Maarten Prak, Patrick Wallis

Transferring useful knowledge. Quality mechanisms in European apprenticeship

1. Introduction

Between roughly 1400 and 1800, Europe experienced a slow but in the long run significant process of industrial product and process innovations. Blinded by the light of steam engines and spinning jennies, historians and economists have long associated innovation with break-through inventions. At the same time, they tend to portray pre-modern crafts as inefficient and hostile to innovation. The Applied Arts of the period suggest a very different story: museums hold numerous objects that show an increased capacity on the part of their makers to improve their products to an astonishingly high quality.

Clockmaking was one such craft. In addition to illustrating the potential for technological advances, it is also one in which we trace in detail some of the steps in the process by which innovation spread (Kelly and O'Grada 2016; 2022). In the later seventeenth-century, much of the improvement in European clockmaking was occurring in London, where natural philosophers such as Robert Hooke were working in collaboration with highly skilled artisans such as Thomas Tompion, George Graham and William Clement to develop new types of escapement and spring that allowed for greater accuracy. Clockmaking offers a powerful example of the collaboration between natural philosophy and an upper-tail of skilled artisans that Joel Mokyr and others have emphasised as a key ingredient of the long process of industrialisation (Mokyr 2009; Kelly, Mokyr and O'Grada 2014).

Why was this group of highly skilled artisans available? We can take Thomas Tompion as an illustration. Tompion was a leader in his field: he supplied clocks to the Royal Observatory that employed a new escapement, designed by Richard Towneley, that only needed to be wound once a year. Tompion also produced some of the first watches that used balance springs, devised by Hooke. The first step in this career began while he was a teenager, when Tompion was bound as an apprentice and moved to London to train from a small village in Bedfordshire. His presence in the city was a product of an institution that allowed his family to invest in his human capital and mobility.

The contribution that apprenticeship made to economic and technological development in pre-industrial and industrialising Europe has been noted by a number of authors. However, in this paper we investigate a specific element of

Maarten Prak, Utrecht University, Netherlands, m.prak@uu.nl
Patrick Wallis, LSE, London School of Economics, United Kindom, p.h.wallis@lse.ac.uk, 0000-0003-1434-515X

Referee List (DOI 10.36253/fup_referee_list)
FUP Best Practice in Scholarly Publishing (DOI 10.36253/fup_best_practice)

Maarten Prak, Patrick Wallis, *Transferring useful knowledge. Quality mechanisms in European apprenticeship*, © Author(s), CC BY 4.0, DOI 10.36253/979-12-215-0092-9.11, in Giampiero Nigro (edited by), *L'economia della conoscenza: innovazione, produttività e crescita economica nei secoli XIII-XVIII / The knowledge economy: innovation, productivity and economic growth, 13th to 18th century*, pp. 177-192, 2023, published by Firenze University Press, ISBN 979-12-215-0092-9, DOI 10.36253/979-12-215-0092-9

qualitative improvement that has so far been overlooked in the literature: the selection of teachers by apprentices. As we will demonstrate, this selection was far from random. Previous authors have already observed that many masters apprenticed few or even no youngsters at all, while others trained many apprentices. We combine this observation with a second: those training many apprentices were usually the most skilled and successful masters in their trade.

We argue that this selection process provided a Darwinian mechanism of quality improvement in the pre-modern industrial sector. Apprenticeship was high-skill biased. A disproportionate share of young workers received their training in the workshops of the leading practitioners of their crafts and trades. What mattered was not just that Tompion was himself once an apprentice, but that, as one of the leading figures in his trade, he would, in turn, train at least 23 apprentices in his workshop between 1673 and 1699.[1]

Before we present our evidence, we need to explain how the transfer of industrial skills worked in the past and how it might have contributed to innovation. Our analysis proceeds in several steps. First, we argue that innovation by skilled workers was particularly important in pre-modern contexts and that the contexts in which it occurred relied on importing labour, not reproducing skill within the family. Second, we summarize the key institutional frameworks within which apprenticeship operated, identifying the importance of contract law and the more complex contribution of guilds. Third, we set out our model and key predictions. Fourth, we provide evidence to show that the patterns of concentration of training and the connection between training and skilled masters in England and the Netherlands are consistent with the idea that in early modern Europe training was biased towards transferring high quality skill between generations of workers in a way that helped sustain incremental innovation and development.

2. Innovation and Human Capital

Innovation is defined for this paper as «the multi-stage process whereby [producers] transform ideas into new/improved products, service or processes, in order to advance compete and differentiate themselves successfully in their marketplace» (Baregheh 2009).[2] Various types of innovation can be, and have been, distinguished, but most studies of innovation concentrate on two in particular: product and process innovations. Product innovations concern changes in the output; these include design, quality, price, and so on. Process innovations concern changes in the way that the output is produced; these include division of labour, tools (including machinery), volume, and so on (Fagerberg 2005). Both types of innovation occurred across most sectors during the centuries before the industrial revolution.

Famously, economist Joseph Schumpeter portrayed innovation as a process of «creative destruction» resulting from dedicated efforts that led to new technologies

[1] Tompion's career is well summarized in the *Oxford Dictionary of National Biography*, s.v. 'Thomas Tompion'. Tompion's training career is reconstructed from the guild records.

