indicating a peer effect on farmers' farming practices.

Table 21.3 shows the determinants of disease outbreaks using neighbors' disease outcomes as covariates. The percentage of disease outbreak is instrumented with higher-order neighbors' outcomes in the IV model. In both models, we found consistent evidence that the higher likelihood of a neighbor's disease outbreak leads to a higher likelihood for the farmer. This suggests that there is a physical spillover of disease across farmers.

Overall, our study results confirm the presence of spillover among farmers both via physical spillover and peer effects in adopting similar practices. This suggests that in implementing policies to reduce disease outbreaks, government and donor agencies should consider farmers and their neighbors as a unit to conduct interventions.

21.4.2 Effective Intervention to Promote Changes in Farmer's Practices

To prevent disease outbreaks, some farmers use antibiotics, which are prohibited internationally. We conducted a randomized controlled trial (RCT) in our study site to examine effective methods to encourage a change in farmers' behavior. Based on our fieldwork, we hypothesized that the reasons why farmers use antibiotics may be due to (1) lack of technical knowledge, (2) lack of awareness of how much residue remains in their shrimp, and (3) lack of financial incentives to comply with good farming methods. We designed an RCT with three arms, each addressing these issues. In particular, we conducted a technical workshop for farmers, quantified antibiotic residues by taking shrimp samples from farmers' ponds, and offered a price premium for farmers whose shrimp passed the quality test ex-post. We collected primary data from shrimp farmers in 2015, 2016, and 2017 while conducting the workshop experiment in 2015, quantification of quality information intervention in 2016, and price premium intervention in 2016. The shrimp samples were taken only in the 2015 and 2017 surveys.

Our intention-to-treat (ITT) results show that quantifying quality intervention was the most effective, while price premium also worked for those who tested positive for residues at the baseline (Table 21.4). Quantifying the quality of shrimp had positive effects on increasing chemical knowledge and conducting better recording practices, while it worked to reduce antibiotics detection ex-post in full sample analyses. When we divided the sample into those who received positive and negative detection results at the baseline, we found that the previous positive effects observed came from those whose shrimps tested positive at the baseline (Panel B). The same result was not observed among the farmers whose shrimp tested negative at the baseline survey. For the price premium group, those whose shrimp tested positive improved their

Table 21.2 Spillover effects on farming practices

	OLS		
	Record	Water	Equipment
	(1)	(2)	(3)
Neighbor effects			
Education completed	−0.026* (−1.938)	−0.008 (−0.617)	−0.012 (−1.292)
Shrimp farming experience	−0.067*** (−3.566)	−0.004 (−0.452)	0.013 (−0.976)
Shrimp farming knowledge	−0.089** (−2.348)	−0.01 (−0.690)	−0.011 (−0.575)
Practice: recording	1.077*** (−3.509)		
Practice: water check		0.991*** (−7.086)	
Practice: equipment			0.605 (−1.806)
Constant	1.104** (−2.701)	−0.292 (−1.289)	0.233 (−0.955)
Observations	616	616	616
R^2	0.211	0.2	0.137

Notes Cluster-robust *t*-statistics at commune levels in parentheses. *, **, and *** indicate statistical significance at $p < 0.10$, $p < 0.05$, and $p < 0.01$ level. Other controls on farmers' own characteristics that were included are male dummy, age, years of education, shrimp farming experience, shrimp farming knowledge, membership in cooperatives, total plot size, number of buyers that the farmer knows, whether engaged in nonfarm activities, frequency of farmer meetings, and trust proxy variables in villages.

Table 21.3 Spillover effects on disease outbreak

	% Disease outbreak per household	
	IV	OLS
	(1)	(2)
Neighbor effects		
% disease outbreak[a]	2.122*** (−3.496)	1.214*** (−4.091)
Education completed	−0.014 (−0.558)	0.013 (−0.579)
Shrimp farming experience	0.061*** (−3.931)	0.070*** (−3.613)
Shrimp farming knowledge	0.078 (−1.259)	0.016 (−0.41)
Constant	−1.318** (−2.318)	−0.618 (−1.169)
Observations	616	616
R^2	0.119	0.146
Wald chi^2 for main regression	2221***	
F-stat for test of endogeneity	3.346	

Notes Cluster-robust *t*-statistics at commune levels in parentheses; *, **, and *** indicate statistical significance at $p < 0.1$, $p < 0.05$, and $p < 0.01$ level, respectively; (a) treated as endogenous and instrumented in Column (1). The same controls as Table 21.2 are used

water management practice and reduced the probability of detection ex-post. This also translated into higher revenue ex-post.

Our RCT result indicates the importance of quantifying quality for farmers to improve their practices. Many aspects of aquaculture are unobserved unless tested, such as various aspects of water quality and shrimp health status. While this is a challenge in this sector, it is becoming easier for farmers to obtain such information via smartphone apps with recent advancements in digital technology. In fact, many IT start-up companies have already introduced various digital apps for farmers, with which farmers can search for market information, calculate the appropriate amount of feed to give, learn about technical issues, and even predict shrimp health status by taking photos (ADB 2021). Farmers themselves upload their farming methods using YouTube or Facebook pages to share information (Lee and Suzuki 2020). Assuring traceability from the upstream, which is critically important to tackle the issue of disease outbreaks and prohibited chemicals, can now be implemented more effectively with digital technologies. It has been implemented at a large scale using IBM Food Trust in countries like Norway and Ecuador, although not at the small-scale farmers' level in Asia. This area needs further work to develop this sector more sustainably.

Table 21.4 ITT effects on knowledge, practice, detection, and revenue

	Knowledge on Chemicals	Test Water Daily	Keep Records	= 1 if one detected above MRL	ln Total Revenue
	(1)	(3)	(4)	(6)	(4)
Panel A: Full sample					
Workshop × 2016	0.006 (0.05)	−0.001 (0.01)	−0.029 (0.28)		−1.705 (1.47)
Workshop × 2017	−0.019 (0.16)	−0.01 (0.07)	−0.200* (1.67)	−0.03 (0.36)	1.501 (0.82)
Quality info × 2016	0.170* (1.70)	−0.182 (1.30)	0.079 (0.74)		1.035(0.86)
Quality info × 2017	0.000 (0.00)	0.041 (0.28)	0.216* (1.78)	−0.282** (2.34)	1.409 (0.75)
Premium × 2017	−0.089 (0.71)	0.22 (1.60)	−0.045 (0.37)	−0.057 (0.45)	−0.005 (0.00)
N	515	515	510	302	514
R^2	0.368	0.091	0.065	0.098	0.02
Wald χ^2	30.59***	4.68***	2.92***	2.16*	0.91
Panel B: Tested positive at baseline sample					
Workshop × 2016	0.07 (0.29)	−0.278 (1.52)	−0.141 (0.69)		−4.656*** (2.76)
Workshop × 2017	−0.238 (1.04)	−0.412 (1.65)	−0.237 (0.89)	0.119 (0.50)	−4.072 (1.13)
Quality info × 2016	0.321*(1.69)	−0.274 (1.01)	0.205 (0.91)		5.135** (2.53)
Quality info × 2017	0.097 (0.41)	0.195 (0.99)	0.406* (1.85)	−0.548** (2.31)	10.899*** (3.62)
Premium × 2017	0.217 (0.93)	0.662*** (2.84)	0.183 (0.78)	−0.458* (1.93)	5.886** (2.13)
N	144	144	142	83	147
R^2	0.405	0.199	0.097	0.572	0.185
Wald χ^2	11.95***	3.39***	1.61	8.13***	5.41***

Notes Results of FE reported. Numbers in parentheses indicate absolute values of *t*-statistics based on clustered standard errors at the individual household level; *, **, and *** indicate statistical significance at $p < 0.1$, $p < 0.05$, and $p < 0.01$ level, respectively

21.5 Conclusion

In this chapter, we have illustrated the recent development of the aquaculture sector in Asia, with a particular focus on the case of shrimp farming in Vietnam, and examined the persistent issue of disease outbreaks more in-depth based on our fieldwork. The benefits of the sector to the economy and livelihoods seem undeniable, particularly in terms of increasing income opportunities for producers, improving nutrition for consumers, and the important role that the sector plays in maintaining a good natural environment. However, as farming methods become more intensive to meet the growing global demand, better farming management becomes essential. Our studies have shown that consideration of spatial spillovers, both by physical spillover and peer effects among farmers, is important in reducing disease outbreaks, and quantifying unobserved quality is important in changing the behavior of farmers. For this, effective use of digital technology is a promising way forward.

Recollections of Professor Keijiro Otsuka

I was truly lucky to be in the first batch of the FASID-GRIPS International Development Studies Program, led by Professor Keijiro Otsuka and Professor Yujiro Hayami. Learning development economics with their guidance changed my life thereafter. Among the things I respect most about Professor Otsuka were his sharp insights to grasp the essence of problems in the field, his willingness to always provide thorough editing of his students' writings, and his utmost optimism in facing any challenges. I am very honored to be a part of this book to celebrate my sensei's lifetime achievement.—*Aya Suzuki.*

I first met Professor Kejiro Otsuka in 2003 when I joined the IDS Master program in GRIPS. I went to the field for a survey for the first time in my life with him in 2007 in Vietnam. That changed my life and career as a researcher. I am honored to be part of this book to celebrate Professor Keijiro Otsuka's achievement.

—*Vu Hoang Nam.*

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Chapter 22
Integrating Agricultural and Industrial Development

Takeshi Aida

Abstract The Green Revolution has brought about a significant increase in agricultural productivity, expediting a shift in industrial structure. Although economic theories have been based on the dichotomy of agricultural and industrial sectors, the actual shift is more gradual. In this chapter, we discuss the role of upstream and downstream industries of agriculture in development strategy from the perspective of global value chains. We claim that agricultural processing and retail industries can integrate agricultural and industrial developments. In this regard, the model of cluster-based development is informative, and the role of human capital investment and associations is essential. We also provide an overview of the development of the tapioca industry in Thailand as an illustrative case study. This discussion ultimately aims to redefine agricultural development as a part of long-term economic development.

22.1 Introduction

In the late twentieth century, the world experienced a dramatic increase in agricultural productivity. The Green Revolution occurred with the introduction of high-yielding varieties (HYVs), mainly in the major grains of rice, wheat, and maize. According to a recent estimate, the introduction of HYVs increased yields of food crops by 44% between 1965 and 2010 (Gollin et al. 2021). The revolution indeed played a pivotal role in avoiding the Malthusian trap, much-touted at the time.

The increase in agricultural productivity and the associated decline in real food prices led to poverty reduction at the micro-level, especially in Asian countries (e.g., Datt and Ravallion 1998). The impact of the Green Revolution is indeed different between favorable and less favorable environments. However, these unfavorable environments also benefited through technology spillovers and migration (David

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and Otsuka 1994). Furthermore, poverty reduction led to higher human capital investment, expediting the development of the nonfarm sector (Estudillo et al. 2006).

The effect of the Green Revolution on economic development and structural change can also be found at the macro level. For example, Gollin et al. (2021) show that the increase in agricultural productivity and the gross domestic product due to the Green Revolution is associated with the decrease in the share of agricultural employment. Admittedly, some Asian countries experiencing the Green Revolution are now considered emerging economies, and the role of agriculture as a driver of economic growth is declining.

Traditionally, economic development has been associated with industrialization, and agricultural and industrial sectors have often been viewed as dichotomous (e.g., Lewis 1954; Harris and Todaro 1970; Matsuyama 1992). However, at the micro-level, the change can be more gradual. For example, historical evidence shows that the Dutch cultivation system in colonial Java led to the development of the downstream industries that used the produced crop (e.g., Dell and Olken 2020). Thus, the development of an agriculture-related industry can be a crucial missing link in the dichotomy between agricultural and industrial development.

This chapter aims to discuss the issues of integrating agricultural development into broader economic development and poverty reduction, employing the perspective of global value chains (GVCs). In the modern economy, the production process is fragmented worldwide (e.g., Feenstra 1998; Timmer et al. 2014). However, the level of value-added is heterogeneous across production stages, and firms in developing countries tend to be trapped in the low value-added middle stage of the production process due to their comparative advantages in labor-intensive industries. Similar arguments hold for agriculture and how linking the development of the upstream and downstream industry to farm production is a key to integrating agricultural development and industrial development. In this regard, we aim to redefine agricultural development as a part of long-term economic development.

22.2 Conceptual Framework

22.2.1 Upstream and Downstream Industries in Food Value Chain

Our benchmark concept in analyzing agricultural development in terms of GVCs is 'smile curves' (e.g., Mudambi 2008). It is a graphical depiction of the difference in value-added across the production stages: the value-added is high for firms located upstream and downstream of the production process. However, it is low for firms in the middle stages of production. Because of their comparative advantages in labor-intensive industries, firms in developing countries tend to be trapped in this middle stage. Thus, they need to involve upstream and downstream industries via functional upgrading (e.g., Murakami and Otsuka 2020). The concept was originally proposed to illustrate the manufacturing value chains, though it also helps analyze the agricultural value chains.

To define the upstream and downstream industries of agriculture, we need to consider the complex structure of the value chain. Reardon et al. (2019) define the food system as a 'dendritic cluster' of six value chains: (1) 'core' supply chain of agricultural products; (2) 'feeder' supply chain of farm input; (3) 'feeder' supply chain of post-farmgate segments; (4) 'pan-system feeder' supply chain of financial credit; (5) 'feeder' supply chain as a broad set of public assets; and (6) 'feeders' supply chain of technology and product innovations via research and development (R&D). However, for simplicity, this chapter focuses only on industries directly connected to crop production as an input/output relationship. Specifically, we set farm production as a midstream and define the agricultural R&D sector as upstream and the food processing and the retailing sector as downstream.

22.2.2 Upstream: Agricultural R&D Sector

Scientific knowledge is considered a public good due to its non-excludable accessibility and non-rival use. Therefore, without strict patent control, agricultural R&D faces underinvestment. Furthermore, the development of new varieties, especially those specific to the environment of developing countries, is not a profitable market for leading biochemical companies. For this reason, the public sector, especially international research institutes, has played an essential role in agricultural R&D.

The development of HYVs that enabled the Green Revolution was led by the international research institutes currently known as the Consultative Group for International Agricultural Research (CGIAR). The International Rice Research Institute (IRRI) and the International Center for Maize and Wheat Improvement (CIMMYT) played central roles in the Green Revolution. However, CGIAR spending peaked in 2000 and has since gone downward, accounting for only 1.1% of global agricultural R&D as of 2015 (Alston and Pardey 2021). Instead, the role of the private sector has been increasing over time, and the discrepancy across countries can be accelerated.

Figure 22.1 shows the food and agricultural R&D per capita trend by income levels. The spending on R&D is increasing over time, except in low-income countries. The shares of upper- and lower-middle-income countries in R&D spending have been increasing since 2000, mainly due to the rise of China and India. However, most agricultural R&D is still conducted in high-income (and upper-middle-income) countries. Since the sector is highly knowledge- and capital-intensive, the comparative advantage still exists in developed countries.

It is also important to note that the research agenda in the agricultural R&D sector has been changing from productivity to non-productivity. For example, the investment shares in productivity-oriented activities decrease over time within CGIAR (Pingali and Kelley 2007). Similarly, in the United States, the research agenda has been shifting from productivity-oriented to quality-oriented, focusing on food

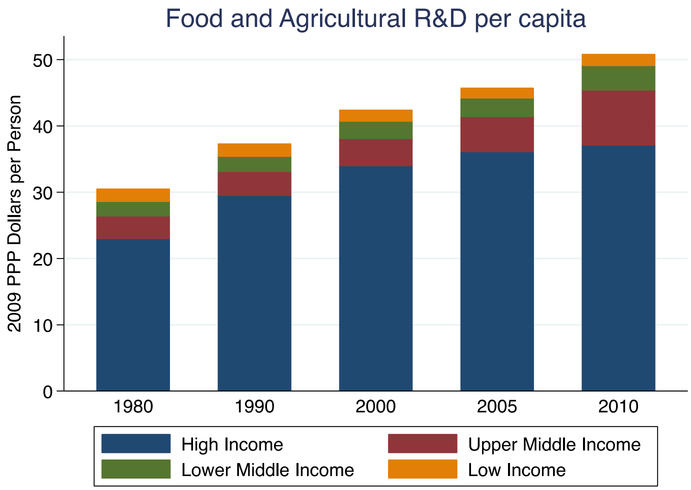


Fig. 22.1 Food and agricultural R&D per capita by income levels (Pardey et al. 2016)

safety, human nutrition, food security, natural resources, and environmental concerns (Alston and Pardey 2021).

However, the lack of comparative advantages do not necessarily justify under-investment in agricultural R&D. For example, in Sub-Saharan African countries, agricultural productivity growth continues to be an important issue (e.g., Otsuka and Larson 2016; Otsuka and Muraoka 2017). Furthermore, recent plot-level data evidence shows that most of the actual yield differences would disappear if countries produced according to their potential yield (Adamopoulos and Restuccia 2021). Thus, identifying the factors that hinder efficient resource allocation is still essential in agricultural development. In this respect, agricultural extension services and technology localization are important issues. Even though the role of the public sector is declining, it is still important for developing-country governments to continue to work with the CGIAR on localizing advanced technologies, as the social benefits outweigh the individual benefits in this sector.

22.2.3 Downstream: Food Processing and Retail Sector

In the downstream of the modern food supply chain, the role of supermarkets is becoming essential, especially since the 1990s. While the development is driven by income growth and urbanization on the demand side, the supply side is driven by foreign direct investment (FDI), logistics technology, and inventory management (Reardon et al. 2003). The rapid development of supermarket chains also changes the food procurement system, leading to the development of fresh products and food-processing industries (e.g., Gereffi et al. 2005). It is also important to note that FDI leads to such value chain development while domestic investment is increasing in some Asian countries (Reardon et al. 2012).

In this context, Reardon et al. (2012) advocate development strategies that “bring the markets to the farmers” (p. 12,336). The concept is to create a cluster to link farmers to downstream channels, providing them with missing services and products by utilizing economies of agglomeration. By doing so, small-scale farmers can participate in the food value chain, and vertical integration is expected to lead to industrial development.

Such a concept is parallel to the model of cluster-based industrial development (Sonobe and Otsuka 2006, 2011). It describes industrial development as a process from an imitation phase to quantity expansion and quality expansion phases. A key factor that drives the phase shift is human capital investment: as the shift continues, entrepreneurs are required to innovate in various ways, including product differentiation and management techniques, which require a higher level of human capital.

Another critical factor in facilitating industrial development is the existence of associations. Otsuka and Sonobe (2018) summarize the role of associations in (1) marketing research, (2) dissemination of new production methods and management practices, and (3) ensuring the quality of products. The role of associations is indeed highlighted in the studies of industrial development (e.g., Hashino and Otsuka 2013). Thus, utilizing the role of associations can accelerate the economic merit of agglomeration.

In light of the cluster-based development model, it is thus essential to take advantage of industrial clusters by attracting FDI to acquire advanced technologies and investing in human capital and associations to enhance absorptive capacity. Furthermore, the development of the downstream industries can increase the demand for crops, integrating the development of the agricultural and industrial sectors.

22.3 Plantation Agriculture and Contract Farming

The vertical integration of the production and post-production stages is not new. Historically, we can find an example in plantation agriculture. Plantation agriculture is known as cash crop production by a large number of unskilled laborers under the supervision of a management body. In general, family farms have an advantage in agricultural production because they have less incentive to shirk work than hired labor (e.g., Hayami and Otsuka 1993). However, plantation agriculture occurs when there is large scale merit in the post-production agricultural processing stages (Hayami 2010). For example, tea production has economies of scale in the fermentation process, which requires strong coordination between farm production and processing. To meet this end, tea companies have an incentive to internalize tea farming as long as the benefit from scale outweighs the inefficiency of crop production. However, as Hayami (2010) argues, the role of plantations has been declining due to the increasing drawbacks of the system.

A modern counterpart of the system can be found in contract farming. Contract farming is an agreement between a grower and a processor regarding the production of an agricultural commodity (Bellemare and Bloem 2018). In practice, it refers to a pre-harvesting contract between a farmer and a processor/firm to deliver an agreed quantity and quality of product, usually at a predetermined price. In relation to GVCs, an important issue is the contract farming between firms in developed countries and farmers in developing countries.

Otsuka et al. (2016) classify contract farming into production and marketing. In a production contract, the contractor provides essential credit, technical assistance, and inputs in return for the delivery of harvest or produce. The contractor strictly controls production and farm management decisions under the production contract. On the other hand, the marketing contract primarily leaves production autonomy to the growers. Such differences can be interpreted as 'captive' and 'relational' in the typology of GVCs (Gereffi et al. 2005). The captive firm refers to the case where small suppliers are transactionally dependent on large buyers, facing high switching costs. In contrast, the relational firm refers to the case where complex interactions between buyers and sellers create mutual dependence and high levels of asset specificity. One of the significant differences between these two types is the supplier's ability. Thus, captive firms must achieve functional upgrading to be relational firms (Murakami and Otsuka 2020). Similarly, farmers in production contracts need to enhance their managerial ability to enter marketing contracts and obtain larger residual claims.

