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FROM PRINT TO PATENTS: LIVING ON INSTRUMENTS IN EARLY MODERN EUROPE

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Surprisingly, patents are nowhere as central to the history of scientific instruments as they are to the history of technology.¹ It will take much archival work to fill such an historiographical gap. My goal here is substantially more modest: to outline some patterns and chronological trends emerging from a comparison of printed patent rolls up to 1800 (which I am making available electronically) and other tactics used by instrument makers and designers to protect their businesses and authorship.² My definition of instrument is capacious. I consider mathematical, optical, and philosophical instruments, but also include evidence about clocks, calculating machines, globes, and maps.³

Defining ‘patent’ and ‘inventor’ within the chronological and geographical boundaries of this study is, however, a more difficult matter. Not only are modern patents profoundly different from early modern privileges (which are nevertheless customarily referred to as “patents” in anglophone literature), but the role and form of privileges underwent changes in the 1500–1800 period discussed here. For simplicity’s sake, I use the terms ‘privilege’ and ‘patent’ interchangeably while also highlighting the differences between modern intellectual property and early modern privileges whenever relevant. I take a similarly pragmatic approach to the definition of inventor, which I equate to that of patent-holder while specifying, when important, whether that person was a designer or a producer, a maker or an investor, or whether inventorship was individual or multiple. Early modern mathematical and natural philosophical texts were usually assigned to one single author (whose shadow may have erased other technicians and contributors), but we will see that it was not uncommon for instrument patents to be shared by a group of inventors, each bringing different skills and resources. Multi-inventorship, it seems, predates multi-authorship.

A question informing much of this essay concerns what the use of patents and other forms of protection can tell us about the early instrument makers’ and designers’ evolving markets, business practices, international mobility, relations with craft guilds, and changing sense of property in their instruments.⁴ A second question concerns the changing nature of the credit attached to instrument making and design. Instruments sit uneasily between the two main early modern systems of credit: one based on priority and publication (rewarded with symbolic, “philosophical” credit), and one based on the exchange of objects or labour for money. Many instruments were sold, but others — like Galileo’s telescope or Tycho’s apparatus — remained proprietary and often tightly guarded.⁵ They gained credit for their makers through

the production and publication of new claims, not sales. Patenting practices may tell us something about the specific conditions that placed instruments on either side of the divide between philosophical and financial credit, as well as about the conditions under which such divide could become permeable.

A study of the patenting of instruments also helps to revisit the long-standing discussion about openness and secrecy by questioning the association between these values and specific socio-professional groups in the early modern period. Huygens, Pascal, Smethwick, Bruce, Fatio de Duillier, Ramsden, Galileo, Short, Nairne, and Dollond — all of whom sought or obtained patents for instruments — cannot be made to fit one single socio-professional profile. Their backgrounds ranged from noble to lower-class and their disciplines from mathematics to theology. None of them had problems mixing the allegedly closed world of patents with membership in the allegedly open world of scientific academies.⁶ Nor did their institutions. The Royal Society took out a patent in 1664 under the name of Abraham Hill, its treasurer, listing several inventions including a pendulum clock “to be used at Sea for exact measuring of tyme; towards the finding of the longitude and knowing the true Course and place of A shipp”. Half of the revenue was to go to the Society and the rest to the members who had invented it: Edmund Bruce and Christiaan Huygens.⁷ The much-debated blurring of academic and commercial values in today’s university, therefore, has such a long history that there does not seem to ever have been a time when openness and secrecy stood apart as clear and distinct values.⁸

Early modern tools for the protection of inventions, books, prints, and music were remarkably different from those provided by modern patent and copyright law. There was, in fact, no intellectual property rights doctrine in seventeenth-century Europe, only so-called privileges. (The term ‘patent’ comes from the letter patent on which the privilege was made public.) Legally defined as expressions of the sovereign’s will, privileges came in a wide range of shapes. But despite the different applications and administrative frameworks that shaped them in different countries, all privileges shared one feature: they provided monopolies. The practice of granting privileges to inventors spread fast in early modern Europe. The Republic of Venice pioneered the systematic application of privileges to inventions and books from the late fifteenth century.⁹ It was soon followed by the Hapsburg and Spanish Empires, the Netherlands, and England.¹⁰ While the political fragmentation of German and Italian states makes it difficult to develop an overall picture of patenting in these countries, we know that they granted privileges for inventions quite early — 1421 in Florence.¹¹ Early modern Russia barely used privileges for inventions, while the complexity of the pre-Revolutionary French procedures for the protection of inventions defies simple generalizations.¹²

Privileges drew no legal distinction between what we now call “copyright” and “patent”. They covered the production and use of machines as well as the book trade. In time, these two kinds of privileges assumed different features, but those differences were of an administrative rather than legal nature. For example, a five-year privilege was granted in 1469 to John of Speyer, a German immigrant, for bringing

the printing press to Venice — a privilege that covered the whole printing press as an invention.¹³ But John of Speyer expired within a year, and so did his privilege. Realizing that book publishing was becoming big business, the Venetian Senate did not reissue a privilege on the printing press, but started to award privileges for individual books instead. Shortly after, the issuing of publishing privileges became grafted on the process of manuscript censoring and licensing and started to follow different administrative paths than those of privileges for machines.¹⁴

It is important to note, however, that what we might read as a transition from a “patent” on the printing press to “copyrights” on books involved no shift whatsoever in the legal definition of the privilege. Simply, the privilege came to be applied downstream (to books) rather than upstream (to the printing press) — an administrative adjustment stemming from the realization that Venice would have had more to gain from supporting its burgeoning printing industry by protecting the products rather than the technology of their production. Furthermore, the boundaries between the objects that today we see protected by patents and copyrights overlap but do not coincide with those between objects that used to be covered by privileges for inventions and printing privileges. As we will see, printed nautical charts and globes (which, as printed matter, one would expect to be protected by printing privileges) were in fact often listed in patent rolls, next to brass globes.¹⁵ One of the patterns traced in this essay is that, depending on the context and the specific features of the instrument, the practices of its protection could resemble either those of machines or those of books. Uneasily located between books and machines, the history of the protection of instruments may provide insights not only into the practices of instrument makers and designers but also into the historical development of the very categories of patent and copyright.

Twentieth-century cases involving oil-eating bacteria, genetic sequences, plant varieties, computer software, cancer-developing mice, and chicken breeds have taught us how uneasy the fit between the products of technoscience and the categories of intellectual property law can be.¹⁶ I hope to show that those tensions are not the result of the law lagging behind the increasingly fast pace of modern science. The presence of comparable tensions in the early modern period indicates that legal and administrative tools are always already ‘out of synch’ with the specificities of technoscientific production.