[2] To reflect pre-modern conditions, the definition has been changed by substituting «producers» for «organizations».

replacing older ones (Ruttan 1959). In a classic paper on the topic, Nelson and Winter have, however, pointed out that much innovation can be «evolutionary», and a «stochastic» (i.e. randomly determined) process (Nelson and Winter 1977; also Nelson and Winter 1982). Their approach downplayed the importance of formalised R&D and inventions, and underlined the small, but in the long run significant innovations introduced by workers within the production process itself; think of the on-going improvements in motor cars (Dosi and Nelson 2010). As this research shows, much innovation is the result of attempts, often anonymous, for improvements, rather than resulting from dedicated research.

This model of innovation foregrounds the role of workers instead of science as a crucial source of progress. Obviously, R&D efforts have contributed significantly to innovation, but they are not the exclusive source of either product or process innovation. Today, this applies especially to small and medium-sized enterprises, unable to afford their own R&D facilities. The small role for formal scientific enquiry, the link to the small size of firms, and the lack of dedicated research all provide reason to believe that incremental, evolutionary and stochastic innovation by workers is the most appropriate way to understand the situation before 1800 (Epstein and Prak 2008). The balance between the drivers of innovation changed in the nineteenth century; before, innovation is seen as the outcome of trial-and-error by producers; after, it became more often the result of dedicated efforts, informed by science. In modern terms: it was human capital that made the most difference to innovation before the Industrial Revolution.

In fact, we can go further. The contribution of skilled artisans' human capital to premodern innovation was also essential to the limited amount of «science»-led innovation that occurred in this period. Their supply of manual skills served as an essential complement to cognitive knowledge, enabling the implementation of early science-based innovation. This process has been emphasised heavily in recent work by Joel Mokyr, and his arguments naturally centre on the availability of an abundant source of highly skilled artisans in relevant sectors, such as clockmaking and metalwork (Mokyr 2009; 2020).

Many of these effects are the unintended outcomes («spillovers») of interactions between practitioners. Nowadays, we can observe them in Silicon Valley, but they were probably as relevant during the Italian Renaissance, or indeed the Industrial Revolution. Well-known examples are the Venetian glass industry, Lyon's silk industry, and watch-making in the Swiss Jura. Clustering was a general feature of premodern urbanisation. In early modern London, for example, various crafts used to be concentrated in small pockets of the city. Quite how artisans innovated within these clusters is, unfortunately, in many ways still a mystery (Prak and van Zanden 2013). What is clear, however, is that innovations in clusters occur as a result of collective efforts, in locations with relatively high densities of craftsmen that are open to new knowledge and new people, and possess facilities for high quality training.

The importance of these two factors - skilled workers and clustering - had critical consequences for innovation in premodern Europe. On the one hand, the importance of incremental improvements made within workshops meant that much innovation was embodied, in the sense that the product or process was not fully articulated into prescriptive knowledge. Spreading innovations therefore relied on

spreading skilled workers, as S.R. Epstein and others have argued (Epstein 2013). The movement of people between different leading centres served both to transmit practices and ideas and to cross-fertilize between them in a way that further advanced knowledge, while movement between leading centres and producers in other locations allowed new ideas to spread out gradually. This process of knowledge exchange and diffusion through migration is visible in a number of industries, from beer brewing to silk weaving.

On the other, the harsh demographic realities of premodern towns and cities meant that clusters were inherently unable to sustain themselves through natural replacement. Artisans could not rely on drawing on workers from within their family. Maintaining a skilled labour force, let alone expanding, instead depended on importing workers. While some of these workers might arrive with skills, others would need to be trained. Viable clusters needed to be centres for training, in short. They therefore needed a framework through which training could be organized. In the absence of large firms that might train workers over a career, apprenticeship provided this framework.

3. Skills and training: apprenticeship and premodern Europe's institutions

One of the implications of the tacit character of craft skills is that they can only be acquired through inter-human, person-to-person interactions. Aspiring craftsmen have to learn their trade from experienced practitioners. The traditional – and perhaps also original – setting for such transmission is the household. Almost as fundamental is apprenticeship, observed in diverse societies around the world as a way of exchanging training for labour.

In premodern Europe, apprenticeship connected with three distinctive and connected institutions. The first is contract law, particularly the legal instrument that allowed the master and apprentice and family to agree an employment contract that combined service and training. The second is the system of courts, especially urban tribunals, that offered a way for both parties to address problems that developed during contracts. The third are the guilds that assimilated apprenticeship into their selection systems, adding an incentive to seek apprenticeship and providing some monitoring, quality control and certification to it.

In an important recent paper, De La Croix, Doepke and Mokyr set out a model in which guilds offer a middle stage of enforcement situated between the clan, in which human capital is transferred within limited kinship networks, and the modern market in which access to training is open to all (De la Croix, Doepke and Mokyr 2018). The effect of the guild is to widen access to skill by providing a system for local enforcement of contracts in specific occupations and towns. However, the institutional evolution they present does not match historical developments in Europe, at least, where open contracting for apprenticeship preceded guilds, and local courts were the key institution for enforcement.