22.4 Case Study: Tapioca Industry in Thailand

An interesting example illustrating the relationship between agricultural development and industrial development is Thailand's cassava/tapioca industry. Thailand is the largest exporter of cassava products and the third-largest producer of cassava roots after Nigeria and DR Congo.

Figure 22.2 shows the long-term trend of the area harvested and production amount of cassava since 1960. Cassava production in Thailand experienced a remarkable increase in the last 60 years. Production and the harvested area have expanded by about 16 times. Until the year 2000, the trends of both indices were almost parallel: the harvested area and production increased until around 1990 and decreased in the next ten years. After that, however, the increase in production amount outweighed that of the harvested area, suggesting a clear increasing trend in yield, especially after 2000.

Part of the increase in productivity can be attributable to the HYVs of cassava. In particular, Kasetsart 50 is an important breeding achievement. It was released from 1992 to 1995 as a result of a public breeding program involving Kasetsart University and the International Center for Tropical Agriculture (CIAT). It had a higher yield and starch content than the previous varieties and is considered a successful cassava breed in Thailand (Malik et al. 2020). As a result, it still occupies a large share of the planting area in Thailand and Southeast Asian countries (Labarta et al. 2017).

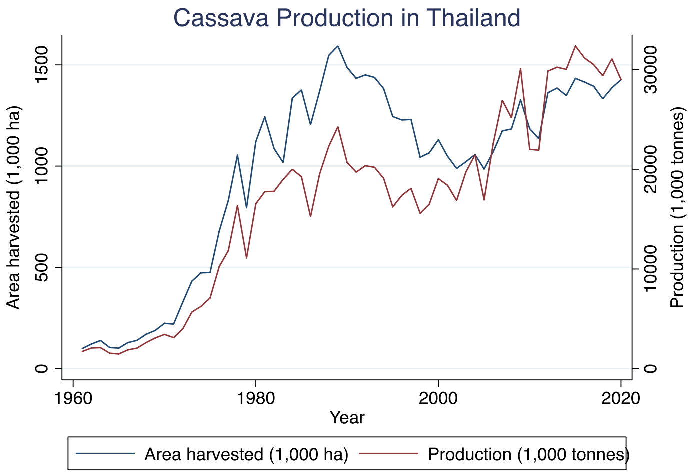


Fig. 22.2 Trend of cassava production and harvested area in Thailand (FAOSTAT 2022)

Another important factor that drives cassava production development is the demand side. Figure 22.3 shows the export trend of dried cassava and cassava starch. Interestingly, until around the mid-1980s, most cassava products were exported as a form of dried cassava. However, cassava starch exports began increasing in the 1990s, whereas dried cassava exports temporarily dropped from the 1990s to 2000. As a result, more than half of current cassava products are exported as starch, with higher value-added. Importantly, in tandem with yield growth, the export of cassava products has been increasing since 2000. Such a trend is mainly driven by expanding trade volume to China. In 2020, 99% of cassava roots and 63% of cassava starch were exported to China; in 1989, shares for both were less than 1%.

Associations also appear to have played an essential role in the development of the industry. There are several cassava/tapioca industry-related associations. One of the most influential is the Thai Tapioca Starch Association (TTSA). TTSA is an association of firms producing tapioca starch and was awarded the license under the trade association act in 1976. Its primary mission is price stabilization. Since market price fluctuates as per the seasonal fluctuation of cassava supply, TTSA provides the venue to address the issue and identify possible solutions. Frequent meetings can also serve as a place for information sharing among producers. Although membership is voluntary, TTSA claims that almost all tapioca starch manufacturers in Thailand are association members or affiliated companies (TTSA [n.d.]).

The geographic distribution of TTSA member firms is also informative in discussing patterns of industrial clusters. Panel A of Fig. 22.4 shows the map of cassava yield in 2010, calculated from FAO-Global Agro-Ecological Zoning (GAEZ) data. The yield is high in the northern and northeastern regions. In contrast, the central and the eastern regions show low yields as they are more urban. Panel B shows the plot of TTSA membership firms. The firms are concentrated in the central and the northeastern regions. Two important centers of the industry are Bangkok and

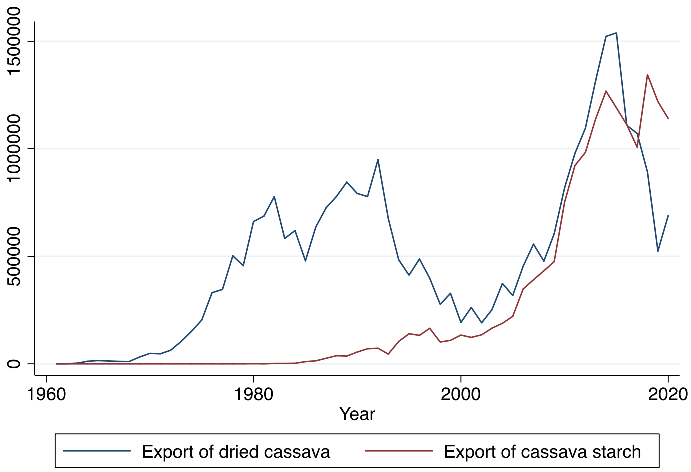


Fig. 22.3 Export of cassava products in Thailand (FAOSTAT 2022)

Nakhon Ratchasima province. The firms in Bangkok are typically the main offices, and their factories are in other cassava-producing provinces. In contrast, firms in Nakhon Ratchasima, known as a processing center of tapioca, utilize the advantage in procuring cassava roots and saving on transportation costs.

According to an interview with factory managers in Nakhon Ratchasima, many of them procure cassava roots on the spot rather than through contract farming. One possible reason is that cassava roots are relatively storable. Although a constant supply of raw materials is necessary for operations, this is not the case in reality if storage is possible (Hayami 2010). Indeed, starch factories have large warehouses for storing raw cassava roots. Other reasons can be that many cassava farmers sell roots to processors, and differences in quality, other than starch content, are not very important.

Cassava products in Thailand can be classified mainly into four categories: chips, pellet, native starch, and modified starch (Fig. 22.5). The simplest product is chips, often processed by local small-scale entrepreneurs. Chips are further processed into pellets for feedstuff, mainly for the foreign market. Another important production process is the extraction and modification of cassava starch. Cassava roots are first processed into native starch for domestic consumption and export. The native starches produced are further processed physically, enzymatically, or chemically into modified starch for multiple applications, including food products, pharmaceuticals, and binders, mainly for export. Modified starch production is highly capital- and knowledge-intensive, making higher value addition than native starch.

Table 22.1 shows the number of firms producing native and modified starch among the members of TTSA. Thirty out of 95 firms produce modified starch, while 83 firms produce native starch. This is because the production of modified starch is capital-intensive, requiring a higher level of production technology. Interestingly, 18 firms produce both native and modified starch, indicating the existence of economies of

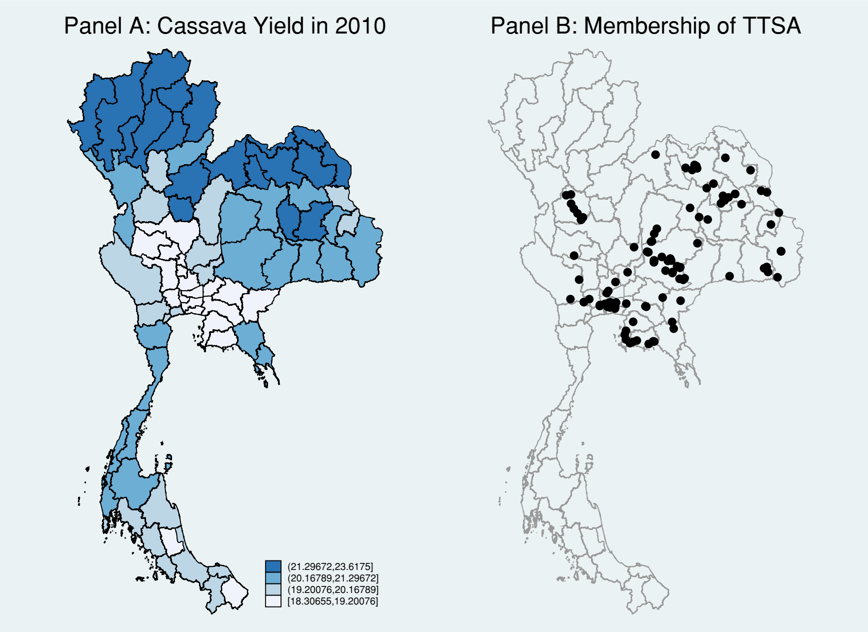
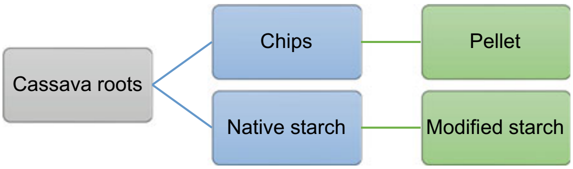


Fig. 22.4 Cassava yield and TTSA membership (FAO and IIASA 2021; TTSA [n.d.])

Fig. 22.5 Classification of cassava products



scope between these products. In terms of the cluster-based development model, the development of chips and native starch production, which require relatively low entry costs, can be viewed as the quantity expansion stage. Thus, to shift to the quality expansion stage of modified starch production, further human capital investment and foreign collaboration to absorb new technologies would be essential.

Table 22.1 Production of native and modified starch. (TTSA website, n.d.)

	Modified starch		
Native starch	Yes	No	Total
Yes	18	65	83
No	12	0	12
Total	30	65	95

To summarize, the development of the cassava-related industry in Thailand is driven by the introduction of HYVs on the supply side and integration into the global value chain, especially in China, on the demand side. The industry's development process can be explained by the model of cluster-based development, where associations play an important role. However, further investment in human capital and attracting FDI is essential for the firms to enter the production of a higher value-added starch product.

22.5 Conclusion

In this chapter, we discussed the integration of agricultural and industrial development. To overcome the dichotomy of the agricultural and industrial sectors, we need to pay close attention to the development of the upstream and downstream industries of the agricultural value chain. Especially in terms of GVCs, it is important to integrate crop production and downstream food processing and retail industries. As an illustrative case study, we provided an overview of the development of the tapioca industry in Thailand, which has utilized the merit of cluster-based industrial development. On the other hand, due to the high data constraints of such a topic, elucidating the long-term industrial development process based on micro-level data remains a significant future challenge.

Recollections of Professor Keijiro Otsuka

I first met Otsuka sensei at a small conference as a graduate student. I still vividly remember the advice he gave me at the reception. After finishing my Ph.D., I joined GRIPS as a postdoctoral research fellow, though I did not have the chance to interact with him very much. However, after I joined IDE-JETRO, I was fortunate enough to start a research project with him focusing on the role of FDI in industrial development in Thailand and India. I have been learning his research style closely and intensively since then. I am greatly indebted to him for his mentorship and honored to be part of the Festschrift.

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Chapter 23
Cluster-Based Agricultural Development: A Comparison Between China and Africa

Xiaobo Zhang

Abstract Clusters for high-value crops are ubiquitous in China and in African countries. Drawing from three case studies (potato cluster in China, medicinal and aromatic cluster in Egypt, and dates cluster in Tunisia), this chapter discusses the major challenges facing cluster development and the roles of different agents (e.g., entrepreneurs, business associations, and local governments). Cluster development involves supply-side or demand-side bottlenecks along the way, which are beyond the capacity of individual enterprises. Whether a cluster can develop to the next stage depends crucially upon whether the bottlenecks can be resolved. Because the bottlenecks are context- and temporal-specific, it would be impossible for a planner or outsider donor to prescribe a one-size-fits-all intervention to overcome all the binding constraints. Instead, local elites, such as business leaders and local officials, can play a greater role in identifying the emerging bottlenecks and figuring out indigenous solutions. In China, because local governments have an embedded interest in promoting local economic development, they are keen to provide local public goods or initiate joint actions to address the successive binding constraints and facilitate cluster development. By comparison, the role of the local government is more muted in Africa, limiting the growth potential of agricultural clusters.

23.1 Introduction

Clusters, where similar economic activities are concentrated in a limited geographic area, are popular production modes in many sectors in developed and developing

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countries (Porter 1990; Sonobe and Otsuka 2006, 2010). Marshall (1920) pointed out that enterprises in clusters enjoy many competitive advantages, such as access to markets, labor pooling, and easy learning. In addition, the fine division of labor embedded in clusters helps lower the capital requirement for new entrants enabling more potential entrepreneurs with limited resources to get a head start on their aspirations, thereby generating employment (Ruan and Zhang 2009; Long and Zhang 2011). This point is particularly important for developing countries where labor is abundant and jobs are badly needed. Promoting cluster-based development has been identified as a key development strategy in many countries and regions, such as Egypt (Abdelaziz et al. 2021a, b). There is a strong interest in learning the know-how of cluster-based development in both the academic and policy arenas.

Despite the keen interest, the literature on cluster formation is rather thin. The limited literature largely focuses on developed countries and high-tech sectors (Braunerhjelm and Feldman 2006). By comparison, the studies on cluster formation in developing countries in the agricultural sector, in particular, are scanter. It is unclear whether the lessons from developed countries are relevant for agricultural clusters in developing countries. What is the respective role of different agents, such as local government, entrepreneurs, and business associations, in agricultural cluster development in developing countries?

Drawing from three in-depth case studies on agricultural clusters in China and Africa, this chapter tries to answer this question. Our analytical framework stems from the seminal work by Sonobe and Otsuka (2006), who classified cluster growth into two stages: quantity expansion and quality upgrade. The previous literature has also paid attention to the emergence of clusters (i.e., the incipient stage from zero to one) (Braunerhjelm and Feldman 2006). This chapter divides the cluster formation process into three stages, $0 \rightarrow 1$, $1 \rightarrow N$, and $N \rightarrow Q$, where N and Q stand for quantity and quality, respectively. This chapter refers to $0 \rightarrow 1$ as the incipient stage, $1 \rightarrow N$ as the growth stage, and $N \rightarrow Q$ as the quality upgrading stage.

In the initial stage of cluster formation, pioneering entrepreneurs face large uncertainties in the viability of a new product or business model. Therefore, it is hard for a central planner to come up with a sound development strategy. In this stage, entrepreneurs often play a more important role. Once the success is observed, others follow the suit.

However, as the cluster size grows, there is often an increasing demand for public goods, such as marketplaces and product safety standards. It would be difficult for individual entrepreneurs to provide the necessary public goods. Instead, joint actions are called for.

In the empirical analyses, we first identify the stage of cluster formation and the corresponding major challenges. Then we documented the major measures taken or potential solutions to address the binding constraints, paying particular attention to the roles of different agents.

The case studies show that the bottlenecks vary greatly across different stages of cluster development and are context-specific. The binding constraints can be on the demand side or the supply side at other times. After one bottleneck is addressed, another one emerges. Thereby, continuous tinkering is required. It is hard for an outsider (or planner) to design an ex ante universal strategy applying to clusters in different stages of development worldwide. Thereby, more ‘searchers’ (Easterly 2006) are needed to look for local solutions to the emerging binding constraints. The key searchers are entrepreneurs and local community leaders. They have an informational advantage in diagnosing the major challenges facing cluster development.

The role of searchers and planners in the cluster growth process has been discussed in the literature (Porter 1990; Braunerhjelm and Feldman 2006; Easterly 2006). However, the literature rarely distinguishes their roles in different stages of cluster development, particularly in developing countries. We pay particular attention to this point in this chapter.

This comparative study sheds some light on the design of industrial policies in the context of cluster development. While the donor community and national governments strive to find a panacea for economic development, the three case studies show that it is too idealistic to prescribe one-size-fits-all policy interventions to promote cluster development. Putting the local elites in the driver’s seat and aligning their interest with local economic development is a more viable option for navigating the bumpy road of cluster development.

23.2 Comparison of Three Clusters in China and Africa

23.2.1 Potato Cluster in China[1]

The potato was not introduced to Anding County of Gansu Province until the 1960s as a crop to fight hunger. In several decades, Anding has become one of China’s four major potato clusters. The cluster formation was not smooth, with various binding constraints constantly evolving. Table 23.1 lists the major challenges in the incipient stage, growth stage, and quality upgrading stage, as well as corresponding solutions.

Although potato was suitable for production in Anding, farmers were initially reluctant to plant potato because it was not part of the traditional diet. To promote the potato as a major crop, local governments asked village cadres to first adopt potato production, demonstrating that it was suitable for the local environment. Because of the embedded trust in village cadres, the demonstration eased other villagers’ reservations about adopting potato farming in Anding.

It would be almost impossible for individual farmers to develop suitable local potato varieties, so local agricultural research organizations played a key role in filling the gap. The Gansu Academy of Agricultural Science bred a high-yield variety for starch processing (high starch and low sugar content). The county agricultural extension station and a farmer accidentally bred Xiadaping, which became the most popular vegetable potato. These two varieties have been widely used in Anding. The

[1] This section mainly draws from Zhang and Hu (2014).

Table 23.1 Anding potato cluster in China by development stage: challenges and the role of different agents in figuring out solutions (Zhang and Hu 2014)

Development stage	Key bottlenecks	Role of individuals and the private sector	Role of public organizations or governments
0 → 1 (incipient)	Developing and promoting local varieties	Village cadres were asked to set up demonstration fields on their own land	Gansu Academy of Agricultural Science bred a high-yield variety for starch processing (high starch and low sugar content) County agricultural extension station where a farmer accidentally bred Xiadaping, which became the most popular vegetable potato The county set up a breeding center to produce disease-free potato seeds
1 → N (quantitative expansion)	Selling potatoes to outside markets Transporting potatoes during the peak season	A former teacher initiated the establishment of trader and producer associations, sending informants to collect price data in major wholesale markets	The county government gave seed money to set up the association The county broadcasts the information in local media (radio, TV, and newspapers) and on large monitors in major gathering places (central squares, railway and bus stations) Marketplaces were set up across the county Because of lobbying, the Ministry of Railways increased the quotas of direct freight trains, which lowered the transportation cost Subsidies were provided to producers to build indigenous storage areas

(continued)

Table 23.1 (continued)

Development stage	Key bottlenecks	Role of individuals and the private sector	Role of public organizations or governments
N → Q (qualitative upgrading)	Absorbing surplus production and extending the value chain	Outside private firms set up plants to process potatoes for industrial starch, flour, and chips	To the first movers, the county government provided free land, helped secure subsidized bank loans, and guaranteed a stable potato supply

potato seed is vulnerable to diseases, and to address this problem, the county set up a breeding center to produce disease-free potato seeds. These measures largely addressed the binding constraints on the supply side.

After the supply-side constraints were removed, the demand-side challenges emerged. Since outsider traders controlled the market channels, they had a larger say in prices when purchasing potatoes from farmers. Thereby, farmers' profit was squeezed despite the expanded cropping area. Seeing the problem, a former schoolteacher proposed to the local government to set up a producer association, which would lead joint actions in place of outsider traders. The county government provided seed money to establish the association. The association then hired informants to gather market information in several major wholesale markets nationwide and set up collection points across the county. In addition, the association and local government broadcast the information in local media (radio, TV, and newspapers) and on large monitors in major gathering places (e.g., central squares, railway and bus stations). Thanks to the more transparent and timely market information, farmers could get a better farmgate price.

Potato production is seasonal. After the harvest, one key challenge was transporting the potato to the outside market. Road transportation was much more costly than the railway. However, the freight train quota assigned to Anding by the Ministry of Railways was too low to meet the demand. To tackle the challenge, the local government asked a provincial leader, who was originally from Anding and who used to work in the Ministry of Railways, to help lobby the ministry to increase the quotas of direct freight trains. Thanks to the lobbying effort, the quotas increased, easing the transportation glut for a few years.

The potato price tends to drop after harvest and goes up right before the Chinese New Year. If farms can store their potatoes for a few months, they could sell them at a higher price. The local government decided to subsidize farmers to build indigenous storage in response to the need. The increased storage facilities enabled farmers to better buffer price fluctuations.