PATTERNS OF INSTRUMENT PATENTS

Because printed patent rolls for some countries are either incomplete or not available, the generalizations I present here must be taken with a grain of salt. One finding that seems reliable, however, is that only a handful of instruments were patented in Europe prior to 1600 despite the fact that, by that time, patents had been granted to hundreds of inventions.

No instrument is listed either in the complete Venetian rolls to 1550 or in the partial rolls published for the 1550–1797 period. This was not the result of high thresholds of patentability. By 1797, Venice had awarded more than two thousand privileges for

inventions, including several for perpetual motion devices.¹⁷ When in 1771 Lorenzo Selva applied for a patent for achromatic lenses (in competition with those patented in England by Dollond in 1758), he only received the title of “Public Optician” and a stipend — a gesture comparable, in kind, to the reward the Venetians extended to Galileo for his telescope in 1609.¹⁸ I have not encountered any instrument patent in sixteenth-century France, and only a handful before 1700.¹⁹ Three privileges for instruments are found in early modern Spain. Concerning nautical instruments claimed to find the longitude at sea, all are clustered in the 1572–74 period — probably in response to the prize announced by King Philip II in 1567.²⁰ None of the instruments of the famous Louvain school is found in Belgian printed patent rolls.²¹ Only one instrument, by Josua Habermehl, is listed in the 52 patents issued between 1500 and 1605 by the Elector of Saxony.²²

Negligible instrument patenting activity is also found in pre-1700 England. Between 1561 and 1661 only one patent (out of a total of about 50) was awarded to Edward Wright in 1598 for a device that might have been a mathematical instrument.²³ Issued to the Marquis of Worcester, the first unambiguous English instrument patent dates from 1661 and concerns clockmaking technology.²⁴ Only two pre-1700 English patents covered instruments other than clocks — a marine barometer by Daniel Quare and a machine to grind aspherical lenses by Francis Smethwick.²⁵ Smethwick — a librarian and amateur instrument maker — was elected to the Royal Society as a result.²⁶ Multiple inventorship becomes conspicuous around this time. Besides the pendulum clock patent shared by Huygens, Bruce, and the Royal Society, we find Fatio de Duillier (Newton’s protégé and member of the Royal Society) who, in 1704, shared a patent for the use of rubies as bearings in clocks and watches with two French émigrées clockmakers, Pierre and Jacob Debaufre.²⁷ And in 1695 Thomas Tompion (a distinguished clockmaker and collaborator of Robert Hooke) patented a cylinder escapement with William Houghton and Edward Booth.²⁸

The rolls of Habsburg privileges (available for the 1531–1697 period) are relatively thin — they list a total of 111 inventions — but are quite unusual in including eight instruments, seven clustered in the 1580–1602 period.²⁹ Some of them are by well-known makers and refer to instruments that are still extant: Gemma Frisius in 1536 for a globe; Christoph Schissler in 1583 for an “instrumentum geodeticum”; Josua Habermehl in 1581 for what appears to be another land-surveying instrument (patented in Saxony as well);³⁰ Joost Bürgi also for an “instrumentum geodeticum” in 1602; and Thomas Rueckert in 1580 for an odometer (now at the British Museum).³¹ Other privileges were awarded to lesser-known or unknown makers such as Christof Markgraf (in 1595 for a “clockwork & planetarium”), Elias Huetter (in 1595 for a “planetarium”), and Melchior & Caspar Strobel (in 1598 for “new clockwork”).³² Such a high percentage of patents for instruments, however, may not reflect a common practice among Hapsburg instrument makers as much as the Emperor’s personal taste. All but one of these patents were issued by Rudolph II — someone well known for his passion for instruments and wondrous mechanical devices — and involved makers who either worked at the Rudolphine court or were highly regarded

by him (Bürgi, Schissler, Markgraf).³³ Other patentees had court connections as well: Rueckert was a client of the Elector of Saxony, and Habermehl was a supplier to the Bavarian court and a relative (or an associate) of Erasmus Habermehl, one of Rudolph's favourite makers.

As it is difficult to believe that Bürgi's or Schissler's landsurveying instruments had such high market potential to benefit from monopolistic protection, it would not be surprising if these patents were, in fact, patronage gestures. Christine MacLeod and Eric Ash have detected related patterns in sixteenth- and seventeenth-century English industrial patents.³⁴ The same can be found also in sixteenth-century Spain where one of the recipients of instrument patents — the famous architect and engineer Juan de Herrera — was a distinguished courtier.³⁵ Père Cherubin too received a French privilege around 1670 for his binocular and drawing instruments, thanks to his patronage connection with the King and the Dauphin.³⁶ Similarly, Christiaan Huygens's Dutch and French patents for clocks and watches in 1657, 1664, and 1675 as well as in Blaise Pascal's French 1649 patent for his calculating machine were obviously facilitated by their fathers' excellent political connections.³⁷ In Pascal's case, the patent was awarded gratis and did not specify an expiration time — a further indication of the privileged relation between Pascal's father, Etienne, and the regents.³⁸ Pascal's connections with the crown may explain the extraordinary breadth of the claims protected by the privilege.³⁹ Huygens's French 1665 privilege (for the same remontoir clock he patented in the Netherlands in 1664) was requested directly by his father from Louis XIV.⁴⁰ Robert Hooke's attempt to obtain an English patent for his spring watch in 1675 (in competition with Huygens) also hinged on his direct access to Charles II.⁴¹ Princely patronage also came in handy when one was trying to extend the coverage of a privilege to other countries through a prince's diplomatic networks.⁴² Membership in royal academies provided inventors with key, patent-facilitating connections.⁴³ In 1675 Huygens (by that time a star of the Académie des Sciences) managed not only to obtain a French privilege for his spring watch, but to do so in ten days.⁴⁴

Given the pervasive relationship between privileges and patronage, it makes sense to ask to what extent patronage was a means to obtaining or extending patents as business tools, or whether some of these patents were intended to be used as personal badges of honour comparable to titles like “Ingénieur du Roi pour les instrumens de mathématiques”, “Mathematical Instrument Maker To the King's most Excellent Majesty”, or “Horiolaio di Sua Altezza”. That early patents amounted to privileges rather than property rights — not to mention that it was common to reward inventors with jobs, pensions, titles, and cash awards rather than patents — further complicates the question.⁴⁵ It seems, however, that individually authored patents were more likely to be badges of honour, while collective patents functioned more like legal titles to an invention.

To judge from evidence from instrument makers' business cards, the connection between patents and prestige changed in eighteenth-century England. As we will see in a moment, the patenting of instruments increased dramatically after 1700 and,

given how widespread printed advertisements of instruments had become by then, one would expect to see patents widely used in that context. But while mentioned in some advertisements, patents were not featured as prominently or frequently as other selling points such as, say, a maker's prestigious clients.⁴⁶ As the market became larger and more competitive, it seems that patents became increasingly sought and used as legal tools rather than as prestigious endorsements. Even when they continued to be used as badges of honour, the meaning of honour had changed.