The earliest records of apprenticeship in Europe are legal contracts for service, surviving in Genoa and a few other cities with early notarial archives (S.A. Epstein 1991). Contracts remained fundamental to apprenticeship into the nineteenth century. In some places, as for instance medieval Genoa or early modern Paris, these

were notarial contracts, which would still be phrased in quite general terms, requiring the master to share «the secrets of the trade», or «mystery of the craft», with his apprentice (S.A. Epstein 1991, 63-76; Kaplan 1993, 437-41). Such contracts also spelled out such details as the amount of money the apprentice's parents or guardians were paying for the boy's education, as well as his room and board. In others, contracts were oral agreements, or relied on simple printed forms that set out standard terms. These contracts, however, presupposed the existence of a regulatory framework for enforcement.

This framework was found in Europe's courts, particularly its urban courts which oversaw the largest populations of apprentices, and which possessed the legal authority to oversee and adjudicate disputes over contracts of this kind. We have substantial evidence that urban courts were at the centre of enforcement in many centres for training in Europe, including England, Venice, Madrid, and Turin (Prak and Wallis 2019). By the sixteenth century, these were often tribunals with specialized jurisdictions in which apprenticeship had a specific place.

What about the guilds? European guilds from very early on assumed responsibility for apprenticeship and helped shape the system (Prak and Wallis 2019). However, craft guilds combined a variety of roles (Prak, Lis, Lucassen and Soly 2006; Kluge 2007; Epstein and Prak 2008). They worshipped the patron saint together. They lobbied local governments for legislation favourable to the trade. They sometimes accepted responsibility for public services like firefighting or militia duties. To improve their bargaining position, and perhaps to also make life easier for their members, they attempted to restrict access to the craft to their members only. The regulation of apprenticeship was only one of the roles that many guilds took on, and the way guilds influenced training intersected with these other roles.

At a more basic level, guilds also incentivised entry to training. We know that the apprenticeship was not required by all craft guilds at all times, but so far the indications are that completing training became the normal route to membership in many guilds. It has been established for seventeenth-century England that more than half of all apprentices failed to complete their training contracts. However, those who aspired to open a workshop and thus had to acquire membership of a guild, almost invariably did so. As a result, those in charge of industrial workshops in seventeenth-century English towns had spent a substantial period – at least seven years – in training and at least some had ended this by demonstrating their skill by producing a sample product to the satisfaction of the examiners. Those who dropped out earlier, usually three of four years, must have acquired a reasonable amount of expertise along the way, even if they were not able to obtain the certificate (Wallis 2008, 839; Minns and Wallis 2012).

Guilds also frequently imposed quotas on the scale of training that any individual master could offer. Usually, this took the form of rules on the number of apprentices they could employ in any period. This set of regulations was rarely a binding constraint, as we will see. However, it did serve to limit the degree of concentration we will discuss below, and so reduced the visibility and the impact of the pattern of high-skill biased training that we discuss below.

We should be clear that guilds did *not* regulate the contents of the training as such. S.R. Epstein has suggested that guild regulation was needed to overcome the

imbalance between the interests of the apprentice (who was learning the craft during the early stages) and the master (who stood to profit from the apprentice's labour during the later stages of the contract). Given the number of drop-outs observed in early modern cities, this cannot have been more than one part of the explanation (Wallis 2008, 853-54; Schalk et al 2017). The fact that both the regulations and the meticulous registration of apprentices seem to prioritise the administrative side of the education suggests two things. First, that contemporaries may have found it difficult to articulate tacit knowledge which was also subject to changes as industries innovated. However, it is more likely that the guild's primary responsibility was to make sure that apprentices' education as such was properly recorded. The outcome would have been covered by the final exam constituted by the requirement to produce a master piece, if there was one, or by the market if there was not.

Before, and even during the Industrial Revolution, apprenticeship was a distinctive and massive phenomenon in Europe. Perhaps in Europe as a whole as much as 25 per cent on average of all boys, and quite a few girls as well, passed through the corporate apprenticeship system. Apprenticeship is therefore a likely element in the explanation of industrial development before the Industrial Revolution. There can be no doubt that it was essential to the *reproduction* of skill. However, we still have to establish the channels through which apprenticeship contributed to the *advancement* of skill – to innovation.

3. Apprenticeship and the development of skill

The example with which we began of Thomas Tompion's combination of outstanding technical skill with the provision of an abundance of technical training to the next generation of artisans offers us an example of one important mechanism that accelerated the process of innovation that we have described above: the concentration of training in the workshops and firms of highly skilled masters. To understand how this concentration of training in the hands of more skilled and productive artisans might affect innovation, consider the implications of three possible ways in which apprenticeship might affect the supply of skill in the next generation of workers.

First, if apprentices are evenly distributed across all workshops, then productivity will stay the same between generations. The capacities that each apprentice acquires will simply echo those of their master: skill levels will be replicated. Second, if most apprentices are learning with masters who are primarily interested in exploiting them as unskilled or semi-skilled labour, then the average skill level, and so the productivity, of the next generation of artisans will be relatively low. Finally, if apprentices mainly train with the most productive masters, then we might expect the average productivity of the next generation to increase as they pick up the best techniques and learn about the most profitable products and business strategies. This last «high-skill biased» distribution of apprenticeship training offers a method by which productivity grows incrementally and innovations are diffused.

Each of these ideal types is distinguished from the others by two factors that determine how effective apprenticeship is as a training system: first, the productivity of each master involved in supplying training; and second, the degree to which they

tie up their apprentices in semi-skilled or unskilled tasks, rather than advancing them in their occupation by moving them through different aspects of the trade. For high-skill biased training to be in place, masters need to be both skilful and not exploitative.