The profit margin for raw potatoes is limited. One way to increase value-added is to expand the value chain. The county government made a great effort to attract starch processing firms by offering preferential treatments, such as tax breaks and bank loans. As Hausmann and Rodrik (2003) point out, there is a discovery cost

Table 23.2 Medicinal and aromatic plants (MAPs) cluster in Egypt: challenges and potential solutions (Abdelaziz et al. 2021a, b)

Development stage	Key bottlenecks	Role of individuals and the private sector	Role of public organizations or governments
0 → 1 and 1 → N	Organically formed with a long history	Production and export are mainly organized by farmers, traders, and exporters	Subsidy for lab testing used to be provided but was later on removed
N → Q	Water scarcity and contamination prevent farmers from producing enough organic MAPs for the booming export market	Need to provide farmers with incentives to reduce pesticides and residues from other crops contaminated by drainage water Joint actions between the private and public sectors to develop or adopt low-cost test instruments to ensure that produce complies with international standards	The Ministry of Water Resources and Irrigation and the Ministry of Agriculture and Land Reclamation need to work together to solve the water scarcity and contamination problem

to pay for first movers. However, once the pioneering investment is proved to be successful, others can easily imitate and quickly dilute the profit margin of first movers. The negative externality can deter potential entrepreneurs from investing in the new processing industry. Government support, to some extent, offsets the negative impact, inducing investors to set up processing plants in Anding. Within a few years, a burgeoning potato processing industry had emerged. To ensure sound quality, a few leading processing enterprises signed contract farming agreements with farmers through producer associations, under which farmers are obligated to plant the designated potato varieties and comply with quality standards. All these measures facilitated the cluster's transition toward the quality upgrading phase.

23.2.2 MAPs Clusters in Egypt[2]

Medicinal and aromatic plants (MAPs) have been farmed along the Nile River for thousands of years. Organic MAPs production clusters have formed in Fayoum and Beni Suef. The external demand for Egyptian organic MAPs is strong, and Egypt has become one of the largest exporters of organic MAPs globally. However, the growth of this sector is limited by a few binding constraints (Table 23.2).

[2] This section draws heavily from Abdelaziz et al. (2021a, b).

For farmers, the most limiting factor is water contamination. Water from canals linking to the Nile is provided every 35 days. In the period between, farmers rely on the agriculture drainage water remaining in the canal, often contaminated by household waste. While agricultural drainage water is suitable for watering some agricultural crops, it is not suitable for organic farming as it would contain chemical fertilizers and pesticides from neighboring non-organic farms. Consequently, when MAPs farmers irrigate their crops using contaminated water, the MAPs harvest may not pass the safety test required for export to the OECD countries. Even though many farmers attempt to cultivate their lands organically (relying on organic fertilizers and zero pesticide use), the produce likely ends up being affected by the drainage water and consequently downgraded. As a result, the produce is sold at a much lower price. The water contamination problem presents a clear binding constraint to the MAPs cluster that is impossible to solve by individual farmers, making local government intervention and joint action necessary.

Another major problem is the sharp increase in the costs of agricultural and postharvest lab tests to ensure produce quality and safety. The cost for each test, which was previously subsidized by the government, has increased from EGP 35 to EGP 1,700 over the past several years as the government waived the subsidy. This is a big blow to small farmers with less than 5 feddans (a unit of area used in Egypt, equal to 4,200 m^2). They can no longer afford to test the quality of their produce, losing bargaining power with traders on their harvest's grade or quality. To save on testing costs, instead of conducting separate lab tests for each farmer's harvest, traders pool different farmers' harvests to do fewer lab tests, making it impossible to trace problems to individual farmers once the test reveals positive results. Thus, the problem of one farmer will lead to a downgrade for a large group of farmers, even if their produce is compliant. If the government can encourage the entry of private companies specializing in lab testing, the cost may come down dramatically. Providing subsidies to offset the cost of lab testing is another option.

During the field visits, many processing enterprises complain about the problem of business licensing. The government only grants licenses to processing companies located in industrial zones, not the desert fringe. However, the industrial zones are often far away from the MAPs production and residential areas. The cost of transporting workers and products to the industrial zones is double that of transportation costs to local processing plants within the cluster. This forces numerous local processing hubs to conduct operations without a license (or illegally) because they are not allowed to register. In fact, a few owners of the processing plants we interviewed displayed interest, ability, and willingness to expand their processing capacity and upgrade their equipment quality if they were granted a business license. They were reluctant to make large investments without a license because the government could shut down their operation anytime. This binding constraint calls for the government to relax the business license requirement.

In summary, despite the growth potentials of organic MAPs in Egypt, the production clusters are subject to some binding constraints, which can only be addressed by joint actions or policy reforms. Although the challenges facing the clusters can be easily diagnosed, local governments have kept a blind eye. Non-government organizations, such as business associations, are largely absent. There is a lack of searchers at the local level.

23.2.3 Dates Clusters in Tunisia[3]

Oases in the south of Tunisia are well known for dates production. There is a strong external demand for Tunisian dates, and its export value accounted for about 20% of the total value of Tunisia's agricultural exports in 2018, having more than doubled since 2000. The rapid growth lies in the active collaborations between the public and private sectors.

Various government agencies and cluster- (or sector-) organizations are involved in the cluster development of dates (see Appendix 5.1 in Abdelaziz et al. 2021a, b). The government agencies and research organizations include the Office of the Commissioner for Agricultural Development (CRDA), Investment Promotion Agency (APIA), Industry and Innovation Promotion Agency (APII), Date Technical Centre (CTD), ISET (Higher Institute of Technological Studies) training centers, Institute of the Arid Regions of Medenine (IRA), and Regional Research Centre for Oasian Agriculture (CRRAO). The cluster/sector-specific organizations include the Interprofessional Date Group (GID), Pole Djerid, and the Date Palm Cluster.

Yet, a few supply-side factors limit the growth potential of date clusters in southern Tunisia. External environmental and ecological threats are high on the list. One big problem associated with monocropping relates to insects and disease. Farmers have to cover fruit bunches with mosquito nets to protect dates from insects, incurring extra labor and material costs. Climate change has made it harder to predict the exact timing of harvest. Higher temperatures during the harvesting season harm date quality.

Date productions also encounter challenges with inputs and technologies. There is a lack of new varieties, and the labor shortage is a problem, especially during harvest time. The cost of electricity and water has also been rising, and water salinity has become an increasingly serious problem.

Consequently, supply-side policy interventions are called for. The major policy options include more government investment in new and disease-resistant varieties, promoting mechanization, and introducing water-saving irrigation technologies. As shown in Table 23.3, numerous government agencies and associations work on the dates cluster. With such a strong local capacity, we believe that the bottlenecks can be eventually overcome, and the cluster can move up to the next stage.

[3] This section draws heavily from Abdelaziz et al. (2021a, b).

Table 23.3 Date cluster in Tunisia: challenges and potential solutions (Abdelaziz et al. 2021a, b)

Development stage	Key bottlenecks	Role of individuals and the private sector	Role of public organizations or governments
0 → 1 and 1 → N	Organically formed	Production and export are mainly organized by farmers, traders, and exporters	Various government agencies and cluster- (or sector-) organizations are involved: – Office of the Commissioner for Agricultural Development (CRDA) – Investment Promotion Agency (APIA) – Industry and Innovation Promotion Agency (APII) – Date Technical Centre (CTD) – Interprofessional Date Group (GID) – Pole Djerid and the Date Palm Cluster – ISET (Higher Institute of Technological Studies) training centers – Institute of the Arid Regions of Medenine (IRA) – Regional Research Centre for Oasian Agriculture (CRRAO)

(continued)

23.3 Conclusions

Sonobe and Otsuka (2006, 2010) document two important regularities related to cluster development. First, clusters are widespread in developing countries and important for generating employment. Second, cluster development goes through different stages. Despite the ubiquities of clusters, cluster development has generally been more rapid in East Asian economies than in African countries. We compared the major challenges facing three agricultural clusters in China, Egypt, and Tunisia. Over

Table 23.3 (continued)

Development stage	Key bottlenecks	Role of individuals and the private sector	Role of public organizations or governments
N → Q	External environmental and ecological threats (climate change, inadequate water, insects, and diseases) Labor shortages Lack of new varieties and limited value addition	Increase mechanization at all stages of the value chain through hiring labor-cum-machine services Adopt water-saving irrigation technologies Explore investment opportunities in new date derivatives and palm waste products Improve coordination along the value chain to increase value-added through business associations	Urgent need for research organizations to develop new date varieties with higher water efficiency, are resilient to climate change, and are less prone to disease The government should promote more investment in the final processing and higher value-added products and cooperation between research organizations and firms to commercialize derivative date products

the course of cluster development, many challenges emerge. They are context-specific and largely beyond the capacity of individual enterprises to resolve, thus, calling for joint actions. However, it is hard for an outsider or planner to use one-size-fits-all strategies to overcome all the challenges, although donors prefer to mainstream a particular intervention strategy across countries. Entrepreneurs, civil society, and local governments are better positioned to identify local indigenous solutions to the bottlenecks discussed. In particular, in the incipient stage of cluster development, entrepreneurs and their social networks can play an important role in discovering the right seeds suitable for the local environment. Later, as clusters grow, more joint actions are often needed to overcome emerging bottlenecks. At this stage, local governments and organizations can play a great role in providing necessary public goods and leading joint actions.

As shown in the three case studies, the key difference between China and the two African countries lies in local state capacity and incentives. In China, local officials are keen on promoting local economic development because of career concerns and fiscal decentralization. Thereby, they tended to pay more attention to local businesses' needs and helped initiate joint actions to solve cluster development's common bottlenecks. In Tunisia, there are strong public–private partnerships. Moreover, the cluster/sector-level organizations work together with government agencies and research organizations to tackle emerging problems.

The international demand for Egyptian MAPs and Tunisian dates has been very strong. However, the clusters in the two countries face a strong headwind on the supply side. In the case of the Egyptian MAPs cluster, water contamination, high cost of lab tests, and rigid business license requirements on processing plants are major impediments to cluster growth. However, local governments and organizations are largely absent in leading joint actions.

The key challenges facing dates clusters in Tunisia include lack of value chain coordination, inadequate water supply, labor shortages, diseases, lack of new varieties, and limited value addition. More joint actions between the private and public sectors are needed to address these binding constraints.

The literature on industry policy has called for a shift from why to how (Rodrik 2009; Lin 2010). However, the discussions on industry policy still largely focus on policies at the national level. The three case studies demonstrate that local industrial policies matter more to cluster development. However, more research is needed to study the role of local industrial policy in cluster formation. Since cluster formation is a continuous process, encountering various binding constraints along the way is to be expected, thus, it is crucial for people on the ground to identify the bottlenecks and figure out indigenous solutions by using existing local strengths. To do that, the incentives of local leaders need to be aligned with local economic development. However, it would be a daunting task to reform the incentive system of local officials in the short run. A more viable option is to encourage non-government organizations, such as business organizations, to play a more active role in initiating joint actions in countries lacking incentives for local officials. This is particularly relevant for the MAPs clusters in Egypt.

Recollections of Professor Keijiro Otsuka

I first met Keijiro Otsuka in 1998 when I joined the International Food Policy Research Institute (IFPRI) as a research analyst while finishing up my dissertation. Our offices were next to each other. As a mentor, Kei spent time reading my dissertation chapters and gave extremely valuable comments. In 2005 we jointly organized a workshop on cluster development in China and visited several industrial clusters in Zhejiang Province together. The workshop and field trip was eye-opening, inspiring my research interest in clusters. Kei and Professor Sonobe kindly shared their first wave of survey data in the Zhili children's garment cluster, enabling me to conduct a follow-up survey in the same cluster. His two seminal books on clusters, coauthored with Tetsushi Sonobe, have become my bibles on cluster research.

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Chapter 24
Solar Power to Transform Food Systems and Rural Livelihoods: Evidence from a Solar-Powered Cold Storage Intervention in Nigeria

Futoshi Yamauchi and Hiroyuki Takeshima

Abstract In developing countries, a substantial amount of perishable and often highly nutritious commodities, such as fruits and vegetables, are lost after harvest, mainly caused by the lack of key infrastructures, such as electricity and cold chain facilities. On the other hand, the world has recently seen the potential of solar power in decarbonizing economies and transforming rural livelihoods in developing countries. A new technology, such as solar power photovoltaics, is highly divisible and, therefore, can be easily introduced to overcome the lack of sustainable electricity supply. In 2020–2021, we implemented an intervention to rebuild rural livelihoods in conflict-affected northeast Nigeria by building solar-powered cold storage facilities that can reduce food loss and increase consumption of perishable, micronutrient-rich horticulture products; increase incomes of market agents and producers; and improve employment. The intervention brought a significant increase in the number of days that horticulture products remain fresh, market sales for cold storage users, and the amount of vegetables available to the local population. Cost-benefit analysis showed a significant net economic gain in the long-run. Our example shows that a technological innovation, which overcomes the lack of an essential investment for development, can trigger economic transformation.

24.1 Introduction

As the electricity grid in many developing countries is not expansive, the share of households connected is very low. About 759 million people are without power, and most are concentrated in Sub-Saharan Africa (World Bank 2021). For example, in rural areas of Nigeria, only 30% of the rural households had access to power in 2019 (National Bureau of Statistics 2019), and this proportion significantly decreases in more remote areas. In the Northeast region, 79% of the households have no access

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to electricity (National Bureau of Statistics 2019). In such technologically–disadvantaged situations, people face additional burdens. For example, household activities are seriously constrained outside of daylight hours, and children have difficulty studying in the evenings. A large volume of perishable and often nutritious foods are spoiled due to the lack of cooling technologies that normally require a stable electricity supply. Access to electricity is a key bottleneck in creating transformation in many aspects of rural livelihoods in developing countries.

The inability to cool and keep perishable, often highly nutritious foods (e.g., fruits and vegetables) fresh and edible results in food loss and waste on a large scale. A rough estimate of food loss in fruits and vegetables is 15–50% in Sub-Saharan Africa (FAO 2011, 2019). It is a loss in income and nutritional values potentially available to the population. Foods are lost through various stages of postharvest value chains: soon after harvest, transportation to local markets, wholesale/retail markets, and food processing.

Modern cooling technologies are an important instrument to address a multitude of challenges emerging in increasingly complex food systems, including food loss and waste, food safety, food and nutrition security; poverty and economic growth; and environmental sustainability. Cold storage, including cool transportation, has been an increasingly important technology to reduce food loss and food waste globally by reducing microbial growth that causes spoilage (Lichtenberg and Ding 2008; Häsler et al. 2019; IFPRI 2020; Mayton et al. 2020; Kashyap and Agarwal 2020). Cold storage is also expected to reduce the growth of most human pathogens, ensuring enhanced food safety (Uçar and Özçelik 2013). The use of cold storage has also been a milestone toward improved food and nutrition security through micronutrient-rich horticulture crops like vegetables and fruits (Ali and Tsou 1997; Schreinemachers et al. 2018; Surendran et al. 2020). Earlier, Japan had seen the above transformations in the 1960s, promoted by the Science and Technology Agency Resource Research Committee (1965) in its so-called "cold chain recommendations",[1] which pushed the modernization of its food systems, leading to improvements in diets and health.

Studies also advocate for the potential of cooling technologies, including cold storage facilities, to accomplish inclusive economic growth, either through its contributions to export growth of horticulture commodities (Gebreeyesus and Sonobe 2012; Whitfield 2012; Minten et al. 2012) or improved market functioning in the domestic market (Schreinemachers et al. 2018), including higher or more stable prices received by suppliers (Rakshit 2011; Lichtenberg and Ding 2008) combined with increased sales achieved through reduced loss (Allen and de Brauw 2018). Such growth promises that similar technologies can be relevant in Sub-Saharan Africa today (Tschirley et al. 2015).

Recently, the potential of solar power technology has been increasingly recognized not only in decarbonizing economies but also in transforming livelihoods in rural areas of developing countries. Over the last decade, solar photovoltaic module prices have fallen dramatically, nearly 80%. Essentially, solar radiation is a free resource,

[1] Also known as the Recommendations on Modernization of Food Distribution System that Contributes to Systematic Improvement of Eating Habits.

which is non-exclusive, though depending on climate. The solar photovoltaic module is a new technology that is highly divisible and therefore easily adaptable in those areas, depending on its relative costs, to overcome the lack of key infrastructure, such as grid electricity supply.

The World Bank (2020) reports that 70 countries have excellent conditions for photovoltaics, where the long-term daily photovoltaic power potential averages or exceeds 4.5 kWh/kWp. Countries in the Middle East, North African region, and Sub-Saharan Africa dominate this category, accompanied by Afghanistan, Argentina, Australia, Chile, Iran, Mexico, Mongolia, Pakistan, Peru, and many countries in the Pacific and the Atlantic. Nigeria, which we present as our case study, is a high potential country, among others from Sub-Saharan Africa.

This chapter is organized as follows. The next section details the intervention to install solar-powered cold storage facilities in northeast Nigeria. The impacts of the intervention are shown in Sect. 24.3. Food loss of horticultural products is substantially reduced through solar-powered cold storage, which has implications for local incomes and nutrition intake. Results of the cost-benefit analysis we conducted are shown in Sect. 24.4, where we demonstrate that the internal rate of return for solar power is comparable to that for grid electricity, which is not available in most areas in the target region. Concluding remarks are mentioned, focusing on the linkage between investment complementarities and economic transformation.

24.2 Intervention to Install Solar-Powered Cold Storage Facilities

In this project, seven cold storage facilities were installed in seven horticulture markets in northeast Nigeria between December 2020 and January 2021. The project was supported by the Government of Japan as an emergency response to rebuild livelihoods in a conflict-affected region. Northeast Nigeria was selected as the region had long suffered from the destruction of livelihoods by insurgent groups. In 2019, 79% of the households in the region had no access to grid electricity. Since only 30% of the households in rural areas have access to grid electricity, very few households in the region's rural areas have stable access to electricity.

We first identified 14 eligible markets across five states: Adamawa, Bauchi, Gombe, Jigawa, and Yobe in northeast Nigeria. These 14 markets were selected because they are horticulture markets and operate daily, where the installation of cold storage can have maximum potentials. We selected seven horticulture markets from this list where cold storage facilities were installed (intervention markets), leaving the remaining seven as comparable markets where cold storage facilities were not installed (comparison markets). Fig 24.1 shows the locations of these 14 markets. The seven intervention markets and the seven comparison markets are scattered across five states, with two markets each in Adamawa and Bauchi states and one market each in Gombe, Jigawa, and Yobe states.

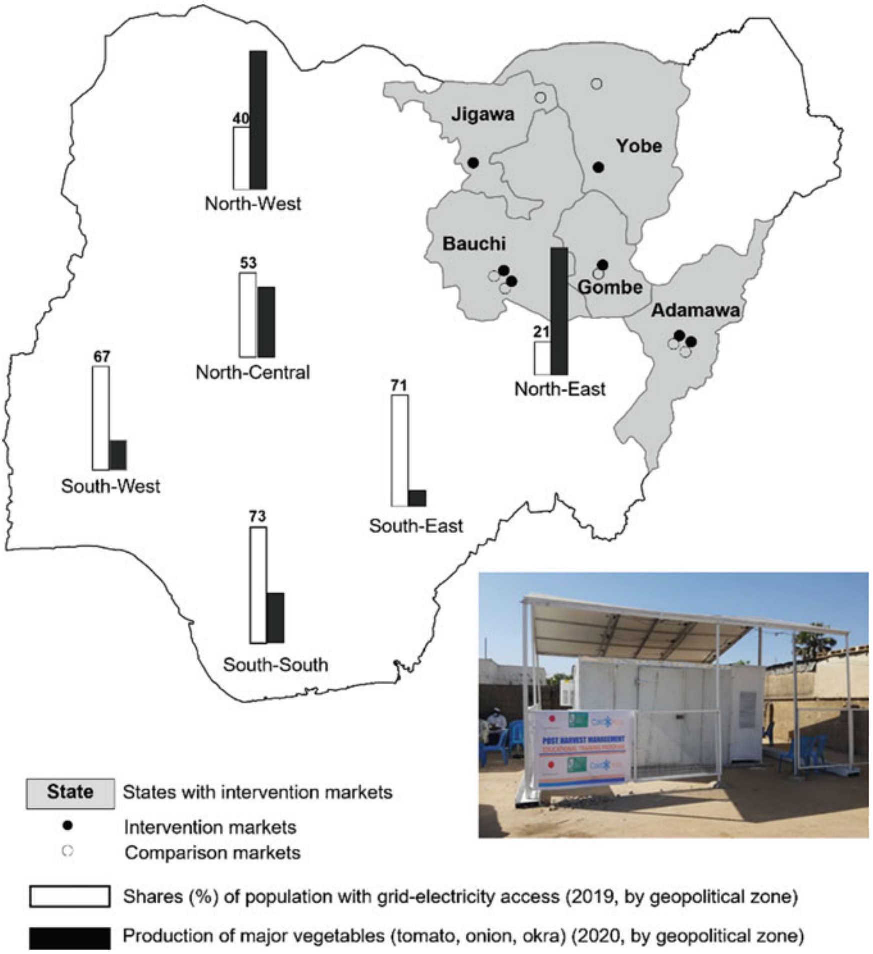

Fig. 24.1 Locations of horticulture markets where solar-powered cold storage facilities were installed (intervention markets) (IFPRI Survey 2020, National Bureau of Statistics 2019, and National Agricultural Extension and Research Liaison Services 2020)

The installed cold storage facilities were designed as prototypes and used and already operated by ColdHubs Ltd., a Nigeria-based social enterprise, in about 30 other horticulture markets across Nigeria at the time of our study. The cold storages installed in this study are relatively small, each with a maximum capacity of 3 tons of common horticulture products.[2] Each cold storage is powered by 5.6-kilowatt solar panels, that is, 18 of the 380-W photovoltaic panels manufactured by Panasonic. The surplus electricity generated during the day is stored so that it can be released to

[2] These may be significantly smaller than cold storage facilities studied for other crops in Asia. For example, potato cold-storage in India that expanded significantly between 2000 and 2009 have typically been larger, with a capacity of a few thousand tons per unit (Minten et al. 2014).

enable continued refrigeration at night. Cold storage also uses environment-friendly refrigerants like propane, which is less harmful to the ozone layer.