John Dollond's 1758 patent for achromatic lenses (which he shared with Francis Watkins) is an example of such a shift. Although the patent was used as an advertisement tool and was not enforced for a few years, it would be a mistake to assume that Dollond and Watkins were still operating in the older honorific economy of patents of Markgraf or Bürgi. Their initial decision not to take legal action on infringers stemmed from the simple fact that the market had become too big for them to supply. Unable to meet the high demand for achromatic telescopes, Dollond and Watkins let other opticians produce them as well, while at the same time advertising the patent to distinguish their product from 'generic' copies.⁴⁷ It worked. According to a competitor, Dollond managed to sell achromatic telescopes "at a much higher rate than that what they have always been sold at by others in the Trade".⁴⁸ But as soon as Peter Dollond increased productivity by modifying his father's original design and became able to supply a larger share of the market, he took the patent out of the drawer and started bringing (and winning) infringement suits (twelve of them) against seven opticians whom he had previously allowed to infringe. The prices of English achromatic telescopes went up as a result of Dollond's legal success, to drop by almost one-third after the expiration of the patent in 1771.⁴⁹

I would argue that even during the period in which Dollond and Watkins did not enforce their patent, it functioned as a different kind of intellectual property tool, that is, as a trademark.⁵⁰ They did not simply use it to advertise themselves and their business, but rather to *brand one specific product* of theirs. And as soon as their productivity increased, the role of their patent moved from trademark to patent proper.

A different picture is found in eighteenth-century France. French makers did use the patent system (or at least parts of it) quite extensively, but they seemed more attracted by the prestige of having their instruments approved for patenting by the Académie des Sciences than by actually getting those patents.⁵¹ The presence of so many approvals and so few actual patents reflected, in part, the enduring strength of the Paris guilds. Still, the difference between England and France is quite striking. At the time when London instrument makers were very busy patenting, advertising, and selling their instruments to whomever could afford them, the top Parisian makers were being organized in a new exclusive guild (high in status but low on patents) to provide the Académie des Sciences with its observational and experimental apparatuses.⁵² (The consequences of the abolition of both the guilds and the privilege system in 1791, and the passage of the first patent and copyright law in the same year, are not discussed in this essay.)

The Netherlands provide the only partial exception to patterns of minimal or

honorific patenting encountered in the rest of Europe before 1700. Dutch patents were relatively inexpensive and several of them were issued for instruments. Three were patented in the Netherlands between 1593 and 1600, twelve more by 1650, and another eleven by 1700. The last group includes five clock patents, four of which were taken out by Huygens (in some cases with the artisan who worked for him) or by clockmakers who claimed to have devised clocks that were either different from or better than Huygens's.⁵³ Patenting activity dropped significantly thereafter, with only six instruments receiving patents between 1700 and 1756.

But if the Dutch figures were significantly higher than in other countries, the typology remained similar. Most patents concerned either clocks or nautical instruments. Interestingly, the most famous early modern instrument maker from the Netherlands, the Musschenbroeck firm, patented none of its products. This is intriguing given that the Musschenbroeck did not belong to guilds — the other common early modern strategy for intellectual property protection.⁵⁴ Also absent from patent rolls are the names of other famous Dutch or immigrant makers of philosophical instruments such as Fahrenheit and Cuthbertson.

Taken as a whole, the available evidence from Spain, France, England, Venice, the Hapsburg Empire, the Netherlands, Saxony, and England indicates that: (1) only fifteen patents for instruments are found in Europe by 1600 (and about half of those might have reflected high-ranking personal connections rather than common business practices); (2) the additional thirteen patents we find between 1600 and 1650 indicate no real increase in the pace of patenting; (3) the overwhelming majority of pre-1700 patents concerned clocks and navigation instruments;⁵⁵ (4) philosophical instruments such as air pumps, telescopes, microscopes, and electrical machines do not seem to have been patented anywhere in Europe in the seventeenth century;⁵⁶ and (5) only one meteorological instrument (a portable barometer by Daniel Quare) was patented before 1700.⁵⁷

This scenario changed dramatically after 1700. England had, perhaps, one instrument patent by 1650 and about seven by 1700, but issued 93 more by 1800. Such an explosion matches the remarkable development of the instrument business in that period. The Office of Ordnance alone ordered over 1500 instruments worth £2,425 from one London instrument maker, George Adams, between 1748 and 1772 — orders that still did not exhaust the Office's overall needs for that period.⁵⁸ And toward the end of the century, a shipping company could buy 42 achromatic telescopes in one single order.⁵⁹ Such remarkable expansion is reflected in the increases of workshops' size (up to fifty artisans in some cases), in the shift toward a more industrial mode of production, in the market differentiation between high-end custom-made and popular 'off-the-shelf' devices, in levels of specialization within shops and between competing establishments, and in the increased use of advertisement, often aimed at a more dilettante market.⁶⁰

It would be difficult to overstate the relationship between patenting and the size of the instrument market. A patent on Hadley's quadrant made sense given how widely used such instruments were in the eighteenth century, but it would have made much

less business sense to take out an expensive patent on a quadrant at the end of the sixteenth century.⁶¹ And while Peter Dollond was surely skilful at using his patent, his success ultimately hinged on the fact that his father had hit upon an invention whose use was not limited to one specific telescope but concerned a doublet that became a key component of a variety of optical systems, thus making his patent applicable to many different optical instruments.

Another factor behind the dramatic increase in patenting in England may have been the clustering of instrument makers in specific areas of London — a concentration that turned secrecy and confidentiality into highly perishable goods.⁶² Such a geographical concentration was not altogether new, but the probability of and damages from leaks increased with the size of the market, the number of makers, and especially the increasing farming out of the making of specific elements of certain instruments to out-of-shop artisans.⁶³ Furthermore, as discussed by MacLeod, the rise of patenting triggered more reactive or defensive patenting. As soon as technologies begin to be fenced off from the public domain, there is a rush to stake claims on what's left. Lastly, the weakening of the guilds' power (and the fact that these increasingly differentiated products would be hard to fit the guilds' product classifications) went hand in hand with increased patenting.⁶⁴