European history offers some evidence for the existence of all three modes of training. The first clearly echoes the idea of a standard artisan household with its complement of servants and apprentices that can be found in work on the European marriage pattern and, perhaps, the impact of rationing by guilds and cities which sometimes imposed quotas on the numbers of youths each master could take. The second existed in the sweat shops of nineteenth-century cities, and in some examples of pauper apprenticeship. The third fits well with accounts of early-modern parents investing considerable energy in identifying a suitable master for their child (eg: Ben-Amos 1994).

What we lack, however, is evidence for which of these modes of training was dominant within key locations for training. However, there are several clear predictions that we can use to identify which model is operating.

The first is that if the first of these modes of training – replication of skill through an even distribution of apprentices – is dominant then apprenticeship should be widely spread without concentrations of youths with any individual masters. The presence of clustering among apprentices is an indication that either low-skill or high-skill biased training (or perhaps both) may exist.

The second prediction is that if training is high-skill biased the skill of masters should correlate with the number of apprentices they train. We would expect the best masters to train the most apprentices if this model was dominant. Ability and achievement should be associated with concentrations of apprentices.

The third prediction is that in a high-skill biased situation the price of training should be higher where apprenticeships are being obtained in workshops that have an established cluster of training. Conversely, if concentration is driven by sweated labour and training is low-skill biased, then training in larger workshops should be cheaper.

Testing the applicability of these models of skill production requires us to look at the distribution of training and apprenticeship. In the rest of the paper, we approach this in three steps. First, we examine evidence for the concentration of training, engaging with our first prediction. The British workforce had a reputation for being exceptionally well-trained and we use evidence from England to test this idea (Mokyr 2009, 107-09). Then, we examine evidence for the association between skill and training in London and the Netherlands. Finally, we provide some evidence on the link between price and concentration of training.

3.1 The clustering of training

Was apprenticeship widely spread or was training concentrated? It is much easier to ask the question who trained apprentices than it is to answer it. In order to examine what we might think of as the training careers of masters, we have to first link together disparate individual records of apprentice contracts to a single master. To do this on any scale means addressing a series of problems, mostly centred on the

potential for multiple masters to share the same or similar names, and for this reason few studies have considered this.

In this section, we focus on apprenticeship in four English cities of different types from the late sixteenth to the late eighteenth centuries: London was the centre of English training; Bristol was an expanding second-tier port; Gloucester was a substantial third-tier city; and Boston, was a small country town. For each, we reconstructed the training careers for large samples of masters using robust nominal linkage methods. We also created samples of guild members or urban citizens who did *not* appear in these registers taking apprentices. This group of individuals all had the ability to take apprentices, at least in contemporary legal and civic theory, but for some reason they did not.

Using this dataset, we can identify the main characteristics of the distribution of training. First, most freemen or urban citizens *never* bound any apprentices: only 43 per cent of guild freemen in London bound an apprentice in the forty years after they entered their guild. In Boston, Gloucester and Bristol, just 20 to 25 per cent of burgesses and freemen in these towns took apprentices. For these provincial cities, the share may be under-estimated because increasing numbers of citizens lived outside their towns from the early eighteenth century. Even allowing for that, only a minority of freemen or citizens can have taken apprentices. Masters who did train apprentices usually only bound a few over their careers. Nearly two-thirds of masters recruited between one and three apprentices.

Training large numbers of apprentices was very rare: just a tiny fraction of masters – between four and eleven per cent took six or more. In London and Bristol, only one percent of freemen took twenty or more. The norm among English urban masters was to have only a limited number of apprentices.

Yet, the majority of apprentices were trained by the minority of freemen who did take apprentices in larger numbers. In London and Gloucester, over half of all apprentices were trained by the 20 per cent of masters who took more than five apprentices. More than a quarter were trained by the seven percent of masters who took ten or more. In Bristol, 42 per cent of apprentices were taken by the 12 per cent of masters who took more than five over their career. In Boston, 62 per cent of apprentices trained by the 33 per cent of masters with more than five apprentices. Large masters had a disproportionate effect on the supply of labour and the formation of the next generation of the workforce.

The majority of apprentices were trained by one of the minority of masters who did take apprentices repeatedly: concentration of training existed. We can safely reject the idea that in England apprenticeship was evenly distributed across workshops in a way that would simply reproduce the skill level of the workforce.

3.2 Training with skilled masters

What type of master was taking apprentices? As we have seen, the majority of youths were crowding into a minority of businesses. These were certainly the most active firms in terms of training, but were they also the best and most skilful masters as predicted in our model of high-skill biased training? In this section, we consider indicators about the quality of masters who trained most youths.

Skill is perhaps the hardest of indicators to isolate historically. For most trades, the products have long since disappeared and their consumers left no record of their opinions. However, a handful of occupations – clockmakers, furniture makers, apothecaries, merchants and artists – allow us to observe the training practices of those who were working at the pinnacle of their profession based on surviving evidence of skill judged by contemporaries and later experts. We apply our method to evidence from England and the Netherlands.