These cold storage facilities were installed within the market premises; the exact locations depended on the negotiations between ColdHubs and market authorities, based on leveled-space availability, general ease of access from most market stalls, and the absence of nearby objects that block sunlight.

Solar panels used in our intervention are the 380-W monocrystalline (passivated emitter and rear cell or PERC) solar photovoltaic module manufactured by Panasonic. Panasonic solar panels achieved significantly higher efficiency (i.e., the conversion rate of solar energy to electricity outputs) at 19.6% compared to 16.9% and 15.5% by competing products. Their temperature coefficient (i.e., the indicator of how electricity output capability drops as the panel temperature rises above 25°C) is also slightly better than the competing products (−0.39% per °C vs. −0.40 and−0.41%).[3] Even though Panasonic solar panels were slightly more expensive than competing products per watt (USD 0.58 per watt vs. USD 0.51 and USD 0.57), they are competitive and likely to be more efficient and stable in solar power generation, especially in a high-temperature environment in the long-term.

As is common for typical solar panels, the electricity generation capacity lasts quite long, achieving at least 90% and 80% of initial capacity levels even after 12 and 25 years, respectively.

24.3 Impacts

The seven solar-powered cold storage facilities aim to store fruits and vegetables in a temperature-controlled environment. This contributes to improving local livelihoods by reducing food loss, improving nutrition intake, and generating new employment, especially among women. The utilization of the storage facilities as of February 2022 is summarized in Table 24.1.

Table 24.1 shows that, on a typical day, seven cold storage facilities are stocked with a total of about 13 tons (about 1.9 tons per cold storage on average) of horticulture commodities, including major vegetables like tomato, green peppers, onions, okra, cabbage, cucumbers, and fruits like watermelon and orange. The set of commodities stored also varies considerably across market locations. This suggests that cold storage potentially meets varying preferences for horticulture commodities across locations and connects value chains for various horticulture commodities originating from diverse production areas. Despite having the same storage capacities, utilization rates can still vary considerably across the seven storage facilities. The utilization rate in Dutse Daily Market is particularly high, potentially because of its relative proximity to Kano, the second-largest city and a major urban center in Nigeria.

[3] These can lead to significant differences in environments like northern Nigeria where air temperature can reach 35°C in the dry season. With such air temperature, the surface temperature of solar panels can reach around 70°C (or even higher).

Table 24.1 Quantities of horticulture crops stored (kg) (ColdHubs, February 2022)

Horticulture crops	Estimated storage quantity at a typical point in time (kg)*							
	Duste daily market	Gombe main market	Jimeta ultra modern market	Muda lawan market	Potiskum–Mamudo town main market	Wunti market	Yola by-pass market	Total of 7 cold storages (kg)
Tomato	620	410	330	295	1,120	640	86	3,501
Cucumber	184	84	1,194	20	10	60	78	1,630
Lettuce	1,160							1,160
Spring onions (bulbs, green tops)	410	40	80	62	420	65	30	1,107
Spring onions (bulbs)	110	35	70	48	74	120	600	1,057
Cabbage	200	75	161	96	60	84	340	1,016
Carrots	440	60	125	122	94		40	881
Green pepper	42	202	110	84	220	74	7	739
Okra	280	62	10	98	70	140	30	690
Green beans	100	70	210		60		20	460
Pawpaw	140							140
Broccoli	120			20				140
Orange	10	60		30	2			102
Strawberry	60		30			3		93
Watermelon	41					15	10	66
Eggplant	50							50
Grape	30		20					50
Cowpea	10		4				35	49
Cauliflower	30							30
Pineapple	25							25
Spring onions (green tops only)					20			20
Pear			10					10
Total of major horticulture crops	4,062	1,098	2,354	875	2,150	1,201	1,276	13,016

Note *Based on the assumption of 20 kg/crate

The fig in Table 24.1 relative to those captured two months after the launch of these cold storage facilities (i.e., March 2021), reported in Takeshima et al. (2021), suggest a steady growth over time in the amount of horticulture commodities stored. As demands for perishable horticulture commodities grow in the surrounding areas and cold storage facilities become locally more recognized, the utilization rates of other cold storage facilities are expected to continue rising over time.

The impacts on the quality preservation of fruits and vegetables can be easily seen in changes in the number of days horticulture products remain fresh (Fig. 24.2).

These figures are based on market agents' reports, reflecting the definition of freshness acceptable to various buyers and customers. Commodities stored in cold storage have considerably longer shelf life. When stored at air temperature, most commodities lose freshness within 2–7 days (from 2.1 days for lettuce to 6.6 days for watermelon). This is because of high temperatures that prevail in northern Nigeria throughout the year, which rarely drop below 20 °C even at nighttime and can often reach 35 °C during daytime even under shaded conditions. There are very limited alternative means to keep commodities cooler. Although certain varieties with longer

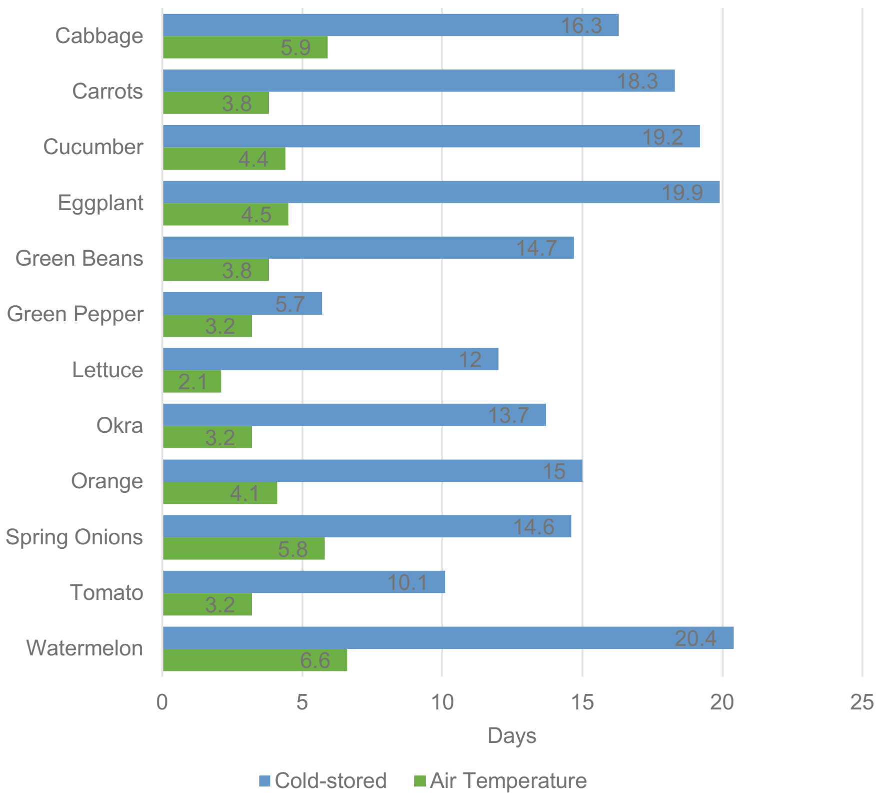

Fig. 24.2 Number of days products remain fresh, by major commodity (reports by market agents) (Authors' calculation based on IFPRI Survey 2020)

shelf life under air temperature have long been grown in Nigeria (e.g., tomatoes with harder skins that slow spoilage), the ability to preserve freshness is limited.

In contrast, major horticulture commodities stored in cold storage in these markets tend to maintain their freshness for 10–20 days (ranging from 10.1 days for tomato to 20.4 days for watermelon). In terms of differences, the extended shelf life ranges from 6.9 days for tomatoes to 15.4 days for eggplants. In terms of ratios, shelf life is extended by 2.5–5.7 times (ranging from 2.5 times for spring onions to 5.7 times for lettuce). The extended shelf life at these magnitudes for horticulture commodities may have substantial economic benefits in horticulture markets in countries like Nigeria, where timely transactions are challenging due to poor infrastructure and high transaction costs.

Panel A of Table 24.2 shows changes in sales volumes, profitability, and reported reductions in food loss for cold storage users by comparing pre- and post-intervention situations. It is important to note that cold storage users are not a random sample of market agents in the intervention markets, so the figures presented are subject to selection bias. They are asked to pay a small amount of user fees too. First, they experienced increased sales volumes and profitability and decreased wastage by using cold storage. If commodities are restricted to those stored in cold storage, the comparison of wastage between the pre- and post-intervention stages shows a significant improvement in reducing wastage; that is, cold storages make the rate of wastage nearly zero.

Next, we aimed to resolve the selectivity bias of cold storage users by applying propensity score matching methods to the difference-in-difference specifications. Panel B of Table 24.2 summarizes the impacts of cold storage on the same outcome variables: sales volumes, profitability, and reported reductions in food loss, estimated at the market-agent level. The results suggest that cold storage led to statistically significant improvements in many of these outcomes. It has led to net increases in sales volumes by as much as 69% and net increases in the share (%) of net revenues to gross revenues by 13% points. It has also led to a net reduction in the share (%) of the value of loss to total gross revenue by 11.2% points for items put in cold storage, which was substantial enough that, even when considering all items sold by market agents, the loss was reduced by 4.7% points at the market-agent level.

These effects are largely consistent with other propensity score matching specifications. The estimated Rosenbaum bounds suggest that statistical significance holds even when the odds ratio of using cold storage changes by about 40%, meaning that the results are reasonably robust against hidden bias, which propensity score matching results are sometimes sensitive to. The increase in sales may be due to reduced loss and supply responses to increased prices.

24.4 Cost-Benefit

In this section, we compare the internal rate of return among solar energy, diesel generator and grid electricity to run the cold storage to investigate the relative

Table 24.2 Impacts (Authors' calculations based on IFPRI Survey 2020)

	Outcome variables			
	sales volume (kg/week)	Share (%) of net revenue to gross revenue	Share (%) of the value of loss to total gross revenue	Share (%) of the value of loss to total gross revenue among cold-stored items only
Panel A: Descriptive statistics				
Pre-intervention	372	6.0	13.0	13.0
Post-intervention	414	12.2	8.9	2.3
Panel B: Impacts of cold storage on agent level based on DID-PSM				
Unit of impact	Percent increase/100	Percentage point increase/100	Percentage point change/100	Percentage point change/100
Estimation methods				
Primary method				
Nearest neighbor (4)+caliper (0.005)	0.691** (0.351) [1.40]	0.132*** (0.040) [1.75]	−0.047*** (0.013) [1.70]	−0.112*** (0.015) [4.00]
Robustness check through other matching methods				
Nearest neighbor (1)+caliper (0.005)	0.744* (0.426) [1.60]	0.121*** (0.049) [1.45]	−0.039*** (0.016) [1.45]	−0.104*** (0.017) [4.10]
Kernel method	0.650** (0.304) [1.85]	0.139*** (0.044) [3.25]	−0.047*** (0.013) [2.20]	−0.138*** (0.014) [17.60]
Sample size	678	678	678	678

Asterisks indicate statistical significance: *10%, **5% and ***1%. Numbers in brackets are Rosenbaum bounds

economic viability of solar-powered cold storage in the empirical setting quite common in rural areas of developing countries.

A simple framework is laid out here. The probability of being consumed is $P^j = \Pr[t_c < \tilde{t}_j]$ where t_c is the time consumed and $\tilde{t}$ is the time spoiled. Let j denote no storage ($j = 1$) and cold storage ($j = 2$). Here $\tilde{t}_j$ is larger in cold storage than in no storage, therefore $P^1 < P^2$. The probability of being spoiled is $1 - P^j$. Let y and q denote the quantity and retail price vectors, respectively. That is, $y = [y_1, y_2, \ldots, y_N]$ and $q = [q_1, q_2, \ldots, q_N]$. The expected value of commodities consumed is $\sum_{i=1}^{N} P_i^j y_i q_i$, where $j = 1, 2$. The net benefit of storing commodities in cold storage is $\Delta = \sum_{i=1}^{N} (P_i^2 - P_i^1) y_i q_i$. If $P_i^2 \approx 1$, it is $\Delta \approx \sum_{i=1}^{N} (1 - P_i^1) y_i q_i$.

Net benefit relative to no storage comes from the difference in food loss rate (probability) between cooled and non-cooled conditions. For simplicity, we assume that the food loss rate is almost zero if cooled in storage and that commodities are replaced every five days (Fig. 24.2). In the following calculation, we use the

Table 24.3 Cost-benefit (Authors' estimations)

	Case 1	Case 2	Case 3
Electricity source	25% loss without cold storage, 5-day cycle (turnaround 6 times a month)	20% loss without cold storage, 5-day cycle	15% loss without cold storage, 5-day cycle
Generator with diesel	11.9%	8.3%	5.8%
Grid	39.5%	12.2%	9.0%
Solar	33.2%	11.4%	8.6%

Note Figures are based on the transaction quantity from the Dutse market in Jigawa State and commodity prices from all 14 markets, which are updated assuming a 16% inflation rate between 2021 and 2022

utilization data from the Dutse market (Table 24.1). Though the net benefit from food loss reduction is not only in economic gains but can also include positive health effects through preserved nutritional values in horticultural commodities, the latter is not included in our analysis below. For brevity, operational costs are assumed to be negligible in all scenarios. As mentioned, there are two alternative scenarios compared to solar power: diesel-generated electricity and grid electricity.

We consider three cases differentiated by food loss rate: Case 1 (25%without cold storage), Case 2 (20%), and Case 3 (15%). The monthly internal rate of return is shown in Table 24.3.

First, in Case 1, we see relatively large rates of return in the grid (39.5%) and solar electricity (33.2%). The rate of return for diesel-generated electricity is 11.9% due to relatively large fuel costs incurring monthly. The large rates of return for the grid and solar scenarios may be due to a relatively high food loss rate in Case 1. Second, in Cases 2 and 3, we lowered the food loss rate to more realistic figures, as shown in Table 24.2. We obtained rates of return for the grid and solar scenarios, respectively, 12.2% and 11.4% in Case 2 and 9.0% and 8.6% in Case 3. The diesel scenario shows 8.3% and 5.8%, respectively, which are much lower than the grid and solar options.

The above analysis shows that the internal rates of return for the grid and solar power scenarios are relatively similar and that the diesel generator may not be a practical option, at least in the context of Nigeria. However, it is important to note that, in general, grid electricity is available in urban residential areas only. In fact, 79% of the households in the northeast region have no access to grid electricity. Thus, the grid option is not a practical option for cooling, which is needed mostly in rural farming or local market areas.

24.5 Conclusions

Cooling technologies are becoming increasingly integral elements of global food system transformation. For example, these technologies can potentially lead to a greater and more stable supply of perishable horticulture commodities and a reduction in food loss and waste, income growth for low-income producers and traders through strengthened linkages with more modern markets, and food and nutrition security for consumers through increased consumption of micronutrients. In recent years, the rapidly declining cost of off-grid solar electricity has enhanced the potential economic viability of providing such cooling technologies in disadvantaged regions like northeast Nigeria, where access to a conventional source of grid electricity has remained largely unavailable.

Complementarities across investments and coordination failures have been an important idea for industrialization in the literature on economic development (e.g., Bardhan and Udry 1999). The big push was proposed by Rosenstein-Rodan (1943) with insight from backwardness in Eastern Europe's early stage of development, and a more recent version of his big push theory was translated into a game-theoretic framework of strategic complementarities and multiple equilibria (Murphy et al. 1989). In this line of thoughts, one crucial component, which is missing or insufficient among the investments that exhibit high mutual complementarities, blocks overall economic development. Electricity is a good example that has high complementarities with many economic activities. The investment to generate electricity has been heavy and indivisible until the emergence of highly divisible solar panels. Our study from northeast Nigeria shows a clear case that a technological innovation, which overcomes the lack of such an investment, can trigger economic transformation.

24.6 Recollections of Professor Keijiro Otsuka

At the early stage of my career as a development economist, I was fortunate to meet Professor Otsuka, who mentors junior researchers through his research activities. The future of small farms in Asia was one of the topics we worked on involving a few of my colleagues from the International Food Policy Research Institute (IFPRI) and China. His field-based empirical works and economic theories are closely linked, offering strikingly intuitive insights into many issues. Joining the National Graduate Institute for Policy Studies (GRIPS) as a faculty jointly appointed from IFPRI, I was also able to witness his strong passion for educating young generations from developing countries. I am honored to be part of the Festschrift, celebrating his lifetime achievements in diverse areas of agricultural and development economics–*Futoshi Yamauchi.*

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Chapter 25
Measuring Women's Empowerment and Gender Equality Through the Lens of Induced Innovation

Agnes Quisumbing, Ruth Meinzen-Dick, and Hazel Malapit

Abstract Using the lens of the theory of induced innovation, we reflect on the development of metrics for women's empowerment and gender equality. The Women's Empowerment in Agriculture Index (WEAI), launched in 2012, was used to monitor women's inclusion in agricultural sector growth. Demand by WEAI users and the supply of tools and methods from researchers shaped the ongoing evolution of the tool to a shorter version and to another that reflected what agricultural development projects deemed meaningful to judge project success. Eventual modifications reflected user demand: a greater interest in market inclusion and value chains stimulated the development of specialized modules for market inclusion. WEAI-related metrics have demonstrated the importance of women's empowerment for development outcomes, helping governments and civil society organizations design and implement gender-sensitive agricultural development programs. Finally, the adoption of SDG5 on women's empowerment and gender equality created a demand for a measure of women's empowerment for use by national statistical systems. Whether such a metric will be adopted globally will depend on the demand from, and utility to, stakeholders as well as existing capacity, capacity-building efforts, a belief in the intrinsic value of women's empowerment, and the commitment of resources to attaining this goal.

25.1 Introduction

The inclusion of gender equality and women's empowerment as the fifth Sustainable Development Goal (SDG 5) requires that progress be monitored using valid and comprehensive measures. Although several indices of gender equality exist, like the Gender Gap Index (World Economic Forum 2021) and Gender Inequality Index (UNDP 2020), it is only fairly recently that direct measures of women's empowerment have been developed (Elias et al. 2021). The growth in empowerment

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metrics reflects innovation in the conceptualization and measurement of women's empowerment, a process that can be viewed through the lens of induced innovation.

This Festschrift to honor Professor Keijiro Otsuka, an esteemed colleague, mentor, and friend, provides us the opportunity to reflect on the development of women's empowerment metrics using the lens of the theory of induced innovation. The Hayami-Ruttan theory of induced innovation is often used to analyze technological change in the context of agricultural development. In this theory, technological and institutional innovations are viewed as endogenous to the development process rather than exogenous factors operating independently (Hayami and Ruttan 1985). These innovations, in turn, shape the trajectory of development, involving "a complex pattern of institutional evolution in order to create an economic and social environment conducive to the effective response by individuals, private firms, and public agencies to the new technical opportunities" (Hayami and Ruttan 1971, p. 2). Applying the induced innovation lens to the development of empowerment metrics, we view the development of empowerment metrics as endogenous to the development process, influenced by both the demand for and supply of empowerment metrics. Policymakers and donors 'demand' empowerment metrics to monitor progress toward women's empowerment and gender equality since these have been recognized as important development goals. Researchers, both theoretical and applied, 'supply' empowerment measures based on theories of empowerment and the development of qualitative and quantitative methods for measuring empowerment. As new empowerment metrics are developed, used, and adapted to specific contexts, they draw attention to the importance of women's empowerment and how development interventions affect empowerment outcomes. The growth in different types of users may create demands for different variants of the original measure, which in turn spurs the development of new empowerment metrics. Such has been our experience as codevelopers of the Women's Empowerment in Agriculture Index (WEAI) (Alkire et al. 2013) and the project-level WEAI (pro-WEAI) (Malapit et al. 2019).