Despite the exponential quantitative increase in instrument patenting, however, we find almost no change in the kinds of instruments that were patented in the seventeenth and eighteenth centuries. Most post-1700 English patents still concerned clocks (both marine and terrestrial) and nautical instruments. A key technical problem like the determination of the longitude and the large military and commercial interests (and prizes) behind it put pressure on designers and makers of both time-keeping devices and optical time-finding instruments based on the lunar distances model.⁶⁵ A similarly steep increase in patent-related activities is found in eighteenth-century France. While privileges for instruments are negligible before 1700, the Académie des Sciences (charged to examine patent applications by its 1699 Statute) approved about ninety instruments for patenting between 1700 and 1754 — about as many as all the patents awarded to instruments in England in the entire eighteenth century.⁶⁶ Clocks and nautical instruments make up the majority of the instruments submitted to the Académie's judgement as they do in English patent rolls from that period, although clock or clock-making technologies are even more conspicuous in French than in English rolls. It is not at all clear, however, how many of these instruments received privileges in the end. A prolific maker of philosophical instruments like the Abbé Nollet had two of his devices approved by the Académie in 1733, but there is no evidence that he ever patented them or any other instrument he produced and sold.⁶⁷

Philosophical instruments remained exceedingly rare in European rolls. Only three are found patented in England, and even so only in the second half of the century: one barometer by Pyefinch and De Magellan in 1765, one electrical machine by Nairne in 1782 (advertised primarily as a medical device), and one air pump by Haas in 1783.⁶⁸ Telescopes of various kinds were patented frequently in eighteenth-

century England (either alone or as components of nautical instruments) by Short as well as by Adams, Blair, Dixon, Irwin, Pyefinch, Rand, and Storer.⁶⁹ They were also conspicuous in the list of instruments approved by the Académie des Sciences in the same period. Both in England and France, telescopes seemed to be treated as mathematical instruments — as problem-solving devices incorporated in time- and longitude-finding apparatuses. By contrast, optical instruments with no clear practical applications were rarely patented. I have found only three patents concerning microscopes — all of them in eighteenth-century England.⁷⁰ Another conspicuous pattern is that, as we enter the eighteenth century, we cease to find evidence of instrument patenting in central and southern Europe. Even the Netherlands that had remained ahead of England (and anyone else) in the second half of the seventeenth century, effectively stopped patenting instruments after 1722 despite remaining a major centre of instrument-making.

These are some of the macroscopic patterns I can detect in the available evidence. In order to make sense of them we now need to turn to what patents could and could not do for the designers and makers of specific instruments, and what other options they had available when it came to protecting their work and businesses. After a discussion of the various ways in which early modern privileges differ from both modern patents and copyrights, I look at how the protection of instruments moved between the world of print and that of patents in a period in which the relationship between publications and patents was quite different from the one we know today.

GOING PLACES: THE LOGIC OF THE PRIVILEGE

If the function of privileges was comparable to that of modern intellectual property law, their logic was not. Modern inventors and authors hold *rights* in the product of their ingenuity and personal expression, but early modern privileges construed inventors and authors as princely *subjects*. The procedures and conditions for the granting of privileges to texts and inventions did vary a great deal across early modern Europe, but shared a key common denominator: privileges and payments to inventors were gifts, not rights.⁷¹ Venetian patents from 1450 to 1550 use terms such as *privilegium*, *gratia*, *concessio*, and *monopolium* interchangeably.⁷² One did not apply but rather supplicated for a privilege.⁷³ The pace of the transition from royal favour to intellectual property rights varied with countries, but it tracked quite closely the demise of political absolutism and the development of liberal economies.⁷⁴

Early modern privileges granted not only the exclusive use or sale of a certain technology over a certain period, but also other benefits such as the authorization to set up business in a certain place, the granting of honorific titles, pensions, cash awards, free housing, capital investments in the invention, the permission to immigrate and assume citizenship, or the exemption from taxes, militia duty, and guilds regulations.⁷⁵ Because its role extended into the business dimension of an invention, the privilege did not draw a logico-legal distinction that is instead central to modern intellectual property law. Modern patents grant exclusionary rights: I own the rights in a certain invention and I can prevent you from using or copying it. Early modern

privileges, instead, functioned simultaneously in the negative and positive register. They were as much about excluding competitors as about providing resources and permissions to set up and operate a business based on that invention.

Another main difference between past and present is that while the modern patent system is deemed to increase local innovation, early modern privileges were frequently used to foster the international mobility of skilled engineers and artisans. The founding document of Venetian patent practices — a 1474 Senate bill — opens with the statement that

Men with most acute minds able to conceive various ingenious devices reside in this City and, thanks to its greatness and tolerance, move here every day from different countries.⁷⁶

The same connection between inventions and mobility is found two centuries later in a passage of Sprat's *History of the Royal Society* critical of the English failure to pursue the kind of immigration and technology transfer policies initiated by the Venetians:

[English tradesmen] are generally infected with the narrowness that is natural to Corporations, which are wont to resist all new comers, as profess'd Enemies to their Privileges: And by these interested men it may be objected, That the growth of New Inventions and new Artificers will infallibly reduce all the old ones to poverty and decay... [This] made the English avers from admitting of new Inventions, and shorter ways of labor, and from naturallizing New-people: Both which are the fatal mistakes that have made the Hollanders exceed us in Riches and Traffic: They receive all Projects, and all People, and have few or no Poor.⁷⁷

Patents, therefore, were simultaneously aimed at importing inventions and at creating spaces for “New-people” outside of the traditional guild-based organization of labour. (The honorific titles and court affiliations that princes granted to their favourite artisans, included instrument makers, often carried comparable freedom from the guilds.⁷⁸) Armenian, Greek, Jewish, Slav, German, French, Dutch, Flemish, Polish, Swiss, English, and Spanish names appear on Venetian patents, while Italian names are found in Imperial, Dutch, Spanish, French, and English rolls.⁷⁹ The technology transfer role of early patents is confirmed by privileges granted to indigenous artisans who had “been abroad to places where [they] learned such a secret”. Occasionally, exposure to foreign technologies was a byproduct of war, as in the case of Richard Dyer who in 1571 obtained an English patent for portable furnaces — an art he had picked up while a prisoner of the Spanish.⁸⁰ In other cases, spying trips were sponsored by the very authorities that would later reward the artisan with patents.⁸¹ It is worth noticing that, far from criticizing such “industrial espionage”, Bacon entrusted some members of the House of Solomon with it.⁸² These people were to sail to other countries every twelve years (in disguise, under fake names, with two ships listing fake ports of call) and with sufficient cash to buy trade secrets as well as recent books and “instruments and patterns of any kind”.⁸³ This is analogous to

the distinctly non-Utopian policies of William Cecil, Bacon's uncle and Elizabeth's chief minister, who "had some special investigators in his employ, with foreign connections ... who regularly plied him with ideas and information on economic projects in progress at home and overseas".⁸⁴