3.2.1 England

Because clockmaking has been widely studied, we can identify thirteen individuals who were among the most important innovators in clock and watchmaking in early modern England. All but one trained apprentices, with the average (mean) being nine apprentices and the median six per master.[3] Tompion's 23 apprentices was the largest cluster, but George Graham – his partner late in his career – indentured 16 and Daniel Quare bound 14. Like Tompion, these were the leaders in their field. Graham made several improvements to the pendulum clock and invented several astronomical instruments, as well as producing the mural quadrant at Greenwich Observatory for Edmond Halley (Britten 1986; Turner 2008, 272-73, n. 25). Quare invented repeating watches and supplied clocks and watches to James II and William III (*ODNB*, s.v. 'Quare, Daniel'; Britten 1986). Their workshops were large, but they were also hubs of innovation: Graham had learned from Tompion; his own apprentices included Thomas Mudge, who later invented the lever escapement that is still used today in almost all mechanical watches (Britten 1986).

The leading craftsmen in the second craft, furniture making and wood carving, were distinguished by supplying the royal court and nobility. The eighteen elite furniture makers and upholsterers we identify in this way were all large suppliers of training: their mean number of apprentices was ten and the median was six.[4] They include William Cleare, who worked as a carver on the triumphal arch for Charles II's coronation, Badminton House, the Sheldonian Theatre and the Divinity School at Oxford university, and William Emmett, who was sculptor to the crown and worked on Whitehall Palace, Hampton Court, Kensington Palace and Temple Church; some of his carving at Temple Church in London still survives (Crook 1965). Cleare bound nine apprentices, Emmett took five. The scale of their work may well

[3] The thirteen were drawn from Britten 1986; Turner 2008 and Landes 1983. They were John Arnold, Josiah Aspinall, William Clement, John Ellicott, Ahaseureus Fromantel, John Fromantel, Goerge Graham, Joseph Knibb, Thomas Mudge, Daniel Quare, Thomas Tompion, Samuel Watson, Joseph Williamson, Henry Wynne.

[4] The sample of manufacturers used here contains 56 individuals selected from the *British and Irish Furniture Makers Online* dataset (https://bifmo.history.ac.uk/) on the criteria that they were active from 1650 to 1700 and are known to have supplied the crown, an aristocratic household, or produced distinguished work. They were linked to London guild records, primarily the Joiners. The Joiners company apprenticeship records begin in 1641, however their freedom records appear to be incomplete and we are unable to safely identify masters who did not train among the larger sample of distinguished makers.

have gave them more need for additional workers, but that work included some of the most distinguished projects of the period.

The elite of the third craft, goldsmiths and silversmiths, can be identified because they produced pieces that survive in collections today. Thanks to the painstaking work of David Mitchell and others, we can identify silversmiths from makers marks stamped into the objects they made – a treasure trove of flagons, tankards, salvers, candlesticks and other plate - and then reconstruct their training from the guilds' records.[5] We focus on 113 individuals whose work is preserved in museums, described in works of connoisseurship, and sold at auctions.[6] Three quarters of these silversmiths are known to have taken apprentices, and they bound an average of five apprentices. Those individuals for whom the most objects survive also trained more apprentices. Those with one surviving piece trained an average of 3 apprentices (median 2); those with two to four objects in collections bound 5 (median 4); those with five or more bound 7. The most prolific producer by this measure – Edward Gladwin whose mark survives on 17 different objects – indentured eight apprentices.

High levels of skill were associated with high volumes of training in London, whether in crafts like silversmithing, furniture making, or clockmaking. Taking apprentices was the norm amongst them: all but one elite clockmaker, and four-fifths of silversmiths bound apprentices, compared to just two-fifths of London's freemen. The average number of apprentices they trained was high. The median elite goldsmith took 5 apprentices, the median elite clockmaker took 6, the median elite furniture maker took 10. The leading figures in each of these crafts recruited heavily and trained prolifically: they were among the group who trained a majority of the next generation. These innovative craftsmen and entrepreneurial traders did not shut their doors to outsiders to keep their secrets to themselves. Instead, the most skilful artisans also trained large numbers.

3.2.2 The Dutch Republic

No equivalent information, let alone across a variety of trades, is available for the Dutch Republic. However, data from the seventeenth-century painting industry seem to support the trend we observed for England: successful masters were training a disproportionate number of pupils.

One obvious example is Rembrandt, who was already a celebrated and internationally famous painter during his lifetime. In the winter of 1667, Cosimo III de' Medici – Grand Duke of Tuscany and the scion of an illustrious family of art connoisseurs – visited Rembrandt's studio to see with his own eyes the «pittore famoso» and his work (Bikker 2019: 181). During a career that lasted from 1625 to his death in 1669, Rembrandt probably taught 18-20 young painters (Broos 1983). One of his first pupils, Gerard (or Gerrit) Dou, came to Rembrandt at the age of fifteen and with only a knowledge of drawing. Rembrandt had to teach him how to

[5] *Goldsmiths' Database for the 17th Century* (database, Goldsmiths' Company, London); Mitchell, 2017.

[6] This is a sub-sample of those Mitchell identified based on taking their freedom between 1600 and 1670, so allowing their training careers to be observed in the guild's records. The linkage between marks and makers is not certain, but based on expert judgement.

paint, but also to prepare the canvas, make paints, and so on. Later in life, Rembrandt seems to have focussed on apprentices who had already acquired the basic skills. Govert Flinck was 21 years old when he joined Rembrandt's studio and had already trained for three years under a lesser master in Leeuwarden, a town quite removed from the Dutch Republic's cultural heartland. Ferdinand Bol was twenty years old when he came to Rembrandt, after initial training in Dordrecht (Middelkoop 2017; see also Bruyn 1991). Rembrandt would collaborate with his 'post-docs', but also asked them to copy his own work. Bol, and Flinck in particular, both worked in a style that displayed similarities with Rembrandt's, to the point that it has proved challenging to identify the originals and the workshop copies made by the apprentices. Rembrandt charged for the privilege of working alongside him, but also claimed the proceeds of his pupils' work.