25.2 Origins of the WEAI

We celebrated the tenth anniversary of the WEAI in February 2022. Over the past 10 years, the adoption of WEAI and its variants has grown beyond our expectations (Fig. 25.1, top panel). The solid arrows represent the linkages between the original WEAI and those versions derived directly from it. The other empowerment metrics in dashed boxes are adaptations of the original WEAI, developed in parallel by other research teams and therefore not direct 'descendants' of the WEAI. From the original WEAI to its many variants, the number of organizations adopting the index has grown from 4 to 231, and the number of countries has increased from 3 to 58 (Fig. 25.1, bottom panel).

The launching of the US Feed the Future (FTF) Initiative in 2010 spurred the development of the original WEAI to measure women's inclusion in agricultural growth. The United States Agency for International Development (USAID) needed

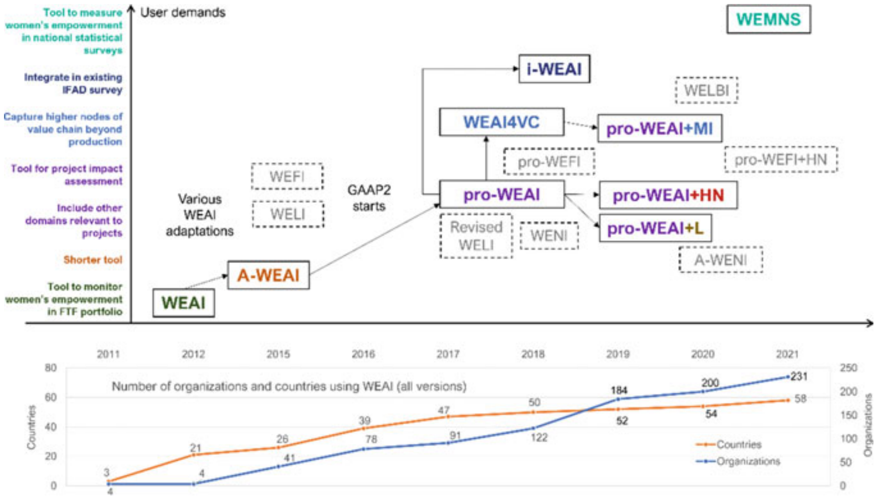

Fig. 25.1 Evolution of WEAI tools, user demands, and number of users. (Authors' records). *Note* Systematic tracking of WEAI users began in 2015; no data for 2013–14

a high-level measure, similar to those used to monitor poverty and malnutrition, to monitor progress toward women's empowerment in agriculture. However, the existing measures at the time, such as those based on the decision-making module in the Demographic and Health Surveys, did not measure empowerment in the productive sphere. Other indicators of economic participation were based on formal employment, which did not reflect informal employment in agriculture. Feminist scholars had developed a rich set of theories and definitions of empowerment, but they had yet to inform data collection and measurement. One of the most influential definitions was that of Kabeer (1999), who defined empowerment as the process by which people expand their ability to make strategic life choices, particularly in contexts in which this ability had been denied to them. In Kabeer's definition, the ability to exercise choice encompasses three dimensions: resources (defined to include not only access but also future claims to material, human, and social resources); agency (including processes of decision-making, negotiation, and even deception and manipulation); and achievements (well-being outcomes). Kabeer's definition was attractive because it lent itself to empirical measurement. There were already well-established ways to measure resources and achievements, but measures of agency were less well-developed.

When USAID approached the International Food Policy Research Institute (IFPRI) and the Oxford Poverty and Human Development Initiative (OPHI) to co-develop a measure of women's empowerment, we decided to focus on developing a better measure of agency. USAID wanted a metric relevant to women in the agricultural sector and covered domains that FTF programming could affect. OPHI provided the theoretical underpinnings of the index, adapting the Alkire-Foster methodology (Alkire and Foster 2011a, b). The resulting WEAI measures women's empowerment in the agricultural sector directly by focusing on women's agency using individual-level data collected from male and female household members in a household survey designed for this purpose.

The WEAI is an aggregate index reported at the country or subnational level and comprises two sub-indices. The first sub-index, 5DE, assesses the degree to which respondents are empowered in five domains of empowerment in agriculture, namely, decisions about agricultural production, access to and decision-making power about productive resources, control of the use of income, leadership in the community, and time allocation (Alkire et al. 2013). These domains were chosen based on the programming priorities of the FTF Initiative. It reflects the percentage of women and men who are empowered and, among those who are not, the percentage of domains in which they achieve a pre-defined threshold for adequacy in empowerment. The second sub-index, the Gender Parity Index (GPI), measures gender parity. The GPI reflects the percentage of women who are empowered or whose achievements are at least as high as the men in their households. For those households that have not achieved gender parity, the GPI shows the empowerment gap that needs to be closed for women to reach the same level of empowerment as men in their households (Alkire et al. 2013). The original WEAI with five domains and 10 indicators was launched in 2012 and was first fielded in the 19 focus countries of the FTF Initiative as part of their population-based surveys.

The data collection instrument on which the WEAI was based reflects learnings from several years of research on intrahousehold allocation and gender dynamics. We drew on our research on gender and assets, particularly the characterization of asset ownership as sole and joint (Johnson et al. 2016). Our previous research also emphasized the importance of different forms of capital, such as social capital embodied in women's groups and community organizations. Findings on the importance of workload and women's productive and reproductive tasks shaped the time allocation module. Our OPHI colleagues were very interested in concepts of autonomy as captured in the Relative Autonomy Index. So, in a sense, the original WEAI was a blend of the different knowledge and experiences of its codevelopers and the demand from potential users of the WEAI.

Although the WEAI is a quantitative measure, qualitative work went into trying to understand what the WEAI captured. Following preliminary results from the pilot surveys, the second round of quantitative and qualitative data collection was undertaken to validate, contextualize, and explore concepts of empowerment, particularly to deepen our understanding of the five hypothesized domains of empowerment (Alkire et al. 2013). The narrative guides for this exercise included applying the individual pilot questionnaire interspersed with semi-structured narratives. One objective was to explore individuals' understanding of empowerment, and respondents were also asked to show how they understood the ways questions were phrased or to give views surrounding assumptions made in coding the quantitative results. The same individuals interviewed for the second round of quantitative data collection were also asked a series of questions to validate whether the people identified as empowered or disempowered according to the quantitative measures matched their own feelings or self-assessment. Although this 'ground-truthing' yielded valuable insights and was an important part of WEAI development, it is fair to say that the first attempt to develop the WEAI was primarily driven by quantitative researchers.

25.3 Adaptation in Response to User Demand

As the WEAI was rolled out, the practicalities of fielding a complicated questionnaire quickly became evident. Data collection teams accustomed to interviewing only one household representative (usually the household head) now had to interview two respondents, male and female primary decision-makers, which created logistic and staffing challenges, particularly in settings where there were not enough female enumerators available to interview female respondents. Contrary to our pilot estimates of 30 min per respondent interview, field teams reported that the actual interview time for the WEAI module alone took much longer, adding to an interview that included other lengthy modules on consumption and nutrition. Respondent fatigue was a common concern. Some field teams, reluctant to add the WEAI module to an already long questionnaire, did not administer it in the same surveys conducted to assess agricultural production, limiting the ability to analyze relationships between women's empowerment and agricultural productivity. Some WEAI submodules were particularly difficult to field. For example, speaking in public was particularly sensitive to ask about in Cambodia and was therefore not collected. In the case of autonomy in production, questions included abstract concepts that were difficult to translate and understand. The 24-h recall time use module used in the WEAI was also problematic because it was an unfamiliar tool that required extensive enumerator training and took a lot of time to implement (about half the WEAI interview time was spent collecting time use).

The demand for a shorter, leaner module was loud and clear. We took on board many of the suggestions we received, such as streamlining skip patterns and sequencing related questions to minimize redundancy (for example, decision-making questions on production and income could be asked together in one section). To address the problems with the autonomy questions, which were too abstract, we developed vignettes to illustrate the concepts around the motivations for decision-making in more concrete terms. We explored alternative ways to reduce the time use module by dropping the collection of secondary activities and collecting information on work-related activities only, rather than the full set. To test these modifications, we conducted a second round of pilots in Bangladesh and Uganda, paying close attention to the ease of implementation and time saved with respect to the interview length. These pilots informed the development of the Abbreviated WEAI or the A-WEAI (Malapit et al. 2017). The A-WEAI retained the five-domain structure of the WEAI but with only six indicators and took about 20% less time to implement than the original WEAI.

The development of A-WEAI also marked the first time we included cognitive interviewing techniques as part of our instrument development process. Cognitive interviewing is an established technique for assessing whether respondents understand survey questions as intended and, hence, elicit valid information (Willis 2005). While the technique is used widely in psychology and other disciplines, it is less well known among economists. Johnson and Diego-Rosell (2015), who led the team that implemented the Haiti FTF baseline survey in 2012, strongly recommended conducting cognitive interviews routinely as part of the implementation of the WEAI. Because it is a new tool, they felt that it was important to evaluate the cognitive validity of questions used in the WEAI and identify areas of particular concern in the Haiti context. They found that the WEAI questions were generally well understood. However, their analysis also revealed cognitive difficulties that can be addressed by simplifying language, standardizing questions, providing country-specific examples, and incorporating cognitive testing in field implementation to ensure locally-appropriate translation (Johnson and Diego-Rosell 2015). Their findings on Haiti were extremely influential in the evolution of WEAI metrics, as cognitive interviewing became standard practice in developing subsequent WEAI versions.

Along with the roll-out of WEAI to the 19 FTF countries, other organizations, including those which implemented agricultural development projects, gradually became interested in using the WEAI to measure the empowerment impacts of their projects. Many of these projects had explicit objectives to empower women; they were interested in indicators that mattered to project success, not necessarily the five domains and 10 indicators in the original WEAI. For example, they were interested in the possibility of a backlash against women through increased intimate partner violence or whether project participation affected relationships within the household. They wanted to know whether restrictions on women's mobility prevented them from participating in market-oriented activities. Beyond impact assessments, researchers began using WEAI to examine relationships between women's empowerment and other factors (e.g., the market orientation of farming systems) (Gupta et al. 2017). Making data publicly available also spurred further analysis of women's empowerment. For example, the Bangladesh Integrated Household Survey (BIHS) 2011–2012, which is representative of rural Bangladesh, collected the WEAI and was made publicly available soon after data collection. This led to many studies being written on Bangladesh by non-IFPRI researchers.

Between 2013 and 2015, different adaptations of the WEAI emerged as users experimented with adding questions on domains not covered (e.g., political participation, mobility, decisions over reproductive health, etc.); modifying thresholds for achieving adequacy for different indicators to better suit the context; and in some cases, interviewing only women to cut costs. Interviewing women only, however, prevents us from assessing gender equality. Although the WEAI includes livestock and aquaculture activities, two notable adaptations were developed to provide greater depth in these sectors, the Women's Empowerment in Livestock Index (WELI), developed by the International Livestock Research Institute (ILRI) and Emory University (Galiè et al. 2019) and the Women's Empowerment in Fisheries Index (WEFI) developed by WorldFish (Cole et al. 2018).

The rapid growth in the use of the WEAI demonstrated the pent-up demand for such a tool. However, it was also clear that the uncoordinated development of various adaptations piloted in different settings with different designs made it difficult to synthesize lessons learned, both in terms of the validity of the tool as well as the evidence it generated on whether and what types of interventions can impact women's empowerment.

Because of the growing demand from projects for a metric for project use, the Bill & Melinda Gates Foundation funded the Gender, Agriculture, and Asset Project Phase 2 (GAAP2), which was also supported by USAID and the Consultative Group on International Agricultural Research Research Program for Agriculture, Nutrition, and Health (CGIAR A4NH).[1] GAAP2 was a portfolio of 13 agricultural development projects that co-developed and field-tested a project-level WEAI (pro-WEAI) and used it in impact evaluations. The projects were selected based on a call for expressions of interest; criteria for selection included being gender-aware or gender-sensitive in project design, with a solid monitoring and evaluation (M&E) framework, and a well-designed impact evaluation plan based on quantitative data and plans (or willingness) to undertake qualitative data collection. At the project's inception workshop in early 2016, participating projects reviewed the existing WEAI and A-WEAI tools and identified indicators they thought should be included in pro-WEAI. Despite overall feedback that the WEAI was too long, projects identified several new indicators of empowerment that they wanted to be included. Hence, the list of potential indicators, and consequently the baseline data collection instrument for the pro-WEAI pilot, was even longer than in the WEAI. The final 13 projects selected in the GAAP2 portfolio focused on either crops or livestock and had income-oriented or nutrition-oriented objectives (though, in practice, many projects included both crops and livestock, income, and nutrition objectives). These projects provided input in designing the questionnaire. Ultimately, they fielded the pilot pro-WEAI survey instrument for their impact evaluation efforts. The projects also undertook qualitative work to validate the concepts of empowerment in each context, using protocols adopted throughout the portfolio (Meinzen-Dick et al. 2019).

The development of pro-WEAI included more qualitative methods to inform the construction of the quantitative indicators and provide contextual information for interpreting the findings of each project or research study. The qualitative research teams developed a set of protocols for key informant interviews, community profiles, focus group discussions, and life histories. These qualitative instruments provided projects with guidance but can be adapted to each project's needs. The qualitative data on emic understandings of empowerment showed, for example, that both women and men did not value women having 'power over' others, so the index does not include indicators on coercive agency. Qualitative data, such as key informant interviews with project staff, can help identify whether project staff understand and support women's empowerment, while seasonality diagrams help understand whether the time use data are from the busy or slack seasons.

[1] This description of the GAAP2 process draws from Malapit et al. (2019).

Pro-WEAI follows the same Alkire-Foster methodology as the original WEAI. However, unlike the original WEAI domains informed by FTF programming, pro-WEAI domains were explicitly linked to concepts of agency: intrinsic, instrumental, and collective.

25.4 Further Development of Metrics for Specialized Uses

It is not unusual for different types of innovations to spin off from the original innovation or for related innovations to develop in parallel. This is illustrated by the development of add-on modules for pro-WEAI. The variety of projects included in GAAP2—projects with crops, livestock, income, and nutrition objectives—unsurprisingly led to an expressed demand for add-on modules tailored to specific project objectives. Because the existing WEAI tools covered crop and income decisions sufficiently, the team developed add-on modules for livestock and health and nutrition projects. The pro-WEAI livestock module was developed in consultation with the ILRI team that developed the WELI, along with specific recommendations for the type of projects that should be using the module. Projects that were primarily livestock-focused were encouraged to use the revised version of the WELI, which now integrated pro-WEAI, whereas projects that worked in mixed crop-livestock farming systems could use the pro-WEAI with the livestock module (pro-WEAI + L). Unlike pro-WEAI + L, which embedded additional livestock questions within the existing pro-WEAI questionnaire, the pro-WEAI health and nutrition module (pro-WEAI + HN) is a separate questionnaire that covers agency over health and nutrition administered to women beneficiaries of nutrition interventions. Similarly, the Women's Empowerment in Nutrition Index (WENI) was developed by Narayanan et al. (2019) to measure what they define as 'nutritional empowerment.' Although also an Alkire-Foster index, WENI involved a different methodology for index development and was validated in India; ongoing work is validating this index in Samburu County, northern Kenya. Responding to similar demands for a shorter tool, an abridged WENI (A-WENI) has also been developed using machine learning techniques (Saha and Narayanan 2020).

The WEAI and pro-WEAI were designed with agricultural producers in mind. Increased interest in value chain development and entrepreneurship as potential avenues for women's empowerment led to a demand for an empowerment metric suitable for value chain projects. This led to the development of the WEAI for Value Chains (WEAI4VC), which used a modified version of the pro-WEAI that collected information by commodity across the value chain and more details on entrepreneurship and wage work. IFPRI piloted the WEAI4VC in two countries in Asia (Bangladesh and the Philippines), and later two more pilots were conducted in Africa (Benin and Malawi), all with very different sociocultural contexts. We have since renamed the instrument, now called pro-WEAI for Market Inclusion (pro-WEAI + MI), to emphasize that it collects the core pro-WEAI module together with complementary information related to market inclusion. All the pro-WEAI add-on modules are designed to measure the core pro-WEAI, plus a dashboard of indicators for market inclusion (pro-WEAI + MI), health and nutrition (pro-WEAI + HN), and livestock (pro-WEAI + L), respectively. Given the strong demand for the pro-WEAI + MI, this tool is furthest along in terms of development. Pro-WEAI + MI also built on the pro-WEAI protocols, gender, and agricultural value chain approaches to identify emic meanings of 'empowerment' and provide a greater understanding of the empowerment environment. These enhancements to pro-WEAI + MI increase its ability to measure and contextualize empowerment and inclusion across value chains.

Along with developing the pro-WEAI and its multiple add-on modules, other parallel metrics also evolved. The ILRI team revised the WELI to nest the pro-WEAI questionnaire to facilitate comparability and is developing a Women's Empowerment in Livestock Business Index (WELBI), expanding the scope beyond livestock production to livestock business. Researchers at WorldFish developed a project-level analog called pro-WEFI and are developing a health and nutrition version that draws on the pro-WEAI + HN.

Despite the continuing development (or 'supply') of specialized modules for pro-WEAI, potential users still thought that it was too long—it had the required level of detail for impact evaluations but was not streamlined enough for use in regular M&E. With funding from the Walmart Foundation, IFPRI is currently developing a short M&E version of pro-WEAI + MI to meet the need for progress checks on the status of women's empowerment interventions. Similar to the portfolio approach used in developing pro-WEAI, Applying New Evidence for Women's Empowerment (ANEW) is working with a portfolio of projects to develop new empowerment metrics to meet the needs of market inclusion interventions, expand the evidence base on empowerment, and increase the capacity of implementing partners to use these metrics.

Other organizations have addressed the need to streamline survey instruments in different ways. One innovation, the integrated WEAI (i-WEAI), was implemented by IFPRI and the International Fund for Agricultural Development (IFAD). The pro-WEAI modules include a long list of questions on assets and decision-making on those assets, similar to questions already included in the extensive household questionnaire used by IFAD in its impact assessments. The IFAD i-WEAI integrates the pro-WEAI questions into the standard IFAD impact assessment questionnaire. Pro-WEAI variables could be collected by modifying the existing IFAD household questions on decision-making, asset ownership, financial services, group membership, and control over the use of income to link responses to individuals in the household roster. The remaining indicators could be collected with only 29 additional questions plus the time use module.

25.5 What's Measured Matters

As with agricultural innovations, innovations in measuring women's empowerment are not an end in themselves. WEAI-related metrics have shown their value in demonstrating the importance of women's empowerment for a range of development outcomes. Using the nationally-representative data from Bangladesh, Sraboni et al. (2014) found a positive association between women's empowerment, production diversity, household calorie availability, and household dietary diversity. Other research using the same dataset found aspects of women's empowerment contributing to crop diversification from cereals to the production of fruits and vegetables (De Pinto et al. 2020). While the original demand for WEAI was for a high-level number, the fact that it could be deconstructed into separate indicators and its data further disaggregated by other population characteristics was crucial for these types of analyses, as well as for providing guidance to projects on the areas where women (and men) had the greatest disempowerment, and how interventions could contribute to empowerment. Indeed, the findings from Sraboni et al. (2014) were used to inform the design of a nutrition- and gender-sensitive agricultural project, the Agriculture, Nutrition, and Gender Linkages (ANGeL) project, which was designed by IFPRI, and implemented by the Ministry of Agriculture of the Government of Bangladesh (Quisumbing et al. 2021). Plans are being made to scale up this project nationwide. At the project level, discovering sources of disempowerment can spur organizations to revise their programming. For example, one of the GAAP2 partner projects in Tanzania found that attitudes toward intimate partner violence toward women were a major source of disempowerment in their project site. Although it was too late to be included in the specific project that was part of GAAP2, they were able to obtain funding to address this issue in a future project.

With the adoption of SDG 5 on women's empowerment and gender equality, there is a growing demand for a measure of women's empowerment that can be adopted as a part of national statistical systems. Although the WEAI and its variants have been fielded in 58 countries and 231 organizations as of December 2021, the demand for a shorter, more streamlined instrument that can be adopted by national statistical systems is unmet. IFPRI is currently working with the World Bank's Living Standards Measurement Study and Emory University to develop a women's empowerment metric for national statistical systems (WEMNS) designed to be implemented as part of a large multi-topic, population-based survey. Working with the 50 × 2030 Initiative, the proposed metric will draw from the SDG framework and inputs from stakeholders in Africa, Asia, and Latin America and build on the lessons learned from developing and using WEAI. Owing to the pandemic, the first round of piloting, which took place in 2021, was conducted using phone surveys. The team is using psychometric techniques to develop a shorter, leaner instrument that can be more easily integrated into national surveys; we plan to field the revised instrument in face-to-face surveys in 2022.