Instrument makers (especially watchmakers) were no exception to these patterns of mobility.⁸⁵ In the case of Thomas Gemini — the most distinguished of early Elizabethan instrument makers — his move from the Flanders to England was the result of religious persecution (as it was to be the case, later on, with many Huguenot artisans like those who triggered the Genevan watch-making trade).⁸⁶ But in many more cases mobility resulted not from threats but from incentives, as with the three clockmakers from Delft who relocated to England in May 1368 with letter patents granted by King Edward III, or the many foreign makers of instruments and clocks found at various European courts.⁸⁷ J. D. Cassini's unsuccessful attempt, in 1788, to relocate the Irish glassmaker Belsaigne to France (from where his Huguenot family had previously emigrated) to produce flint glass for achromatic lenses in exchange of a variety of privileges is another example of the same dynamics.⁸⁸

Venice developed aggressive 'technology transfer' policies and was willing to offer increasingly long and comprehensive privileges that in some cases covered even inventions the inventor had not yet made.⁸⁹ (It also had symmetrically strict sanctions, including prison sentences, for its own artisans if they left Venice to take advantage of patents offered by other nations.⁹⁰) In 1567 Giuseppe Ceredi commented that "anyone who believes to have found some ingenious beautiful thing takes his models [to Venice] to obtain privileges".⁹¹ Along the same line, Sir Thomas Smith wrote in 1549 that "In Venice, as I heard, ... they reward and cherish every man that brings in any new art or mystery whereby the people may be set to work".⁹² And in 1493 Leonardo remarked, with obvious scorn, that he had frequently seen people move to Venice from different countries in the hope of rewards for mills driven by perpetual motion devices.⁹³

The development of patenting increased long-term artisanal mobility, but it also led to the emergence of a new breed of inventors who hopped from country to country to seek and sell patents, often in consort with other like-minded investors, so as to maximize the number of patents obtained for the same technology in a given period.⁹⁴ As inventions could be rewarded with patents, cash, or both, it is difficult to tease apart patent-seeking inventors from another and often denigrated migrant group: the "projectors".⁹⁵ But setting aside Ceredi's or Leonardo's sarcasm for these inventors and projectors, their remarks point to a real trend. The northern European optician who travelled to Venice in the summer of 1609 seeking reward from the Senate for the telescope (just weeks ahead of Galileo's presentation of his own instrument) may have been one of such "patent hunters".⁹⁶

Patents and guilds developed complementary (rather than simply oppositional) roles. Patents were about the establishment or importation of new technologies, trades, and skilled workers. Guilds were about managing existing local trades.⁹⁷ That applied as much to textile trades as it did to instrument making. Patents enticed

instrument makers to move, while guilds worked hard at making sure they would not leave. At Nuremberg, for instance, sundial makers were organized as a “sworn” guild whose masters could not travel abroad without permission.⁹⁸ Venetian glass-makers, as mentioned, were subject to similar sanctions.⁹⁹ If today the knowledge inscribed in a patent eventually flows back into the public domain, the know-how of early modern patents would end up assimilated by the guilds (if deemed sufficiently useful to deserve assimilation).¹⁰⁰

That privileges were as much about the importation of foreign technology and skills as they were about protecting local innovation is reflected in the fact that they made no legal distinction between technologies, knowledge about those technologies, and the business made possible by both that knowledge and those technologies. The differentiation between the invention and the skills required to construct or operate it was a distinction without a legal difference.¹⁰¹ The modern legal notion of “reduction to practice” refers to the invention itself, but early modern privileges used misleadingly similar terms like “reduction to perfection” to cover a wider range of factors that rendered the invention workable, down to stipulations concerning the training of local workers and artisans to operate that invention.¹⁰² There was no need to separate machines, bodies, instruments, skills, tacit knowledge, disclosure, and reduction to practice because what mattered to the authority granting the privilege was that a locally useful manufacture or technology would be made available there and that, hopefully, it would create employment opportunities for local labour while reducing imports.

Privileges were issued by political authorities for a number of years (usually between five and twenty) to a person or company, granting them exclusive use of an invention (or license its use) in a specific area. The area covered by the privilege could be as large as the state that granted it, but it was usually more limited — with the exception of early Papal privileges that were claimed to apply to all Christians wherever they might be.¹⁰³ In many ways, the privilege functioned by assigning a monopoly on a specific space as much as on a specific technology, thus showing once more how much these devices differed from modern intellectual property. One could get a privilege to use a specific boat design (flat-bottomed) to transport specific goods (marble blocks) on a specific river (the Arno) — as Brunelleschi did in Florence in 1421¹⁰⁴ — or to operate a specific cloth-fulling mill in a specific spot (near the Rialto in Venice) — as Franciscus Petri did in 1416.¹⁰⁵ If modern intellectual property is becoming more and more about rights in a *global space*, the privilege was about specific *things* and skilled *bodies* in specific *places*.

The originality of an invention did matter, but it hinged on geography rather than authorial creation. One did not need to be the first developer of an invention or the original author of a text to be granted a privilege for that device or book in a certain place. The inventor was defined as the first person *who brought it there* — yet another indication of the technology transfer goals behind early privileges.¹⁰⁶ With both machines and texts, the privilege did not discriminate between originality and translation (in the literal sense of moving across linguistic or geographical

boundaries). The water-driven silkmill “Bolognese style” was patented in Venice in 1604 (by Ottavio Malpighi), in Turin in 1666 (by Giovanfrancesco Galeani), in Holland in 1678 (by Johan Becher), and in London in 1718 (by John Lombe).¹⁰⁷ We are often told that the term ‘invention’ is semiologically unstable because the Latin verb from which it derives — *invenire* — means both ‘to find’ and ‘to create’. But the very detection of such a semiotic tension may be an effect of our modern conceptualization of invention as an individual creative mental act — what Martha Woodmansee has called the “romantic author”.¹⁰⁸ From the point of view of the early privilege system there was no difference between ‘to find’ and ‘to create’. What mattered was not whether the object was found or created, but rather where it was taken and put to work — its physical place of arrival rather than its point of conceptual origin.

Interestingly, international priority disputes emerged well before a legal framework was set in place for them with the increasingly global patent treaties in the nineteenth and twentieth centuries.¹⁰⁹ What is more intriguing is that instruments — not industrial machines — were the objects of such disputes. Mobility must have been a factor. Instruments travelled more easily and faster than silkmills, thus creating the conditions for claims of simultaneous or independent invention by inventors of different nationalities. But something more structural lies behind the rise of international priority disputes over instruments (like the one between Huygens and Hooke discussed by Iliffe): the unplanned overlap of the new reward system being developed by scientific academies with the traditional privilege system.