Amsterdam was the most important centre for the painting industry in seventeenth-century Holland, and it was with good reason that Rembrandt moved there in 1631. However, next to Amsterdam there were a handful of secondary centres with substantial numbers of painters (Rasterhoff 2017). We have evidence about apprentices and their masters for two of them. In Haarlem we have evidence for the first half of the century about 36 masters training 87 apprentices whose own work has been documented. In other words, these were pupils who applied their skills in the painting trade.[7] The average number of such pupils per master was therefore 2.3. Of those 36, seventeen or almost half, tutored only one or two such apprentices. Among these was Judith Leyster, one of the very few female master painters during the Dutch Golden Age. She had one apprentice. Leyster stopped working as an independent master, however, after she married her colleague Jan Miense Molenaer and the pair moved to Amsterdam in 1636, just a few years after Rembrandt had done the same (Welu and Biesboer 1993). A handful of Haarlem painters from the period taught six, seven, and in one case even thirteen future painters, i.e. more than twice and up to almost six times the average number.

By far the most popular among these teachers was the most famous Haarlem painter of all time, Frans Hals. However, Adriaen van Ostade (7), Salomon de Bray (6), Karel van Mander (6), and Cornelis van Haerlem (6) also produced works that are nowadays in the collections of the most famous art museums in Europe, such as Louvre in Paris (all five), Hermitage in St. Petersburg (Hals, Van Ostade, De Bray, Van Mander), or the National Gallery in London (Hals, Van Ostade and Van Haerlem). Interestingly, Van Mander wrote a substantial book about painting in the Low Countries, inspired by Vasari's *Lives of the Artists*. In his book, Van Mander incorporated a substantial chapter on how to become a master painter.

It is a fact that some nowadays famous Haarlem masters taught few apprentices. This applies most obviously to Pieter Saenredam, whose church interiors are in the collections of the Louvre and National Gallery and were already collector's items in the seventeenth century. So we cannot claim that famous masters were always training many pupils. In Haarlem, however, fourteen per cent of training masters taught 44 per cent of pupils who are known to have been active artists themselves.

[7] Numbers calculated on the basis of Goosens 2001, 474-75 (appendix 4b).

In Utrecht, a school of painting emerged in the early 1600s that was heavily influenced by Italian examples, and one in particular: Caravaggio. These Utrecht painters were later labeled «Utrecht Caravaggisti» (Spicer and Orr 1997, and Ebert and Helmus 2018). In the financial administration of the local Guild of St. Luke, 73 pupils have been identified between 1611 and 1639 who were interested in learning the art of painting.[8] Another 34 were merely interested in drawing and they will be disregarded here. The apprentice-painters were tutored by eleven masters, but according to a by now familiar pattern, eight of them taught only one or two apprentices. On the other hand, Paulus Moreelse and Abraham Bloemaert had 28 and 13 pupils respectively. Together they taught more than half (56 per cent) of those 73 apprentices. Neither Bloemaert nor Moreelse was actually a Caravaggist. Bloemaert was famous for his religious work (he was a Catholic), Moreelse was primarily a portrait painter. Neither of them could match the originality of Frans Hals, but both are represented in the collections of the Louvre and Hermitage, Bloemaert also in the National Gallery, demonstrating their lasting international reputation. Interestingly, the same two men were founding members of the Utrecht Guild of St. Luke and served many turns on the board of the guild. Like Saenredam in Haarlem, Utrecht had another well-known painter who taught a mere three apprentices: Joachim Wtewael (or Uytewael; represented in all three museums). Surprisingly, none of the Caravaggisti features in the list of teaching masters.

The individual example of Rembrandt, who trained numerous pupils, including several who themselves became famous, is confirmed in both Utrecht and Haarlem: the most famous masters attracted a large share of the apprentices trained in their towns during the seventeenth century.

4. Conclusion

The literature on modern Vocational Education and Training (VET) shows how in Europe today, various systems to prepare youngsters for skilled jobs exist next to each other – and have done so for the last hundred years. The implication of this lack of convergence suggests that there is no obvious best-practice solution for all countries to adopt, because this type of education is context sensitive; various industries, but also national traditions of education, determine the effectiveness of skills education (Thelen 2004; Billett 2011). One element that might apply in all systems, it has been suggested, is that high-end skills training is most effective in de-centralised environments and that these are also more innovative (Finegold 2006). This literature is, however, inconclusive about what other elements might determine the outcome of VET.

Our analysis suggests that the focus on institutions shared by modern and historical analyses of apprenticeship may have missed an important element of the contribution it provided. In this paper, we have set out a mechanism by which apprenticeship contributed to incremental economic development by (i) positively selecting the set of skills that were reproduced among the next generation of workers and (ii) disseminating best practice across the economy.

[8] The data were collected and published by Bok 1990: 65-66.