Although the development of WEMNS has been informed by the lessons learned from WEAI, we do not know whether and to what extent it will resemble the WEAI. Like many innovations, the development of a metric for use by national statistical agencies is subject to its own 'supply' and 'demand' forces. Researchers can provide questionnaire modules based on theory and psychometric analysis, but in the final analysis, whether such a metric will be adopted and taken up will depend on the demand from, and utility to, stakeholders, who include governments, staff of statistical agencies, civil society organizations, and those who represent the women and men whose empowerment is being assessed. This take-up, in turn, depends on existing capacity, capacity-building efforts, the belief that measuring women's empowerment matters to attaining women's empowerment and gender equality, and the commitment of resources to attaining this goal.

Recollections of Professor Keijiro Otsuka

I first met Kei when I was an assistant professor at the University of the Philippines, Los Baños, between 1985–1987, and he was about to start working at the International Rice Research Institute. But we did not work together until land reform and agrarian unrest in the Philippines attracted the attention of Yujiro Hayami as an interesting and relevant topic to research. My collaboration with Kei and Professor Hayami started in Los Baños and continued after I went to the University of the Philippines School of Economics and the Economic Growth Center at Yale. Kei suggested that I do my postdoc fieldwork in his and Cristina David's study sites in Central Luzon and Panay. His analysis of changes in land tenure in those sites helped ground my own analysis of gender differences in inheritance customs. We started working together more closely when we were both at the International Food Policy Research Institute. Kei was working on a multi-country study of the relationship between property rights and natural resource management. He was puzzled by his observations in Ghana and Sumatra, both areas with matrilineal inheritance systems, where gender differences in inheritance and property rights were important to tree-planting decisions. But Kei was not a gender researcher, so he asked me to work with him on the project. Through our joint research, Kei realized that it was important to look at gender issues, as they can shape many processes and outcomes. I have often said that Kei is my most famous convert to gender research, and I am happy that I have had the chance to work on gender issues with many of his colleagues and students in the Philippines and Japan. I am honored and privileged to contribute to this collection to celebrate his life and work.

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Chapter 26
Competition, Antitrust, and Agricultural Development in Asia

Arsenio M. Balisacan

Abstract Competition law—also known as antitrust in some jurisdictions—has become part of governments' policy arsenal to achieve efficient and welfare-improving market outcomes. From only a handful of economies in North America and Europe, the adoption of competition law and policy has spread rapidly to Asian economies since 1990. Like their Western counterparts several decades earlier, most Asian jurisdictions have exempted agriculture, albeit in varying degrees, from the prohibitions of competition law, such as those involving the exercise of market power by farmers' associations. Public choice considerations suggest that the exemption serves as a countervailing force for the farmers' comparatively weak position in the balance of political influence for agricultural policy and in bargaining power over the more concentrated wholesale-retail segments of the agri-food value chain. Farm heterogeneity and farm-operation consolidation, induced in part by the economy's structural transformation, weaken the case for broad exemption.

26.1 Introduction

In the past 50 years, rapid economic growth has been the single most important contributor to Asia's record poverty reduction (ADB 2020). This should not be lost in policy discussions on the appropriate responses to regional and global development challenges post-COVID-19 pandemic. Although globalization has not been smooth and neutral across countries and even across population groups within countries, it has generally resulted in faster and sustained growth, poverty reduction, and shared prosperity in economies where good economic governance is the norm. Where market policies and institutions, particularly governance structures, enable efficient resource allocation, human capital formation, and innovation, both growth and poverty reduction are robust and enduring.

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Increasingly in Asia and elsewhere, governments' policy arsenals to achieve efficient and welfare-improving market outcomes have included adopting competition law and policy (hereafter interchangeably referred to simply as competition policy). A competition policy—also referred to as antitrust in some jurisdictions—commonly provides administrative and judicial measures ensuring that markets are not restricted in ways that reduce economic welfare and stifle economic development. These measures include enforcement mechanisms preventing cartels, collusive behavior, abuses of dominant market position, and anticompetitive mergers and acquisitions. They may also involve leveling the playing field between incumbents and potential market entrants or between state-owned or state-controlled enterprises and private enterprises in the same industry or market. If properly designed and implemented to complement other economic policies, including industrial policy, competition policy helps provide an enabling environment for fairer market outcomes, greater innovation, and more durable and inclusive growth.

Interestingly, many jurisdictions, including those in Asia, have exempted agriculture from the discipline of competition policy, such as those involving the exercise of market power by farmer associations or the erection of trade barriers that set an uneven playing field in favor of domestic producers. This stance appears to run counter to the commonly-held observation that, in developing countries, policies and regulations distorting agricultural and food markets have tended to reduce farm incomes and stifle agricultural and rural development. The effective taxation of agriculture is particularly evident from the 1950s to the 1980s (Anderson and Martin 2021). In recent decades, globalization and technological change, along with shifts in the global trade and financial institutions, have reshaped the dynamics of agricultural and food markets.[1] Nevertheless, market distortions in agriculture continue to be pervasive.

The past two decades have indeed seen a rapid global transformation in the agri-food value chain (Barrett et al. 2020). But the high—and rising—concentration in the chain's downstream segments (such as processing, wholesale, and retail) has raised widespread concerns about abuses of market power by players in these segments at the expense of farmers who are perceived to have a weak position in the value chain (Deconinck 2021; Velazquez et al. 2017).

This paper explores the character and role of competition policy in Asia's agricultural development, particularly its enforcement in various segments of the agri-food value chain. It employs political economy perspectives, particularly public choice, to characterize policy formation in agricultural and food markets at various stages of economic development. The effective taxation of agriculture (farm-level production) at low per capita income is seen as balancing the costs and benefits of collective action by various players in the value chain. The resulting inefficiencies, including rent-seeking costs, push agricultural incomes and the economy below its potential. Removing these inefficiencies to engender sustained income growth requires changing the balance of political influence, allowing farmers to acquire a stronger

[1] Various chapters in the volume edited by Otsuka and Fan (2021) provide extensive discussions on the forces shaping agricultural and food markets, both globally and nationally.

position in the value chain and agricultural policy formation. In this view, the exemption of farmers' associations from antitrust laws provides a countervailing force, giving them space to influence the terms of trade in the market.

The rest of the paper is organized as follows: Sect. 26.2 briefly characterizes the spread and influences of competition law and policy in Asia. For context, the discussion starts with the Western character and influences of antitrust law. Section 26.3 describes the treatment afforded to agricultural and food markets by competition policy regimes in Western jurisdictions and their Asian counterparts. Section 26.4 then uses the public choice lens to examine the nexus between competition policy and structural transformation in agriculture. Finally, Sect. 26.5 provides concluding remarks.

26.2 Spread and Influence of Competition Law and Policy

Modern competition policy has its origins in the late nineteenth century when changes in transportation, communication, and manufacturing technologies brought unprecedented economies of scale and scope, fueling the rise of industrial behemoths. In the United States, the eventual formation of cartels and trusts among them sparked concerns about their economic power and the costs to smaller firms and consumers. Motta (2004, p. 3) notes that while "farmers and small businesses had enough political voice and public sympathy to lead to the formation of antitrust in many US states," such laws were inadequate against agreements involving more than one state. This led to the passage of the Sherman Act in 1890, supplemented in 1914 by the Clayton Act and the Federal Trade Commission Act. The Sherman Act prohibits price-fixing and market-sharing agreements among competitors and monopolization practices by an individual firm; the Clayton Act regulates mergers capable of substantially lessening competition.

The decades that followed the Sherman Act saw enforcement actions hard on firms acquiring significant market power. In the late 1970s, influential ideas—associated with the Chicago school—challenged the core tenets of antitrust, describing the antitrust regime as excessive to the point of inhibiting economic efficiency and market dynamism.[2] Consequently, competition enforcement was relaxed, providing a more permissive environment for any type of market structure and conduct. This shift in the regime, lasting until the late 1990s, had "the effect of making it more difficult for plaintiffs to prevail and easier for defendants to establish efficiency justifications" (Baker and Morton 2019, p. 3). But the rise of market power and income inequality in the ensuing decades—arising from the relaxed antitrust enforcement and other changes, including globalization and information technology—once again triggered calls for a stronger, more effective antitrust law and policy. As in the Sherman Act's early years, the demand reflected the concern for consumer welfare and the threat

[2] The late 1970s saw two of the most influential publications—by Robert Bork and Richard Posner—about antitrust law and policy (Baker 2019, p. 1).

posed by substantially rising market power to foment inequality and undermine democracy.

In Europe, in the aftermath of the Second World War, competition policy measures were introduced into the 1951 Treaty of Paris partly to diminish the excessive concentration of economic power, prevent discrimination on national grounds, and guarantee equal access to essential resources, such as coal and steel. Moreover, the measures reflected the increasing appreciation at the time for free competition (broadly, economic freedom) as an organizing structure—instead of the centralized organization of markets that prevailed in countries such as Germany and Austria before World War II—to attain optimal resource allocation, technological progress, and the ability to adjust to changing economic conditions. At the backdrop of this development was the success of the US economy, which had relied on antitrust rules to guard against excessive economic concentration that threatened economic progress and democracy.

Broadly, from the formation of the EU to today, the objectives of European competition policy remain anchored on economic efficiency and European market integration. By preventing market discrimination on national grounds, competition policy serves to make the home market and the European Community (EC) competitive in worldwide markets. However, under certain circumstances, the implementation of the policy also considers social and political objectives, as when the EC regards the high social cost of considerable job losses when it prohibits agreements tantamount to anticompetitive behavior. In particular, the policy accords special importance to small and medium enterprises (SMEs), giving them favorable treatment, including exemptions from anticompetitive agreements. The argument is that the share of SMEs in intra-community trade or in competition is not appreciably substantial (de minimis doctrine). Furthermore, the favorable treatment is seen as a balancing act for the disadvantage that SMEs, including farmers, have in the markets because of their small size.

From a handful of countries in North America and Europe, the adoption of modern competition law and policy, including the establishment of competition agencies, has spread rapidly to over 70 country jurisdictions, both developed and developing, since 1990 (Fig. 26.1). In general, high-income countries adopted it earlier than low-income countries. In Asia, the first to adopt was Japan (1947), as imposed by the Allies after World War II partly to prevent a resurgence of excessive concentration of economic power. In the Association of Southeast Asian Nations (ASEAN) economies, where the adoption occurred mostly during the past 20 years, competition policy has been a key pillar of regional integration.[3] Back in 2007, the ASEAN leaders adopted the ASEAN Economic Community (AEC) Blueprint 2015, which provides for action items to be undertaken and completed by each member state, including adopting competition law, toward establishing the AEC 2015. The AEC Blueprint calls for the harmonization of competition law and policy in member states to effectively deal with cross-border commercial transactions. However, it does not mandate the establishment of a regional competition policy regime. Rather it gives maximum flexibility

[3] Ravago et al. (2021b) discuss the evolution of competition law in ASEAN economies.

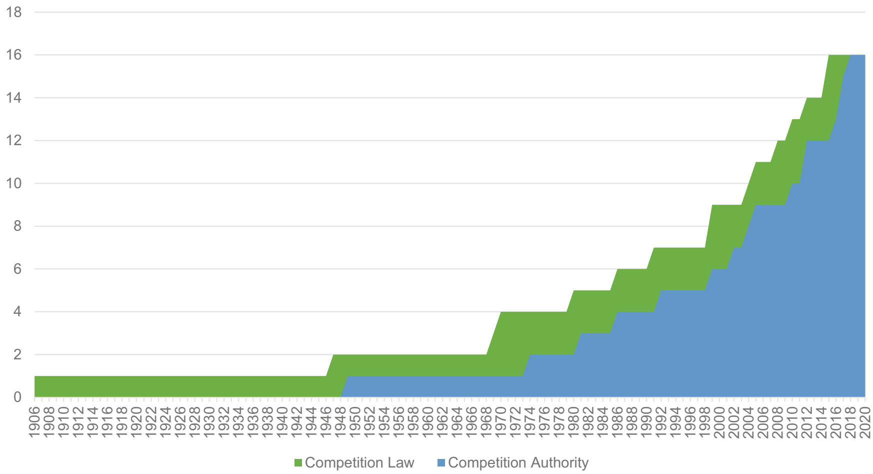

Fig. 26.1 Introduction of competition law and establishment of competition authorities in the Asia–Pacific region (OECD CompStats database in the Asia–Pacific Region, OECD Asia–Pacific Competition Law Enforcement Trends 2021)

to the member states to develop their respective national competition policy, considering each state's socioeconomic and political landscapes, including legal systems and level of economic development.

Apart from the country's level of development and membership in regional associations, the global movement toward greater economic openness and political liberalization partly explained the widespread adoption of competition law after 1990 (Bradford et al. 2019; Hofmann et al. 2017; Palim 1998). This movement—sparked by the promarket revolution in economics that co-evolved with the Reagan-Thatcher administrations—elevated trade liberalization and competition policy in the policy reform agenda, including those of multilateral organizations. The pressure from multilateral organizations, including the Organisation for Economic Cooperation and Development (OECD), World Bank, the United Nations Conference on Trade and Development (UNCTAD), and the Asian Development Bank (ADB), helped catalyze the rapid spread of competition law in developing Asia and elsewhere (Ravago et al. 2021a).

Adoption is one thing; the outcome of competition law and policy is another. For instance, competition laws and policies borrowed from Europe and the United States may be incompatible with developing Asia's economic, institutional, and cultural contexts, including governance and legal systems. However, there is a dearth of understanding on the causal link between the adoption of competition law, on the one hand, and economic development outcomes, on the other, especially in the context of developing Asia. Such understanding would have to involve characterizing the nature of competition law and policy, establishing the competition agency's enforcement intensity (e.g., number and size of penalties) and performance (i.e., effect on market power), and identifying the effects of competition policy in relation to other factors, including institutions and other policies, consumer welfare, and economic development (economic growth, productivity, income distribution, poverty).

Of particular interest is whether the adoption of competition policy considers the stylized characteristics of agriculture in Asia and whether such law provides the countervailing force for reducing market distortions inimical to farmers' total welfare and efficient rural transformation.

26.3 Agriculture in Competition Law and Policy

The primary objective of competition law and policy is to make markets work for the common good by preventing anticompetitive agreements, conduct, restrictions, or behavior that stifle total welfare and economic development. Freeing markets of cartels and dominance abuse is key to enhancing total welfare. In developing countries where policy distortions and rent-seeking activities are rampant, an antitrust consideration that focuses on consumer welfare also enhances total welfare (see discussion in Sect. 26.4). From a general equilibrium perspective, where everyone in society is a consumer, long-term improvement in consumer welfare matters. In practice, as discussed in Sect. 26.2, there may be other considerations, such as preventing excessive concentration of economic power to contain rising inequality or exempting small enterprises from certain market restrictions to enhance their bargaining power in the value chain.[4]

The recent economic history of many countries worldwide shows that the agriculture sector has enjoyed exemptions—albeit limited in many instances—from the ambit of competition law and policy. These exemptions appear to arise from farmers' weak bargaining power in both output and input markets, which, in turn, may have to do with the structural attributes of agricultural production. First, because farming involves biological and physical processes, including weather, agricultural production is seasonal, highly perishable, and susceptible to various production and marketing risks. Second, because of poor infrastructure in rural areas, some markets are missing or occur only in the later stages of development, such as insurance and formal financial intermediation (Binswanger and Rosenzweig 1986; Barrett et al. 2020). High transaction costs arising from poor infrastructure also mean that agricultural markets are weakly integrated across space and over time. Thus, while demand is more evenly distributed throughout the year, supply and prices fluctuate considerably.[5] Third, the sector comprises many small, geographically-dispersed farmers who face a highly concentrated marketing segment in the value chain. On the other hand, antitrust exemption facilitates cooperation among farmers, enabling them to

[4] Cross-country experiences suggest that non-efficiency considerations in competition enforcement have been few and far between (OECD 2016).

[5] As demonstrated elsewhere (e.g., Williams and Wright 1991), competitive markets stabilize but do not eliminate price fluctuations. Price movements would characterize a well-performing integrated market according to storage costs plus the effect of shocks.

improve their bargaining power. Moreover, such cooperation enables them to exploit scale economies in research and development (R&D), production, and marketing, which can be welfare-enhancing for farmers and the entire economy.

The competition laws of both the EU and its member states provide broadly similar exemptions to the agriculture sector concerning permitted and prohibited market practices (Kachel and Finkelshtain 2010; Velazquez et al. 2017). In clarifying the scope of antitrust exemptions afforded by the treaty founding the EC to agriculture, the European Council has included restrictive agreements that form an integral part of a national market organization and those applying to cooperatives or farmers' associations (called the 'cooperative exemption').[6] The cooperative exemption covers agreements, decisions, and practices concerning agricultural products' production, processing, marketing, or joint use of facilities. However, the exemption does not include restrictive arrangements involving the setting of identical prices (cartelistic behavior). Nor does it cover nonfarmers in the agricultural and food value chain—that is, a restrictive arrangement includes only farmers, farmers' associations, or associations of such associations. While these exemptions tend to impair competition and permit farmers' organizations to exercise substantial market power, the evidence is mixed, and the economic relevance of agricultural exemptions is quite limited (Deconinck 2021; Kachel and Finkelshtain 2010).

Antitrust regulation in the United States does not exempt agriculture from prohibited market restrictions. Certain types of agreements prohibited by the Sherman Act, such as price-fixing and market allocation, are regarded as so anticompetitive that they are illegal per se (i.e., require no further investigation). This has created a problem for farmers organized as associations or cooperatives because their collective agreements on the marketing of their produce may be construed as agreements on prices, which are illegal per se. The Copper-Volstead Act was passed to provide the necessary statutory protection for farmers' associations. The statute allows farmers, organized as cooperatives, to agree on prices or terms of sale, coordinate with other agricultural cooperatives, and develop a dominant supply position in the market without violating antitrust law (Kachel and Finkelshtain 2010).

Moreover, it allows agricultural cooperatives to establish joint marketing agencies. There are conditions and limits to the exemption, however. First, the dominant position must not result from anticompetitive conduct vis-à-vis competing firms. Second, mergers with—or acquisitions by an agricultural cooperative of—non-cooperative firms are not exempt and are subject to merger supervision. Third, like in the EU's agricultural exemption, the Copper-Volstead Act also allows intervention by the secretary of agriculture or the courts to prevent abuse of the exemption, as when an agricultural cooperative exploits its market power to substantially enhance the price of an agricultural product.

Studies empirically assessing the effects of farmers' associations on their ability to exercise market power and raise the prices of agricultural products (or reduce

[6] See Article 2 of Regulation 26 on applying certain rules of competition to production of and trade in agricultural products (Official Journal of the European Communities, pp. 129–130).

the costs of agricultural inputs) are sparse and focused mainly on developed countries. Broadly, these studies suggest that farmers' associations bring benefits to farmers, enhance their bargaining power, and do not cause undue harm to consumers (Velazquez et al. 2017). While the laws enable far-reaching cooperation and market dominance without being challenged by competition authorities, certain mitigating factors constrain their ability to behave like cartels. For one, agricultural cooperatives are not immune from the free-rider problem, notwithstanding institutional arrangements such as 'marketing orders,' in which grower referendum and approval by a marketing parastatal are binding for all growers of a specific product in a geographic area.

Antitrust exemptions for agriculture are also seen in many jurisdictions in Asia. As noted in Sect. 26.2, these countries adopted competition laws amid major changes in the global trading order associated with multilateralism and regional economic cooperation. Tables 26.1 and 26.2 present some of the scope and features of the 'agricultural exemption' for northeast Asian countries (Japan, Korea, Taiwan, and China) and the four major emerging ASEAN economies (Indonesia, Malaysia, Philippines, and Thailand).

Tables 26.1 and 26.2 show a broad commonality of competition laws and policies across Asia in providing exemptions to partnerships or associations—including federation of partnerships or associations—involving small-scale enterprises and farmers. As in the United States, the antitrust laws of Japan, Korea, and Taiwan do not specifically mention agricultural exemption, but other statutes carve out farmer associations from the scope of antitrust laws. In Japan's case, the Agricultural Cooperative Law of 1947 provides—and remains—the basic framework of agricultural cooperatives (known as *Nokyo* or JA), including the exemption from the prohibitions of the antitrust law. However, unlike in the EU and North America, where the exemption applies to farmer members only and to farming-related activities (marketing of outputs and inputs), the exemption given to JA is wide-ranging since the cooperatives offer membership also to nonfarmers and are likewise engaged in nonfarming activities, including banking, insurance, and welfare-related needs of both farming and nonfarming communities.[7]

The ASEAN member states, being relatively younger adopters of competition laws, have had the advantage of learning from the experiences of the more mature jurisdictions. Neither their national competition laws nor the AEC Blueprint provides a blanket exemption on agriculture. But both national laws and the AEC Blueprint afford special treatment to cooperatives and groups of small enterprises. Malaysia's law has a provision for "individual or block exemption," while the Philippines' law

[7] According to Kazuhito (2015), the JA (the national federation of agricultural cooperatives in Japan) has been a virtual monopoly in the rice market (more than 95% share in 1985); it has been also dominant in the fertilizer market (80% share) and in both pesticides and agricultural machinery markets (60% share). See Mulgan (2016) for a discussion on the institutional context of JA's market power, particularly the dynamics of agricultural policymaking involving the executives of cooperatives, the Diet politicians, and the bureaucrats of the government's agriculture ministry.