The very local notion of priority (connected to either invention or importation) inherent in the privilege system came into conflict with the radically different reward system of the republic of letters that construed priority in international terms and connected it to authorial originality, not just to the act of making an invention materially available in a given place.¹¹⁰ While Huygens did not have to worry about non-Dutch prior art when he patented his spring watch in the Netherlands in 1675, he did get involved in a bitter priority dispute with Hooke when he tried to gain philosophical credit for the same watch from the Royal Society.¹¹¹

Priority had a complementary relation to local utility. Priority became a contested issue when, instead of pursuing financial rewards for locally useful (and locally operating) devices, mathematicians and philosophers sought non-monetary and non-local credit for non-material objects like the conception of an instrument or a claim about nature. The spring watch could and did enable both kinds of claims and rewards. But because in this case the issue of philosophical credit turned out to be marginal compared to the substantial financial rewards the inventor of an accurate and portable timekeeper could have reaped from helping to solve the longitude problem, the dispute soon exited the Royal Society and its economy of philosophical credit to land where all patent applications landed: the royal court.¹¹² At that point, following common patent practice, issues of intellectual priority, originality, and conception took the backseat to the King’s judgment of the performance of the actual watches that Hooke and Huygens had delivered there and then.¹¹³ An international priority dispute over the conception of the spring watch was reframed (as far as the King was

concerned) as a competition for the award of one local patent.

It is striking how specific and local the early notion of utility was when compared to the increasingly generic definition we find in today's patent law. In the age of global economies utility seems to have no identifiable beneficiary beyond a generic 'public' situated in an equally unspecified future. By contrast, some of the earliest patents — like those related to the making and dredging of canals in Venice or the drying of swamps in the Netherlands — concerned public works, not privately-owned technological products to be sold on a generic market.¹¹⁴ Though not many patents were so site-specific, a distinctly local and immediate notion of utility informed all early privileges, especially those issued before 1700. That applied to instruments too. Philosophical instruments — instruments for 'basic research' — were almost never patented. By contrast, concerns with the determination of the longitude were often behind patents of clock and optical nautical instruments, and attempts to patent early telescopes rested on the claim that enemy ships could be made visible much sooner — claims that were pitched to maritime states like the Netherlands and Venice.

UTILITY, DISCLOSURE, AND REDUCTION TO PRACTICE

By emphasizing local utility and technology transfer, early privileges assigned a modest role to disclosure — a role that, instead, is key to modern patent law. The justification of today's patent system hinges on the *quid pro quo* between the inventor and the state: inventors receive temporary monopolies in exchange for the publication of their patents' specifications drawn up according to specific standards.¹¹⁵ Everybody wins, or so we are told. The inventor draws inspiration from the knowledge freely circulating in the public domain and patent disclosure makes sure that his/her knowledge flows right back to that public domain and enables more innovation well before the patent's expiration.

By contrast, early modern privileges were not conceptualized as contracts between inventors and society. Privileges were granted primarily to improve revenue or to try to solve specific technical or military problems. It makes sense, then, that inventions would be disclosed (if they were disclosed at all) to princes and state officials rather than to society as a whole.¹¹⁶ Disclosure was not a 'value' — a commitment to being open to a generic public or professional community — but rather a practice between specific individuals operating in a specific political economy. Furthermore, if inventors disclosed to the state, the state had little or no interest to re-disclose that knowledge to the public. In the absence of international patent agreements, the publication of patent specifications would have greatly helped industrial espionage (already a serious headache in the eighteenth century).¹¹⁷

The slow emergence of patent specifications did not result from the perceived need to make such information available to the public, but from the mundane practices of state officials charged with administering patent applications. When Dutch patent applicants were asked to include drawings of their inventions, it was to outline the object of the patent to allow state officials to assess whether it entailed an obvious

infringement of older patents.¹¹⁸ These checks performed, the specifications were usually archived or returned to the inventor for safekeeping.¹¹⁹ For instance, an inventor who submitted a longitude-finding apparatus in April 1601 was asked to “submit a drawing of the art invented by him ... with annotations denoting the particulars underlying the art and the secret knowledge, in order that all such drawings and particulars together could be taken care of and kept secret”.¹²⁰ As in the Netherlands, French administrators used patent specifications to adjudicate infringements, but kept such specifications confidential for the duration of the privilege.¹²¹ The same practice was followed both by the Emperor and the Electors. The Imperial city of Nuremberg even passed a specific ordinance in 1532 to the following effect:

The models of all the artfully contrived devices and other works which in this city are found in the arsenal, city hall, or anywhere else, shall be placed in a separate room, locked, under the responsibility of the masters of the Arsenal.¹²²

Similarly, while the Académie des Sciences published volumes of descriptions and detailed drawings of the instruments they had approved for patenting since 1699, it did so decades after the initial submissions.¹²³ Disclosure was equally confidential in Venice.¹²⁴

It was only in 1778 that England adopted the requirement (comparable to the modern one) that specifications should be detailed enough to allow a person skilled in the art to understand and apply it without further experiment.¹²⁵ (This replaced the requirement to train local people to operate and reproduce the invention.) The filing of any kind of specification was rare before the eighteenth century. Only 20% of all English patents issued before 1734 included any specification, though such information would have been made public only after the patent’s expiration.¹²⁶ In addition, some patentees were absolved from disclosure by the application of the “non-obstante” clause.¹²⁷

Even when disclosure became a requirement, the absence of standards kept it uneven and not much more informative than it had been in the previous century.¹²⁸ In 1665, for instance, Sir Robert Moray told Huygens that his pendulum clock (to be patented in England by the Royal Society) needed to be described only “en termes generaux” in the application.¹²⁹ Smethwick’s 1666 patent for a machine to grind aspherical lenses did not disclose whether they were parabolic, hyperbolic, or elliptical — information that the inventor continued to withhold when, in 1667, he asked for an endorsement of his aspherical telescopes and microscopes from the Royal Society.¹³⁰

Details emerged only in the wake of patent infringement disputes, but even in these cases it is not clear how carefully the courts analysed these records.¹³¹ Dollond’s 1758 patent for his achromatic lenses included no drawing of the doublet that constituted his invention, no specification of the different glasses used, etc.¹³² Though he pledged, in his petition, to describe “his said invention and in what manner the same is to be performed”, he never did so — a negligence that, however, caused him no harm when the patent was later litigated.¹³³ A similarly undetailed disclosure is found in

the 1750 patent by George Adams and Richard Jack for an improvement on Hadley's quadrant (whose patent, issued in 1734, had expired), while Ramsden's 1775 patent drawings for his instruments have been described as "crude and deliberately obscure, lacking in proportion and perspective".¹³⁴ The lack of consensus about standards of specification was brought in stark relief during *Boulton and Watt v. Bull* (1794). Even at such a late date James Watt could argue, not without reason, that he could not find in the law any statutory requirement of the patentee to specify.¹³⁵