Training apprentices was a game for the successful in early modern English towns and cities. Apprentices were clustered in the businesses of a minority of masters who took relatively large numbers compared to most of their peers. Not all apprentices experienced this: many masters did take a solitary youth, if they trained at all. Not all apprenticeship contracts would be completed, even in the most advanced workshops. But the masters who recruited the most apprentices and who trained the majority of the next generation were the most skilled and most successful; they were also the leaders of their guilds and the wealthiest members of their communities.

While they took the majority of youths, they were not feeding them into sweated workshops in which apprentices were crowded side by side on a proto-production line. Instead, even those masters with the largest businesses mostly had only a few apprentices concurrently. Apprentices were spread out over a master's career, and often staggered in ways that must have allowed the newcomer to learn from an advanced apprentice on the verge of leaving. That youths were able to receive exposure to the full operations of the firm and training in its activities and areas of expertise rather than simply suffer exploitation in some shallow niche of semi-skilled production seems a reasonable inference for these businesses in early modern English towns and cities.

The associations we can show are strong between different indicators of success and training, but in the final analysis they do not inform us directly about the quality of training and exposure or the creative and productive potential of their workshop the apprentice received. Nonetheless, while we currently lack the evidence that would allow us directly to show with greater precision a virtuous cycle of diffusion with skill, knowledge and technique spreading out from the leading lights of each occupation, it seems likely that this was one important consequence of the distribution of apprenticeship apparent in England's towns and cities. Families chased skill; and skill drove development. By focusing young workers experience of labour and learning in the workshops and businesses of the wealthiest and most substantial masters, apprenticeship spread the best ideas across the economy of England.

BIBLIOGRAPHY

Allen, Robert C. 2009. *The British Industrial Revolution in global perspective*. Cambridge: Cambridge University Press.

Baregheh, Anahita, Jennifer Rowley, and Sally Sambrook. 2009. "Towards a multidisciplinary definition of innovation." *Management Decision* 47: 1323-39.

Becker, Gary S. 1964. *Human Capital: A theoretical and empirical analysis*. New York.

Ben-Amos, Ilana Krausman. 1994. *Adolescence and youth in early modern England*. New Haven: Yale University Press.

Bikker, Jonathan. *Rembrandt, biography of a rebel*. Amsterdam: Nai Uitgevers.

Billett, Stephen. 2011. *Vocational education: Purposes, traditions and prospects*. Dordrecht: Springer.

Bok, Marten Jan. 1990. "'Nulla dies sine linie': De opleiding van schilders in Utrecht in de eerste helft van de zeventiende eeuw." *De Zeventiende Eeuw* 6: 59-68.

Britten, Frederick, Cecil Clutton, and G.H. Baillie. 1986. *Britten's old clocks and watches and their makers: A history of styles in clocks and watches and their mechanisms*. 9th ed. London: Bloomsbury.

Broos, Ben. 1983. "Fame shared is fame doubled." In *Rembrandt: A genius and his impact*, ed. Albert Blankert et al., 35-58. Amsterdam: Reaktion Books.

Bruyn, Josua. 1991. "Rembrandt's workshop: Function and production." In *Rembrandt: The master and his workshop*, ed. Christopher Brown, Jan Kelch, and Pieter van Thiel, I, 68-89. Berlin-Amsterdam-London: Staatliche Museen Preussischer Kulturbesitz.

Crook, J. Mordaunt. 1965, "The restoration of the Temple Church: Ecclesiology and recrimination." *Architectural History* 8: 39-51.

Crowston, Clare. 2001. *Fabricating women: The seamstresses of Old Regime France, 1675-1791*. Durham: Duke University Press.

De la Croix, David, Matthias Doepke, and Joel Mokyr. 2018. "Clans, guilds and markets: Apprenticeship, institutions and growth in the pre-industrial economy." *Quarterly Journal of Economics* 133, 1: 1-70.

Dosi, Giovanni, and Richard R. Nelson. 2010. "Technical change and industrial dynamics as evolutionary process." In *Handbook of the economics of innovation*, ed. Bronwyn H. Hall, and Nathan Rosenberg, I, 51-127. Amsterdam: North Holland.

De Munck, Bert, Piet Lourens and Jan Lucassen. 2006. "The establishment and distribution of craft guilds in the Low Countries, 1000-1800." In *Craft guilds in the early modern Low Countries: Work, power, and representation*, ed. Maarten Prak, Catharina Lis, Jan Lucassen, and Hugo Soly, 32-73. Aldershot: Ashgate.

Ebert, Bernd, and Liesbeth M. Helmus, ed. 2018. *Utrecht, Caravaggio and Europe*. Munich-Utrecht: Hirmer.

Epstein, Steven A. 1991. *Wage labor and guilds in medieval Europe*. Chapel Hill: The University of North Carolina Press.

Epstein, Stephan R. 1998. "Craft guilds, apprenticeship and technological change in pre-modern Europe." *The Journal of Economic History* 53: 684-713.

Epstein, Stephan R. 2013. "Transferring technical knowledge and innovating in Europe, c.1200-c.1800." In *Technology, skills and the pre-modern economy in the East and the West*, ed. Maarten Prak, and Jan Luiten van Zanden, 25-67. Leiden: Brill.

Epstein, Stephan R., and Maarten Prak, ed. 2008. *Guilds, Innovation and the European Economy, 1400-1800*. Cambridge: Cambridge University Press.

Fagerberg, Jan. 2005. "Innovation: A guide to the literature." In *The Oxford handbook of innovation*, ed. David Mowery, Richard Nelson, and Jan Fagerberg, 1-26. Oxford: Oxford University Press.