Table 26.1 Exemptions for agriculture in competition jurisdictions in Northeast Asia

Jurisdiction	Japan	Korea	Taiwan	China
Competition law	Antimonopoly Act (1947)	Monopoly Regulation and Fair Trade Act (1980)	Fair Trade Act (1992)	Anti-monopoly Law (2007)
Exemption features	Article 22 states: The provisions of this Act *do not apply to acts by a partnership (including a federation of partnerships)* … provided, however, that this does not apply if unfair trade practices are employed, or if competition in any particular field of trade is substantially restrained, resulting in unjust price increases…	Article 60 states: The provisions of this Act shall not apply to any acts of an association (including a federation of associations)… provided that this shall not apply to unfair business practices or price hikes by unfairly restricting competition…	The Fair Trade Act does not contain an exemption for agriculture. However, the Agricultural Products Market Transaction Act (1981) contains provisions on joint marketing Chapter 2 on joint marketing, Article 7–11 of the Agricultural Products Market Transaction Act, states: Agricultural products marketing may be joint marketing performed by farmers' organizations, two forms as following: 1. wholesales of supply and reselling or processing as purpose; 2. retails of supply to consumers as purpose…	Article 56 states: This Law is not applicable to the association or cooperation by agricultural producers or rural economic organizations in their business activities of production, processing, sale, transportation, storage of farm products, etc.

Note Information was obtained from the respective laws cited. Italics added by author

Table 26.2 Exemptions for agriculture in competition jurisdictions in Southeast Asia

Jurisdiction	Indonesia	Malaysia	Philippines	Thailand
Competition law	Law Number 5 Concerning the Prohibition of Monopolistic Practices and Unfair Business Competition (1999)	Competition Act and Competition Commission Act (2010)	Philippine Competition Act (2015)	Trade Competition Act (2017)
Exemption features	Article 50 states: *Excluded from the provisions of this law* shall be the following: …h. *business actors of the small-scale group*; or i. activities of *cooperatives* with the specific aim of serving their members	The Competition Act does not contain an exemption specific for agriculture. However, sections of the law *allow for individual or block exemptions* Under Part II, Anticompetitive Practices, Chap. 1 (Anticompetitive agreement): Individual exemption 6. (1) An enterprise may apply… for an exemption with respect to a particular agreement from the prohibition under Section 4 Block exemption 8. (1) If agreements which fall within a particular category of agreements are… likely to be agreements to which Section 5 applies, the Commission may… grant an exemption to the particular category of agreements	The Philippine Competition Act does not contain an exemption for agriculture. However, Section 28 of the law allows for the possibility of forbearance for an entity or group of entities. It states: The Commission *may forebear from applying the provisions of this Act… on an entity or group of entities*, if in its determination: (a) Enforcement is not necessary to the attainment of the policy objectives of this Act; (b) Forbearance will neither impede competition in the market where the entity or group of entities seeking exemption operates nor in related markets; and (c) Forbearance is consistent with public interest and the benefit and welfare of the consumers	Section 4 states: This Act *shall not apply* to the operation of the followings: …(3) *groups of farmers, cooperatives, or cooperative groups* recognized under the law and having the aim in their business operations to benefit the vocation of farming

Note Information was obtained from the respective laws cited. Italics added by author permits "forbearance" from applying competition law to an entity or group of entities. On the other hand, Thailand's law specifically excludes groups of farmers, cooperatives, or cooperative groups from applying competition law.

Like in Japan and Korea, agricultural population densities in the ASEAN member states are high relative to their Western counterparts, as indicated by the rural population per agricultural land area. Average farm sizes were already small in the 1970s, ranging from 1 hectare in Indonesia and Japan to 2 hectares in the Philippines and 3 hectares in Thailand, in contrast to the averages for high-income economies in Europe and North America, where more than 100 hectares of operational farm sizes were quite common (Yamauchi et al. 2021). However, in most ASEAN member states, stark farm-size heterogeneity across crops and each country's administrative subdivisions are not uncommon. As discussed in the next section, this feature of the agrarian structure, combined with other factors, including technological change and external developments, has influenced the political dynamics of agricultural policy and possibly the standard of competition law and policy.

26.4 Political Economy, Agricultural Policy, and Antitrust

Section 26.3 has noted the weak bargaining power of unorganized farmers in the marketing chain as a justification for exempting farmers' associations from antitrust law prohibitions. If organized, they can enhance their negotiating position in the marketplace, including the prices they receive for their produce and the prices they pay for production inputs. But there is a broader context to this exemption, involving public-interest considerations and the political economy of agricultural policy in the development process.[8]

A stylized pattern of agricultural policy is that developed countries tend to subsidize agriculture while developing countries tend to tax it.[9] The policy regime of developed countries tends to create incentives that effectively subsidize the domestic production of agricultural products, making the returns to domestic agricultural production higher than otherwise would be the case. In contrast, the comparable regime for developing countries tends to make those economic incentives discriminate adversely against farmers, effectively making returns to agricultural production lower than otherwise would be the case. The observation aptly referred to as 'development paradox' generally shows up in comparison of countries at different levels of development (cross-section data) and in the recent history of newly industrializing and developed countries (time-series data). However, this pattern has weakened in the

[8] No attempt is made here to review the extensive literature on the political economy of agricultural and food policy. For such a review covering the past 50 years, see Swinnen (2021).

[9] An early attempt to formalize the stylized fact as regression is by Balisacan and Roumasset (1987). See Binswanger and Deininger (1997) for an early review of the patterns and explanations of agricultural policies and Anderson and Martin (2021) on recent trends and policy developments.

past three decades due to several factors, including multilateral trade liberalization and the information technology revolution (Anderson and Martin 2021).

Why governments do what they do in relation to public policies, including agricultural and food policies, has been a fertile ground of inquiry by serious students of development. In particular, the stylized facts of agricultural policy have spawned studies aiming to understand the forces that shape agricultural protection over time periods, the dispersion of rates of assistance to agriculture across countries and across industries within the agriculture sector, the choices of policy instruments to achieve redistributive goals, and governments' responses to economic shocks, including structural adjustment programs. This is not the place for an exhaustive review of the literature explaining public policies in agriculture. Rather, this section focuses the political economy lens on the changing costs and benefits of collective action for agricultural protection during structural transformation and economic development.

Governments' assistance (income transfers) to agriculture can be usefully viewed as the outcome of the relative influence exerted by various groups in society—the proponents and opponents of transfers—as well as other factors, including governance structures, information and communication technology, and external shocks (e.g., sharp swings in terms of trade). Each group's ability to exert influence on government depends on the costs and benefits of its collective action. In the agriculture-protection game, farmers mobilize influence to gain pro-agricultural policies and assistance programs, while consumers, especially urban consumers, seek to oppose increases in agricultural prices arising from these policies.

In developing countries, or in the early stage of development, farmers tend to have a low political influence on agricultural policies relative to urban consumers and industrialists. On the cost side, farmers are numerous and dispersed geographically, making it costly to organize and coordinate them for collective action. This is accentuated by poor transport and information costs in rural areas. On the benefit side, small farm sizes and low farm productivity mean that farmers have a low market surplus, muting their incentives to contribute efforts in collective action for a pro-farmer agricultural policy. The low productivity in agriculture is partly due to farmers' lack of access to productivity-enhancing technologies and working capital. Binswanger and Rosenzweig (1986) elaborated that formal financial intermediation tends to develop in rural areas only later in the development process due to the high unit cost of lending to small farms and the high risks attendant on farming.

On the other hand, urban consumers have relatively favorable conditions for collective action against agricultural protection. Geographic concentration and the relatively favorable transport and communication infrastructure in urban areas make collective action less costly. On the benefit side, the purchasing power of their incomes is sensitive to agricultural prices since, at low per capita incomes, food constitutes a very high share of their consumption spending. Because workers' wages are sensitive to changes in food prices and since profits are sensitive to wage costs, industrialists are likewise supportive of the consumers' cause, thereby tending to oppose agricultural protection. Thus, at the early stage of development, the balance of political pressure tilts in favor of policies and programs that tax agriculture.

However, as development proceeds, rising incomes (and falling food share in total consumption spending) make urban consumers increasingly less sensitive to agricultural policy. Industrial production also becomes more capital-intensive, effectively reducing the sensitivity of profits to wages and food prices. As market surplus increases, farmers' real incomes become increasingly sensitive to agricultural prices. Coalition costs fall as the number of farmers declines and rural infrastructure improves. Over time, farmers' pressure for pro-farm agricultural and food policy eventually dominated those of consumers and industrialists on the taxation of agriculture.

Balisacan and Roumasset (1987) provide empirical support to the stylized depiction of agricultural and food policies above. But the costs and benefits of collective action are by no means the only determinants of agricultural policy, especially in recent decades. Indeed, as shown by Anderson and Martin (2021), the distortions to agricultural incentives in both developed and developing countries have substantially declined—not risen—in the past three decades as rapid urbanization, structural transformation, and industrialization proceeded in Asia and beyond. There is, however, wide dispersal of agricultural assistance even for countries of comparable income levels and across industry segments of agriculture. Swinnen (2021) reviews the evidence on the other key factors, including the role of information technology, accession to the World Trade Organization and other trading agreements, and the rise of global agri-food value chains in shaping policy reforms in the late twentieth and early twenty-first centuries.

The spread of global agri-food value chains in recent decades is noteworthy. Facilitated by transport and information technology revolutions, the integration of domestic and foreign companies in the global value chains has blurred the lines between domestic and foreign interests. For example, domestic companies supplying inputs to the production process of foreign companies in the value chain are not likely to benefit from a collective action that imposes barriers to entry of the foreign final product. Thus, the integration of economies and companies in the value chain is expected to weaken the incentives for protectionist policies.

On the other hand, in jurisdictions with significant external trade barriers, the interests of agribusiness and food-processing companies tend to align with those of farmers. Some evidence suggests that the growth of agricultural protection has been associated with the growth and concentration of these companies (Barrett et al. 2020).

Further, the growing concentration in the wholesale-retail segment of the food supply chain and the emergence of the preferred supplier systems can also potentially affect agricultural and food policies. Such concentration may entail a substantial rise in market power, which the wholesaler-retailer can exercise against farmers (monopsonization) or consumers (monopolization), or both. As discussed above, at the early stage of development, cost–benefit considerations tend to make consumers (and industrialists) relatively more able than farmers to generate political influence that shapes food policy. Moreover, for reasons discussed in Sect. 26.3, wholesaler-retailers tend to have greater bargaining power over farmers than they do over consumers concentrated in urban areas. That is, with or without rising concentration in the wholesale-retail segment, farmers' relatively high cost of collective action may give rise to low investment in a countervailing force for more favorable terms of trade.

Balisacan (2019) makes a case for an independent competition authority acting on behalf of consumers—as a countervailing force—to make markets work better by effectively removing barriers to competition and other business conduct that substantially hinder, prevent, or lessen competition. These barriers, anticompetitive conduct, and economically wasteful influence-peddling activities push the economy down from its potential growth (i.e., inside the production possibility frontier). The consequences are lower long-term growth, higher poverty, and higher income inequality than otherwise would be the case. Society becomes less fair: the numerically large losers are the consumers, and the numerically small gainers are the highly concentrated (non-agricultural) producers and traders.

The observation in Sect. 26.3 that jurisdictions in Asia tend to exempt associations of numerically large, small farmers from the ambit of antitrust law can thus be seen as an effort to address the imbalance between bargaining power and impediments to competition in agricultural and food markets. From this view, an independent competition authority provides the countervailing force to achieve fairer, welfare-enhancing market outcomes. The positive effects of competition policy in food markets on household welfare, economic growth, and other dimensions of development, including equity, have been demonstrated empirically.[10]

26.5 Concluding Remarks

Modern competition law has become part of the institutional architecture for growth and economic development in Asia. The challenge for many of the region's developing economies is to design and implement the law in ways that are respectful of, or consistent with, their legal systems, culture, governance structures, and level of economic development. If framed and enforced effectively, competition policy complements other policies, including agricultural policy, and promotes consumer welfare and sustainable economic development.

Political economy considerations may explain the observed exemption of agriculture from antitrust law prohibitions, at least in the early stage of development. The numerically large small farmers tend to lack bargaining power in relation to the more concentrated wholesale-retail segments of the marketing chain. Left alone, they are less able to prevent collusive conduct or abuse of dominance. This disadvantage reduces their welfare, possibly amplifying the adverse effects of their weak position vis-à-vis urban consumers and industrialists in collective action on agricultural and food policy. The exemption removes the risk that farmers' collective action that may have the object or effect of influencing prices or terms of trade runs afoul with antitrust law. Further, in preventing or reversing harm to competition in agriculture,

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[10] World Bank (2017) provides evidence for a number of country cases.

an independent competition authority serves as a countervailing force to achieve fairer market outcomes and promote economic development.

Nevertheless, caution must be exercised in carving out agriculture from antitrust enforcement, as the agriculture sector in developing countries is far from homogenous. Farms vary substantially in size, physical attributes, crops, and organization, partly reflecting national policies, institutional legacies, and geography. Indeed, it is not uncommon to find small farm holdings (peasant agriculture) coexisting with large commercial farms (corporate plantations), where the costs and benefits of collective action for political influence tend to favor the latter. Excessive protection of highly concentrated farming segments inhibits efficient resource allocation and structural transformation. Extending the exemption to these segments may be counterproductive to the objective of enhancing efficiency and consumer welfare. Moreover, as modernization proceeds and farms become bigger (numerically smaller number of farmers), as seen in East Asia's experience, the political influence of farmers' associations tends to rise, enabling them to exert substantial market power. Again, in this case, it is unlikely that the continuing exemption of agriculture helps advance consumer welfare and sustainable economic development.

Recollections of Professor Keijiro Otsuka

Kei's distinctive hallmark is his twin ability to weave a story out of seemingly unrelated observations and engage colleagues, particularly researchers and scholars in developing countries, to sharpen the links toward a coherent narrative that helps inform policy choices that governments and societies make to end poverty and underdevelopment. His reach has not escaped me. I first met Kei through my early mentor in agricultural economics, Tina David, in the late 1980s, when the two of them were then jointly leading the path-breaking work on modern rice technology and income distribution in Asia. It became then natural to count on him and his ideas in some of the regional initiatives that I later pursued while I was serving as director of the Southeast Asian Regional Center for Graduate Study and Research and Agriculture (SEARCA), president of the Asian Society of Agricultural Economists (ASAE), and chief economist of the Philippine Government. Among these involved taking the role of keynote speaker at the 2008 ASAE Conference, Advisory Board member of the Asian Journal of Agriculture and Development, and contributor to the comparative book *Dynamics of Regional Development: The Philippines in East Asia.* Undoubtedly, Kei's touch and influence on many Asian and African scholars and the theory and practice of agricultural development will endure.

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Chapter 27
Summary and Conclusions

Jonna P. Estudillo, Yoko Kijima, and Tetsushi Sonobe

27.1 Overview

Agricultural development is the major driver of rural transformation in Asia, and the Green Revolution is the flagship of agricultural development. It is characterized by the continuous development of improved seed varieties and their dissemination. The Green Revolution in Asia is focused on three major staples: rice, wheat, and maize. Following the Green Revolution, the yield and production of these three staples rose, and their prices declined, facilitating the move of resources away from the farm and into the nonfarm sector (ADB 2020). The shift of household livelihood activities away from the farm and into the nonfarm sector, in turn, has been observed to be the major source of household income growth and poverty reduction (Otsuka et al. 2009).

In Asia, agricultural development is an evolutionary process, and Africa appears to be following in the same footprints. This volume aims to explore the many pathways of agricultural development in Asia and assess to what extent these pathways have been pursued in the context of contemporary Africa.

This book's main finding is that, indeed, Africa is following in Asia's trail. The common pathways to agricultural development are borrowed technology from abroad; adaptive research in rice farming (modern seeds, fertilizer, and mechanical technologies); secured property rights on natural resources; adoption of ICTs;

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investments in human capital, including training; and spread of high-value agriculture. Like in Asia, these pathways could serve as expressways of African agricultural development and overall development.

Topics in this volume are grouped into four themes: (1) *Green Revolution in Asia and Africa*, (2) *Land Tenure and Sustainable Natural Resource Management*, (3) *Transformation of the Rural Economy*, and (4) *Emerging Issues in Agriculture.* This last chapter has two remaining sections. The next section summarizes important findings for each theme, and the last spells out the policy recommendations.

27.2 Green Revolution in Asia and Africa

In Asia, the Green Revolution rested on a high input and high output principle and was restricted to three crops—rice, wheat, and maize. Here we focus on rice, characterized by a large stock of transferable technology from Asia and a new crop that is gaining importance in Africa.

The Green Revolution in rice in Africa appears to have started to evolve with technologies that have been imported from Asia. We compare the Green Revolution experience of Central Luzon, which is the frontliner of the Green Revolution in the Philippines (Chap. 3 by Kajisa et al. in this volume), with that of Africa in Kenya (Chap. 5 by Njagi and Mano in this volume), Tanzania (Chap. 6 by Nakano and Magezi in this volume), and Madagascar (Chap. 7 by K. Takahashi in this volume). Central Luzon sample sites include lowland rainfed and irrigated ecosystems. Kenya's site is the Mwea Irrigation Scheme, where all farms are irrigated. The Tanzania ones are rainfed and irrigated ecosystems in three major rice-growing regions in the country, namely, Morogoro Region, Shinyanga Region, and Mbeya Region. Study sites in Central Luzon, Kenya, and Tanzania have fairly similar agro-ecological conditions, which are important determinants of the uptake of modern rice technology.

27.2.1 Irrigation and Modern Rice

The availability of irrigation is critically important in the adoption of modern rice varieties, as adoption is often faster in irrigated ecosystems than in rainfed ones. The yields of modern rice varieties are also higher under irrigated conditions, a phenomenon observed in both Central Luzon and Tanzania.

Most of the modern rice varieties in the Philippines were developed by the International Rice Research Institute (IRRI) since its establishment in 1960, and by the Philippine Rice Research Institute (PHILRICE) since its establishment in 1986. Both institutions have played a particularly important role in adaptive research because early technologies in rice breeding were imported from advanced countries whose agro-ecological conditions are different from tropical Asia. Pingali (Chap. 2 in this volume) mentioned that the National Agricultural Research System (NARS) in the

Philippines and other Asian countries, such as China and India, have served as important conduits for accessing and adopting borrowed technology from abroad. The Philippine government established a strong extension system that facilitated the dissemination of newly-released seeds to farmers. PHILRICE also offers training and workshops for farmers on the proper use of new rice technology. Farmer-to-farmer exchange of seeds and information on new technology is another enhancing factor in the spread of new rice technology.

In northern Bangladesh and three eastern states in India (Assam, Odisha, and West Bengal), there has been a steady increase in the diffusion of submergence-tolerant rice varieties (Sub1 series) in response to the rising incidence of flooding (Yamano, Chap. 4 in this volume). The Sub1 series released in Bangladesh was developed by IRRI and the Bangladesh Rice Research Institute, while the most popular Swarna-Sub1 was developed in India. Applying DNA fingerprinting, Yamano found that farmers could not accurately identify the seeds of the rice varieties, raising a question on the accuracy of the reported adoption rate of submergence-tolerant rice varieties in Bangladesh.

The most popular modern rice in Kenya is improved Basmati, a cross-bred between Basmati (a traditional rice) and high-yielding modern rice varieties. Improved Basmati is of lower quality but has a higher yield than the original Basmati rice grown widely in India and Pakistan. In Tanzania, the most popular variety is SARO 5, a semi-aromatic rice developed by a government agricultural research institute in Dakawa (ARI Dakawa) and released in 2002. SARO 5 is a cross-bred between Supa/Pyongyang 8 from North Korea and Supa/Subarimati originally from IRRI. Clearly, there is adaptive research in African rice with technology coming from Asian countries and IRRI.

27.2.2 Fertilizer

In Central Luzon, nitrogen applied to rice fields started at 9 kg/ha on the eve of the Green Revolution in 1966, and it rose steadily over time until it reached the recommended level of 100 kg/ha in 1987 and continued at that level until 2021. In Central Luzon, rice traders and landowners who advance credit to the farmers for fertilizer purchases have paved the way for increased use of chemical fertilizer. In Kenya, fertilizer application is, on average, 140 kg/ha of NPK in 2011 (which is higher than those applied in farms in India, the Philippines, and Bangladesh) and declined subsequently in 2016 and 2018. This is because some farmers left their credit cooperative, which was their main source of credit for fertilizer. Chemical fertilizer usage per hectare in Tanzania increased from 8.8 to 24.2 kg/ha in rainfed areas and from 35.4 to 89.6 kg/ha in irrigated ecosystems from 2009 to 2018.