More than a century earlier, Pascal did not include drawings of his arithmetical machine in his application for a French patent, but simply showed working models of his machine to influential courtiers and royal officials.¹³⁶ The display of models or actual working inventions as part of the patent application process was so widespread in the early modern period (but virtually absent from modern patenting protocols) that it deserves some analysis.¹³⁷ Models were required in Venice — as we know from Galileo who had to borrow money to have one constructed for the water pump he patented there in 1594.¹³⁸ Models were also needed for Imperial privileges, and were requested by the Académie des Sciences to all inventors who wished to submit their inventions for approval.¹³⁹ Hooke too demonstrated a working timekeeper as he was seeking a patent for his spring watch from Charles II in 1675, and so did Huygens when he applied for a patent for his remontoir pendulum clock from the Dutch State General in 1664.¹⁴⁰ No drawings are found or mentioned in Huygens's application for a privilege for his spring watch from Louis XIV in 1675, but we know that he showed Colbert a functioning model a few days before filing the application.¹⁴¹ Similarly, the Dutch optician who sought a reward for the telescope in Venice in 1609 let the Senate test the actual instrument, but did not disclose its construction.¹⁴²

One could say that models were representations of an invention, and thus disclosed it. That depended on the context in which they were used. Models could indeed end up disclosing the invention if they landed in the hands of competitors, but they had a quite different role in the eyes of the patent-granting authorities who required them. State officials looked at models to identify an invention to the extent necessary to determine that it was not identical to previously patented inventions, but they especially relied on models to see if the invention could work — something a drawing or a textual narrative could hardly do.¹⁴³ Rather than "material representations", models functioned as "scaled-down reductions to practice" of inventions.

Originality and disclosure were not high priorities for the privilege-granting authorities, but local utility and reduction to practice surely were. If an invention was rendered operable and local workers were successfully trained to use it, the patent was confirmed and the inventor was often allowed to hold on to its secret. But patents could be voided if the invention failed to be reduced to practice in a timely fashion (typically six months to two years from the award of the privilege).¹⁴⁴ Given the narrow window of opportunity for reduction to practice — a requirement that has been singled out as the biggest obstacle on the path of early inventors — the filing of working models was an obviously appealing option.¹⁴⁵

The case of instruments was more complicated for paradoxical but interesting

reasons. On one hand, makers wanting to patent their instruments did not have to spend much money and time to either reduce the invention to practice (which, with larger inventions, would have typically required finding investors on a very short notice) or to produce a model. Instruments were both relatively inexpensive (or at least not as expensive as watermills) and already reduced to practice. An instrument maker, therefore, could simply file the device itself with the patent application (as Hooke, Huygens, and Pascal did). But this convenience could turn out to be too much of a good thing. The very features of the instrument that made it match the reduction to practice requirements so easily, promptly, and inexpensively could also disclose too much and too quickly. The disputes that, at different times, embroiled Leibniz, Huygens, Coster, Thuret, Douw, Hooke, and Pascal testify to the ease with which clocks and calculating machines could be copied with only limited exposure to a working sample.

No matter how extensive written patent specifications are today, they still leave enough ‘wiggle room’ for the inventor to match disclosure requirements without really disclosing a lot. In addition, modern reduction to practice standards are so weak — boiling down to the ability to “describe that invention with particularity” — that they are virtually identical to specification requirements.¹⁴⁶ While early modern standards of disclosure were significantly more lax than ours, those concerning reduction to practice were much tougher. As a result, the filing of working samples to fulfil the strict reduction to practice requirements could end up providing, unintentionally, a level of disclosure that far exceeded early modern and modern standards of specification alike. All patent applications entailed that risk, but more so those concerning instruments because in that case there was little or no difference between models and the actual invention.

The open distrust that inventors and instrument makers had for each other extended to state officials. Harrison was notoriously reluctant to disclose his “H4” clock to the officials of the Board of Longitude prior to the award of the prize, and the artisan who took the telescope to the Venetian Senate refused to have the construction of his device inspected. (Had the telescope maker known that the technical advisor charged by the Senate to inspect the instrument was Paolo Sarpi — one of Galileo’s closest friends — he would have toasted to his own foresight.¹⁴⁷) Other inventors were equally guarded when approaching scientific academies for approval of their devices (as required in France) or to seek endorsements that, while without legal status, could have helped patent or advertise their instruments. In January 1695 Daniel Quare showed his portable barometer to the Royal Society before applying for a patent (which he received the following August). But while receiving an affidavit about the novelty of his barometer, he “desired to be excused from Discovering the Secrets thereof”.¹⁴⁸ Hooke too came to develop a profound distrust of the Royal Society’s registration system during the 1675 dispute over the English patent of the spring watch.¹⁴⁹

Over and over, instrument makers tried to demonstrate reduction to practice while simultaneously avoiding disclosure. Although such a conduct was perfectly in line with the requirements of the privilege system (which cared little about disclosure),

reduction to practice and disclosure could not be easily kept apart during the patent application process. Fearing a loss of priority, Huygens carefully avoided any publication of his spring watch before receiving a French privilege for it. But while he was able to control leaks on that side, he got very close to losing the privilege to the very clockmaker he had hired to produce a working sample to be filed with the privilege application in order to fulfil the reduction to practice requirements.¹⁵⁰ Like modern scientists who see their work plagiarized as a result of filing grant applications or submitting manuscripts to peer-reviewed journals, early modern instrument makers could come to learn that, because of the specific material features of their devices, the process of patent application could destroy the very thing they were trying to protect.¹⁵¹

Far from being driven by socio-cultural values of secrecy, these inventors seemed to have a good understanding of what they were gambling with, and how. They feared, with reason, the accidental or fraudulent disclosure that could result from applying for patents or for endorsements by academies. Explicit protocols are in place in today's patent offices to prevent examiners from helping themselves to the knowledge disclosed in applications, but that was not the case in early modern Europe. It is startling to see, for instance, that at the same time that the Royal Society was casting itself as the most trustworthy international repository of priority claims, it was also discussing, at its public meetings, the contents of intriguing patent applications that Sir Robert Moray, a member and prominent courtier, happened to have taken home from work.¹⁵²

The peculiarities of early modern patent disclosure may also cast a different light on the Royal Society's "History of Trades" project. As a way to facilitate its planned survey and publication of trade and industrial practices in the 1660s and 1670s, the Society tried (and failed) to develop a reward system that could give artisans credit for their knowledge and know-how in exchange for its disclosure and publication.¹⁵³ One proposal was to pay artisans for disclosing their secrets.¹⁵⁴ Another was to trade disclosure for patents. At the 22 April 1663 meeting, Boyle was asked to inform an artisan whose invention had been shown to the Society that its members

were pleased with this skill of his, and that they were willing to assist him in procuring a patent for him, in order that he might enjoy the benefits of his art, upon condition that he should acquaint them with the secret.¹⁵⁵

It is not surprising that the Society would want to offer 'patent agent' services in exchange for technical secrets (and perhaps a share of the patent).¹⁵⁶ It had patent-facilitating court connections (which the artisan wanted but did not have) and the artisan had secrets (which the Society wanted but did not have). But by the very act of proposing this *quid pro quo*, the Society was also acknowledging the nature of the obstacle faced by the History of Trades project.