Finegold, David. 2006. "The role of education and training systems in innovation." In *Innovation, science, and institutional change: A research handbook*, ed. Jerald Hage, Marius T.H. Meeus, and Charles Edquist, 391-412. Oxford: Oxford University Press.

Goosens, Marion E.W. 2001. *Schilders en de markt: Haarlem 1605-1635*, PhD dissertation Universiteit Leiden.

Honeyman, Katrina. *Child workers in England, 1780-1820: Parish apprentices and the making of the early industrial labour force.* Aldershot: Ashgate, 2007.

Humphries. 2010. *Childhood and child labour in the British Industrial Revolution.* Cambridge: Cambridge University Press.

Kaplan, Steven L. 1993. "L'Apprentisage au XVIII[e] siècle: Le cas de Paris." *Revue d'histoire moderne et contemporaine* 40 : 436-79.

Kelly, Morgan, and Cormac Ó Gráda. 2016. "Adam Smith, watch prices and the Industrial Revolution." *Quarterly Journal of Economics* 131: 1727-52.

Kelly, Morgan, and Cormac Ó Gráda. 2022. "Connecting the Scientific and Industrial Revolutions: The role of practical mathematics." *Journal of Economic History* 82, 3: 841-73.

Kelly, Morgan, Joel Mokyr, and Cormac Ó Gráda. 2014. "Precocious Albion: A new interpretation of the British Industrial Revolution." *Annual Review of Economics* 6, 1: 363-89.

Kluge, Arnd. 2007. *Die Zünfte*. Stuttgart: Steiner.

Middelkoop, Norbert. ed. 2017. *Ferdinand Bol and Govert Flinck, Rembrandt's master pupils*. Zwolle-Amsterdam: Rembrandt House Museum. Amsterdam Museum.

Minns, Chris, and Patrick Wallis. 2012. "Rules and reality: Quantifying the practice of apprenticeship in early modern England." *The Economic History Review* 65: 556-79.

Mitchell, David. 2017. *Silversmiths in Elizabethan and Stuart London: Their lives and their marks*. Woodbridge, Suffolk: The Boydell Press.

Mitch, David. 2004. "Education and skill of the British labour force." In *The Cambridge economic history of modern Britain*, ed. Roderick Floud, and Paul Johnson, 332-56.Cambridge: Cambridge University Press.

Mokyr, Joel. 2009. *The Enlightened economy: An economic history of Britain, 1700-1850*. New Haven: Yale University Press.

Mokyr, Joel. 2020. "The economics of apprenticeship." In *Apprenticeship in early modern Europe*, ed. Maarten Prak, and Patrick Wallis, 20-43. Cambridge: Cambridge University Press.

Mowery, David. C., Richard R. Nelson, and Jan Fagerberg, ed. 2004. *The Oxford handbook of innovation*. Oxford: Oxford University Press.

Ó Gráda, Cormac. 2016. "Did science cause the Industrial Revolution?." *Journal of Economic Literature* 54: 224-39.

Polanyi, Michael. 1966. *The Tacit dimension*. Gloucester: Peter Smith,.

Prak, Maarten, Catharina Lis, Jan Lucassen, and Hugo Soly, ed. 2006. *Craft guilds in the early modern Low Countries: Work, power, and representation*. Aldershot: Ashgate.

Prak, Maarten, and Patrick Wallis, ed. 2020. *Apprenticeship in early modern Europe*. Cambridge: Cambridge University Press.

Prak, Maarten, and Jan Luiten van Zanden, ed. 2013. *Technology, skills and the pre-modern economy in the East and the West*. Leiden: Brill.

Rasterhoff, Claartje. 2017. *Painting and publishing as cultural industries: The fabric of creativity in the Dutch Republic, 1580-1800*. Amsterdam: Amsterdam University Press.

Schalk, Ruben, Patrick Wallis, Clare Crowston, and Claire Lemercier. 2017. "Failure or flexibility? Exits from apprenticeship training in pre-modern Europe." *Journal of Interdisciplinary History* 48: 131-58.

Schultz, Theodore W. 1961. "Investment in human capital." *The American Economic Review* 51: 1-17.

Sennett, Richard. 2008. *The craftsman*. New Haven.

Joaneath Spicer and Lynn Federle Orr. eds. 1997. *Masters of light: Dutch painters in Utrecht during the Golden Age*. New Haven Connn.

Thelen, Kathleen. 2004. *How institutions evolve: The political economy of skills in Germany, Britain, the United States, and Japan*. Cambridge.

Turner, Anthony. 2008. "'Not to hurt of trade': Guilds and innovation in horology and precision instrument making." In *Guilds, innovation and the European economy, 1400-1800*, ed. Stephen R. Epstein, and Maarten Prak, 264-87. Cambridge: Cambridge University Press.

Wallis, Patrick. 2008. "Apprenticeship and training in premodern England." *Journal of Economic History* 68: 832-61.

Wallis, Patrick. 2012. "Labor, law, and training in early modern London: Apprenticeship and the city's institutions." *Journal of British Studies* 51: 791-819.

Welu, James A., and Pieter Biesboer. 1993. *Judith Leyster, a Dutch master and her world*. New Haven: Yale University Press.

Wootton, David. 2015. *The invention of science: A new history of the Scientific Revolution*. London: Penguin.