27.2.3 Machines

In Central Luzon, the proportion of sample farmers using tractors increased between 1966 and 1994 because of the development of the tractor rental market and the increasing maintenance cost of draft animals. In Central Luzon, the early tractors were the 70-horsepower four-wheel types replaced later by the two-wheel power tillers when large-scale irrigation infrastructure opened up. *Tilyadora* (huge threshing machines) were used before the implementation of land reform in 1972 to easily monitor the sharing of output between landlords and tenants (Hayami and Kikuchi 1982). Following the successful implementation of the land reform program, farmers started using the portable axial-flow thresher developed and released by IRRI. The utilization of tractors and threshers accelerated in the mid-1980s because of rising wages. The combine harvesting-threshing machine was introduced around 2015, and by 2021, nearly 100% of sample farmers in Central Luzon were adopting the combine because of a severe shortage of hired labor.

In the Mwea Irrigation Scheme in Kenya, four-wheel tractors were used for rotavation, and draft animals were used for leveling the rice field. While Kenya still has large grazing lands to maintain draft animals, tractorization in Kenya took place because of rising wages. The high proportion of farmers using tractors in Mwea was because of the National Irrigation Authority and because tractor services were provided on credit by a farmer's cooperative.

The turnover of the Mwea Irrigation Scheme management to the farmers' cooperative stimulated the entry of rice traders and rice millers into the market. Some entrepreneurial millers visited China in the early 2010s and learned about modern milling technologies. Most importantly, the destoner module removes small stones and other impurities from dried paddy during milling. Large-scale milling machines were used initially, but smaller modern machines have become widely adopted since the 2010s. Because of the advent of modern milling machines, the quality of rice varieties produced in Mwea improved and facilitated the transformation of the rice value chain. Mwea's rice started to be sold in urban supermarkets and competed with imported Asian rice varieties. Clearly, the development of the rice value chain in Mwea results from the transfer of modern milling technology from China.

27.2.4 Improved Farm Management Practices

In Central Luzon, improved agronomic practices have been widely used, such as bunding, straight-row planting, and transplanting. Direct-seeding, which replaces transplanting as a labor-saving technique, started to rise because of mounting wages and the introduction of an effective herbicide called *machete*.

In the Mwea Irrigation Scheme in Kenya, almost all the farmers adopted transplanting in rows. In Tanzania, the adoption rate of transplanting in rows was higher in irrigated ecosystems (increasing from nearly 30% in 2009 to 43% in 2018) than in the rainfed ecosystem (about 6% in both years). Training had a positive and significant impact on the adoption of plot leveling and transplanting in rows. Nakano and Magezi (Chap. 6 in this volume) reported that farmers who received training increased their adoption rates of improved bunding and straight-row planting relative to those who did not. However, those who did not undergo training were able to catch up, indicating the high possibility of farmer-to-farmer knowledge spillover effects, particularly in the irrigated ecosystem.

In Madagascar, the system of rice intensification (SRI) is widely used. The SRI rests on low-input and knowledge- and management-intensive practices. K. Takahashi (Chap. 7 in this volume) presents an exhaustive review of literature on the impacts of SRI on rice yield and found that in a large number of cases, SRI promotes yield growth even with little use of chemical fertilizer, which is quite different from the high-fertilizer and high-yield principle of the Asian Green Revolution.

27.2.5 Development of Markets

Fertilizer, rice, and credit and land markets have evolved dynamically with the onset of the Green Revolution. In Central Luzon, fertilizer and rice markets were already established before the Green Revolution, while machine repair shops proliferated after the Green Revolution. The number of rice traders, who advance credit to farmers for fertilizer, increased after the Green Revolution. The same phenomenon was also observed in the Mwea Irrigation Scheme (Njagi and Mano, Chap. 5 in this volume). The fertilizer market has started to develop because of the rising demand for fertilizer and the presence of traders who provide credit for fertilizer. Just like in the Philippines, a large number of farmers are engaged in tied-in-credit with traders. Nakano and Magezi (Chap. 6 in this volume) reported the presence of large-scale rice milling companies in Tanzania, indicating that farmers have been selling their marketable surplus to the market.

Land markets in the Philippines were generally suppressed by land reform laws by making share-tenancy illegal and prohibiting transactions for lands obtained under the land reform. One major feature of the Philippine land reform program is the conversion of share-tenancy to leasehold-tenancy and the fixing of leasehold rent and annual amortization fees. When rice yield rose in the 1970s following the diffusion of seed-fertilizer technology, the fixed leasehold rent and amortization payments diverged substantially from the economic rent accruing to the service of the land. Thus, a gap between actual land rent and true economic rent was created. This gap accrues to leasehold-tenants and amortizing owners who were converted from the status of share-tenants by the land reform program. Some opportunistic leasehold-tenants and amortizing owners hired a share-tenant in their plots, asked them to pay the share-tenancy rate, and reaped the economic rent created by the land reform law (Hayami and Kikuchi 1982). Sub-tenancy was illegal but has evolved because of the land reform and the diffusion of modern rice varieties.

Kijima and Tabetando (Chap. 8 in this volume) reported that land rental markets have also evolved in Uganda and Kenya and made land allocation more efficient and equitable. The land is rented out from less productive to more productive farmers and from land-abundant to land-constrained households.

27.2.6 Rice Yield

In 1966, rice yield was about 2 tons per ha (tons/ha) in Central Luzon when traditional varieties were planted. Yield rose to 2.5 tons/ha in 1979 when MV1 was adopted and rose significantly to more than 4 tons/ha between 1986 and 1999 when the pest- and disease-resistant MV2 became popular. According to PHILRICE statistics, rice yield in Central Luzon was about 4 tons in 2001 and rose to 5.2 tons in 2021 when hybrid rice varieties were disseminated.

In the Mwea Irrigation Scheme in Kenya, rice yield was reported at about 5 tons/ha in 2011, 5.4 tons in 2016, and 6.2 tons in 2018. This is higher than those reported in Central Luzon, possibly because fertilizer application was higher in Kenya at 140 kg/per ha in 2011. In addition, water management under the farmers' cooperative has led to more enhanced water access and higher yield. Increased mechanization of land preparation might also have contributed to the rise in yield because of improved soil aeration. In the irrigated ecosystem in Tanzania, rice yield rose from 3.7 tons per ha in 2009 to 4.2 tons in 2018 because of increased fertilizer application and higher adoption of better farm practices, such as bunding, leveling, and straight-row planting.

27.2.7 Lessons from the Asian Green Revolution and the Way Forward

This volume has presented evidence that the Asian-style Green Revolution has been evolving in Africa. First, the 'pre-conditions' for the take-off of the Asian Green Revolution are now apparent in Africa. There is high population growth on closed land frontiers, and there is the availability of a huge stock of transferable mature rice production technology from Asia. Second, adaptive research appears to be ongoing, exemplified by improved Basmati rice in Kenya and SARO 5 in Tanzania, whose genetic materials and breeding techniques came from Asia. These two varieties were developed to suit Africa's local agro-ecological conditions. Third, there is an acceleration in the adoption of modern rice varieties and fertilizers in major rice-growing areas in Africa, indicating a response to increasing land scarcity. Fourth, improved farm management practices, such as bunding, leveling, and straight-row planting, characteristically Asian, are increasingly adopted. This also applies to SRI, which is intrinsically African. Fourth, mechanization is ensuing with machines, such as power tillers, threshers, and milling machines currently used in rice farms in Asia. All of these lead to the decline in the yield gap between Asia and Africa. In fact, rice yield in the irrigated ecosystem in major rice-growing regions in Tanzania is comparable to Central Luzon, and yield in Mwea is even higher. Finally, markets in the rice sector have evolved, responding to increased demand for modern inputs and higher marketable surplus. The rice value chain has been modernized in Kenya to cater beyond subsistence production to a wider market that can compete with Asian rice.

Pingali (Chap. 2 in this volume) reported that the Green Revolution had two major positive impacts. First is the rapid increase in yield that resulted in an increase in global food production and declining food prices. Second, the Green Revolution kickstarted the structural transformation process, which served as the main driver of Asia's income growth and poverty reduction.

But there are limits to the Asian Green Revolution (Pingali, Chap. 2 in this volume). First, it focused on a limited set of crops—rice, wheat, and maize—crowding out nutrition-rich coarse grains, such as millets, sorghum, and pulses with higher nutritional content, which could potentially solve micronutrient malnutrition among the poor. Second, it is focused on irrigated tracts or regions with high rainfall and low agroclimatic risks, leaving out areas with unfavorable production environments. Finally, there are unintended consequences, such as environmental degradation due to injudicious use of inputs, such as pesticides and fertilizers, and the looming water crises.

27.3 Land Tenure and Sustainable Natural Resource Management (NRM)

In both Asia and Africa, secured property rights are by far the most important factor in enhancing the productivity of cropland and in the uptake of sustainable NRM practices in forestlands, timber resources, soil, and water.

For cropland, land tenure policies are important in strengthening work incentives and enhancing land access for the land-poor and landless tenants. Holden (Chap. 9 in this volume) reviewed real-world land tenure policy interventions and found that not all policies were successful. The Chinese household responsibility system, land titling in Thailand and Kenya, and low-cost land registration and certification successfully strengthened landholders' property rights and tenure security. While the 'land-to-the-tiller' program was intended to be distributive, evidence indicates that landowners managed to evict tenants to assume self-cultivation, and tenants were often converted to permanent laborers, as in the case of rice villages in central Philippines.

R. Takahashi (Chap. 10 in this volume) argued that a community forest management system performs efficiently for non-timber forests, whereas a mixed management system (forestland is owned by the community, trees are owned by individual members) is more effective for timber forest management (significantly increasing workdays in pruning, guarding, and watering the trees) based on a randomized experiment in Ethiopia. Place (Chap. 11 in this volume) identifies the following as constraints in the uptake of NRM practices in developing countries: lack of awareness and understanding, the long waiting period to reap the benefits, low economic returns, and lack of recognition that individuals are independent decision-makers. Muraoka (Chap. 12 in this volume) found that tenure security is an important determinant of the adoption of integrated farming management practices in Sub-Saharan Africa, along with farmer characteristics (i.e., age, education, gender, network, and experience) and household characteristics (i.e., labor availability, social safety nets, access to extension services and credit, assets, and nonfarm income).

The emergence and re-emergence of pests and diseases have become common in tropical areas because of changes in global climate. Mottaleb (Chap. 13 in this volume) quantified the economic losses due to maize lethal necrosis (MLN) outbreaks in Kenya, DR Congo, and Tanzania from 1961 to 2020. In Kenya, the estimated loss is USD 124 million, about USD 1 million in DR Congo, and USD 108 million in Tanzania. Since maize is a major staple, these losses could further create havoc on these countries' already critical food security situations. Regarding sustainable green growth, Zaman and Kalirajan (Chap. 14 in this volume) examined the prospective roles of regional cooperation in South-through-East Asian countries. They found that if countries in this block could cooperate, they could exploit the production potential of about 34% without using additional resources. Agriculture emission management efficiency would be 45%.

27.4 Transformation of the Rural Economy

There has been a phenomenal increase in the usage of ICTs (computers, internet, and mobile phones) in both Asia and Africa. Using nationally representative household surveys in 2015–2019, Huang et al. (Chap. 15 in this volume) found a rapid increase in the adoption of ICTs in rural China. Regression analysis shows a digital divide, however. Rural households with access to computers and the internet have a higher number of their members employed in nonfarm employment, have larger farm sizes, and bigger household sizes. The two ICTs also have deeper penetration in these villages. Rural individuals with mobile phones tend to be younger and more educated; males have higher adoption rates than females.

Yet, despite the digital divide, ICTs could be used to bridge the gap in learning between the urban and rural children in China (Abbey et al., Chap. 16 in this volume). Conventional approaches (student migration to the cities, attracting quality teachers to rural areas, and teacher training) to improving teaching quality for disadvantaged children have been largely unsuccessful. Abbey et al. assessed that China is uniquely positioned to harness technology-assisted instruction (EdTech) (high-quality live-streamed or pre-recorded remote instruction delivered in class during the school day) to improve the quality of teaching because of adequate infrastructure in rural areas, ambitious policy initiatives, and a large EdTech market.

The most significant change in Africa is the spread of mobile phones: subscriptions per 100 people rose from 1.7 in 2000 to 82.4 in 2018. 'Mobile money' (electronic payment services via mobile phone) has spread among the population, often used to transfer money at low transaction costs, especially those with no formal financial services. Matsumoto and Munyegera (Chap. 17 in this volume) reported new uses for mobile money, such as school payments, loans and insurance, emergency relief, humanitarian fund transfers, and payment for public services (e.g., birth certificates). Mobile money has positive welfare and equity impacts such as increased per capita consumption, improved likelihood of savings and borrowing, improved access to antenatal care, and increased remittances for children's schooling during health shocks.

Estudillo (Chap. 18 in this volume) presents an illustrative example of the transformation of (Kei's) four villages in the Philippines. The drivers of the transformation in the villages are population pressure, new rice technology, land reform, investments in human capital, urbanization and commercialization, and infrastructure, while the strategic processes that accompany such transformation are rising productivity of rice farming, production of high-value crops, rising incidence of nonfarm work within the local economy, and migration to local towns, big cities, and overseas, among the younger generation. In the process of transformation, participation in the nonfarm labor market and migration serve as the main pathways for poor landless children to move out of poverty.

Sawada (Chap. 19 in this volume) examined the patterns of structural transformation in Asia. This continent has experienced a much faster transformation speed than other developed regions because of the fast decline in the terms of trade of agriculture (i.e., price of farm goods relative to nonfarm goods) brought about by the Green Revolution. The manufacturing industry drives Asia's rapid growth because it has a large scope for innovation and technological progress. Sawada presents the case of West Laguna, which followed the agriculture-industry-service transformation ('canonical industrialization') because of improved road infrastructure that improved its connectivity to Manila, attracting manufacturing investments. On the other hand, East Laguna leapfrogged from agriculture to traditional and modern services bypassing the industry sector ('premature deindustrialization'). The East Laguna pattern appears to be the same pattern evident in Kei's villages, where income from services contributed substantially to household income growth and poverty reduction.

Larson and Bloodworth (Chap. 20 in this volume) examined how mechanization is instrumental in the intersectoral migration of agricultural labor. They found that the migration rates out of agriculture to other sectors are responsive to income differences and that the younger and better-educated workers were most likely to leave agriculture.

27.5 Emerging Issues

Three emerging issues in agriculture are high-value revolution, women's inclusion in agricultural growth, and exemption of agriculture from antitrust laws.

A shift from cereals to high-value crops and livestock is driven by rising household income and global trade integration on the demand side, and new technology and improved farm management, support from trade guilds and government, and infrastructure, on the supply side.

In Vietnam, Suzuki and Nam (Chap. 21 in this volume) identified two major factors in the development of the shrimp industry: (1) a government decree that allowed farmers to convert their rice farms to shrimp ponds, and (2) the introduction of a new farming method ('super-intensive') that requires modern inputs and higher labor input in care activities. Shrimp is more profitable than rice, but shrimp carries higher risks in disease outbreaks caused by the spread of pathogens across farmers' ponds.

Aida (Chap. 22 in this volume) identified three factors that stimulated the development of the tapioca/cassava industry in Thailand: (1) the release of high-yielding varieties of cassava with higher starch content, (2) expanding trade exports to China, and (3) formation of an association (Thai Tapioca Starch Association) whose primary mission is price stabilization, while at the same time serving as a venue in identifying problems in the industry and its solutions. According to Aida, the development of the tapioca industry can be explained by cluster-based development (i.e., evolution from quantity expansion stage [chips and native starch production, with low entry costs] to quality expansion stage [cassava starch for export] where associations play an important role).

Enterprises in a cluster have a comparative advantage in market access, labor pooling, and information spillovers. Zhang (Chap. 23 in this volume) identified the Anding potato cluster in China as a dynamic cluster because of the introduction of a high-yield variety and disease-free potato seeds, the presence of a producer association and enhanced transport services, and the emergence of starch processing firms that expanded the potato value chain. The county government played a proactive role in stimulating the development of the cluster. The medicinal and aromatic plants (MAPs) clusters in Egypt, in contrast, were unable to become dynamic because of water contamination, the high cost of laboratory tests, and rigid licensing requirements. The dates clusters in Tunisia were stagnant because of inadequate water supply, labor shortages, diseases, lack of new varieties, and limited value addition. In these two, the local government was passive in overcoming the growth constraints in the clusters.

There is a need to reduce postproduction losses of perishable horticultural products. Yamauchi and Takeshima (Chap. 24 in this volume) examined the impacts of introducing solar-powered cold storage facilities in Nigeria, where only a small percentage of rural households have access to electricity. Cold storage improved local livelihood by reducing food loss, improving nutrition, and generating new employment, especially among women.

Women are deepening their involvement in agriculture as they face constraints on land, credit, and new technology. The Women's Empowerment in Agriculture Index (WEAI) is a metric launched in 2012 to monitor women's inclusion in agricultural growth. Tools and methods to calculate the WEAI are undergoing revisions to shorten the process and reflect criteria that agricultural development projects deemed meaningful as project success (Quisumbing et al., Chap. 25 in this volume). Eventual modifications reflected the demand for specialized modules for women's market inclusion. WEAI is useful to governments and civil society in designing gender-sensitive agricultural development programs and national statistical systems to assess a country's progress toward SDG 5 on women's empowerment and gender equality.

Agriculture has enjoyed exemptions from competition law and policy because of agriculture's unique characteristics: biological and physical processes, missing markets, and geographically dispersed farmers facing a highly concentrated marketing sector. Balisacan (Chap. 26 in this volume) argues that such exemption strengthens farmers' comparatively weak position in the balance of political influence in agricultural policymaking and increases farmers' bargaining power over the more concentrated wholesale-retail segments of the agri-food value chain.

27.6 Policy Implications

This volume ends with a four-part strategy to enhance agricultural growth in both Asia and Africa. First, for the low productivity agricultural systems in Africa, using agriculture as the engine of growth and poverty reduction continues to be the best option. Green Revolution in cereals is the first step. Evidence in this volume shows that the Green Revolution in rice has begun in Africa and appears to be quickly spreading. Professor Otsuka argues that the primary strategy to pursue a Green Revolution in Africa is to strengthen the agricultural extension system to promote farming intensification with the adoption of improved rice management practices, while the complementary strategies consist of the expansion of irrigated areas, diffusion of power tillers, and the quality improvement of milled rice using improved milling technologies. Pingali (Chap. 2 in this volume) recommends that in Asia, there is a need to further enhance research and development for rice and for other crops; use bio-fortification to include Vitamin A, zinc, and iron to solve malnutrition problems; and develop heat- and drought-resistant technologies and infrastructure like micro-irrigation systems to address climate change. There is also a need to address the spread of pests and diseases, which could be done through coordination between farmers, extension agents, and the government. Externalities of this kind can be internalized by the cooperation of various stakeholders.

Second, secured property rights on natural resources are the most important factor in enhancing the productivity of natural resources and in the uptake of conservative practices. For cropland, formalized land tenure system can increase land-related investments, facilitate land transfer, and enhance access to credit for modern inputs. Community forest management effectively protects forest resources from excessive extraction through cooperation in monitoring. A mixed management system, which is the combination of private and common ownership (forests belong to the community, trees to individual members), appears to create greater incentives for taking care of timber forests (R. Takahashi, Chap. 10 in this volume).

Third, the first step to transforming the rural economy is to improve agricultural productivity through the Green Revolution. Agricultural terms of trade decrease, thereby stimulating the release of resources away from agriculture into industry and services. The Philippine villages (Estudillo, Chap. 18 in this volume) are an illustrative example of how the combination of land reform, irrigation, and the Green Revolution led to rice production and household income growth, stimulating investments in human capital. As Asian agriculture faces a scarcity of labor, mechanization is bound to accelerate to ease the increasing bottleneck in labor (Larson and Bloodworth, Chap. 20 in this volume). Mechanization is an integral part of the whole gamut of processes in rural economic transformation. Supporting the spread of ICTs is a step in the right direction, as ICTs have various uses and have positive welfare and equity impacts (Matsumoto and Munyegera, Chap. 17 in this volume).

Finally, high-value agriculture is most likely to spread far and wide as the demand for a more diversified diet ensues with increased household income. There is a need to support high-value revolution through investments in infrastructure, such as electricity, good quality roads, ICTs, and preservation facilities, such as cold storage (Yamauchi and Takeshima, Chap. 24 in this volume). Since women are observed to have a comparative advantage in the production of fresh fruits and vegetables, their involvement in agriculture will deepen further in the future, and thus there is a need to address women's constraints in access to land, credit, markets, and new technology.

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