It was not that artisanal culture opposed public disclosure, but that inventors were not required to disclose in order to receive a patent. *That was a legal issue, not an ethico-cultural one.* Had privileges required the same standards of disclosure we find

in modern patent law, the Royal Society would have probably been satisfied to let artisans patent their knowledge, as that would have produced disclosure through the application process. But because privileges granted monopolies while not requiring public disclosure, they could render patented knowledge even less accessible than knowledge that had not been patented but simply kept secret.¹⁵⁷ (The privilege system, in fact, is better comparable to modern trade secrets law than to modern patent law.¹⁵⁸) The solution was to entice artisans to patent *and* disclose by offering them patenting services in exchange for public disclosure.

In those cases in which public disclosure was deemed important (or practically unavoidable), the prince or the state relied on prizes or pensions, not patents. Instruments could be rewarded in this manner. The French pension awarded to Daguerre for the invention of photography in 1839 is such an example.¹⁵⁹ Similarly, the English Longitude Act of 1714 promised £20,000 to the person able to find the longitude with a certain precision. While John Harrison's "H4" clock did eventually earn him the prize, the device is nowhere to be found in English patent rolls.¹⁶⁰ Along the same lines, Moray tried to convince Huygens in 1665 that he might get more from his marine pendulum clock by asking Louis XIV for "a good reward for the disclosure of the invention rather than a privilege".¹⁶¹

PECULIARITIES OF "PRIOR ART"

It did not seem to matter that the inventions being patented had already been represented in texts or images — a fact that runs counter to our modern expectations about publications counting as "prior art" against a subsequent patent application. The publication of an invention did not count as disclosure because what concerned the privilege-granting authorities was not whether the idea of an invention might have been known, but whether the invention itself had already been put to work in their jurisdiction. While modern patent law recognizes the right to patent to the person who was either first to invent or first to file an application, early modern privileges treated the inventor as the person who first reduced it to practice or made it available for sale. The water-driven silkmill was represented in Vittorio Zonca's 1607 *Novo teatro di machine et edificii* well before most the related patents were granted, and Giuseppe Ceredi was issued privileges for the Archimedean screw in various Italian states in the 1560s despite the abundant textual evidence of "prior art" stretching back to Antiquity.¹⁶²

Privileges did not cover abstract notions such as the conception of a given machine or process, or what modern copyright law calls the author's "personal expression" embedded in a text or other mediums. They only protected specific objects: books as books and machines as machines. Privileges could indeed protect a machine and a book about that same machine, but did so by treating them as two different objects. Modern intellectual property law would protect the machine and the book with two different legal devices (patent and copyright) but would also consider the machine and a book about that machine as connected by a knowledge link — a form of disclosure. Called "prior art", the existence of that link would prevent the patenting of

that machine. The privilege system, however, did not have the categories to make that link thinkable. A book about a machine or an instrument protected neither the “idea” of that machine nor the writer’s “personal expression” involved in the description of such a machine. Because there was no legally recognized intellectual property relation or disclosure nexus between text and machine, a book about that machine could not count as prior art in the context of its possible patenting.

This means that printed books about instruments (discussed later in this essay) could neither constitute legal intellectual property claim in those instruments nor prevent the patenting of those same instruments by either the author of the book or anyone else. A book written by an artisan on his instrument could reinforce the authorial relationship between maker and instrument, but did not make it legally enforceable in any sense. If the instrument was not covered by a privilege (as it very rarely was) the book could facilitate not only its unauthorized (but fully legal) copying but even its patenting (by someone else) by providing information about the instrument.

Marcus Popplow has shown that several early modern machine books disclosed technologies for which the author had either privileges that had expired by the date of the book’s publication, or valid privileges covering the countries where the book was expected to circulate.¹⁶³ In the first case, the book advertised the author’s technical skills (in the hope of attracting professional offers), while in the second it advertised the machines themselves. But unless the author had patents for those machines (or knew that he could no longer obtain patent protection) publishing a book on a machine or an instrument would have been like shining light on a sitting duck.

That such obvious risks did not stop mathematical practitioners from writing many books describing (often in great detail) the construction and use of astrolabes, staves, quadrants, rulers, sectors, compasses, dials, and land-surveying instruments suggests that, for reasons that we need to explain, Renaissance instrument makers did not see the patenting of their instruments as particularly useful. What is even more striking is that, in many cases, they did not patent their instruments even when they had no access to other kinds of protection such as those provided by guild membership.

(MIS)MATCHING INSTRUMENTS AND PRIVILEGES

Privileges for inventions were reasonably efficient at protecting objects that were large, hard to move, easy to track, expensive to copy, and difficult to operate — scenarios where the overlap between the invention and the business built on it were most extensive. For the same reasons, privileges were less effective with small objects that could be moved in and out of the area covered by the privilege, were hard to detect when transported, relatively easy to copy, and did not require specialized knowledge to use. Windmills and steam engines epitomize the first category, while books exemplify the latter. Instruments oscillated between the ‘machine pole’ and the ‘book pole’ depending on their specific material features and markets.

The large astronomical instruments of Tycho Brahe or of Duke Wilhelm IV of Hesse-Kassel were as “portable” as small mills, while pocket sundials could match the mobility of octavo books. The reproducibility of some optical instruments could

be compared to that of complex machines. Copying them could be difficult to the point of making legal protection unnecessary, as shown by Fraunhofer's decision to keep his prized achromatic lenses clear of the patent office.¹⁶⁴ By contrast, sectors, clocks, or computing machines with exposed lines and gears could be easily copied, sometimes more easily than books.¹⁶⁵

With notable but limited exceptions, we can say that instruments clustered close to the 'book pole' in the sixteenth and early seventeenth centuries (especially mathematical instruments) while swinging toward the 'machine pole' in the eighteenth century. Staves, squares, dials, sectors, Napier bones, and astrolabes were portable devices that (unlike later air pumps, electrical machines, and the like) could be copied, shipped, or smuggled almost as easily and cheaply as books.¹⁶⁶ Unlike their sophisticated eighteenth-century cousins, early telescopes too were deemed easy to reproduce and thus denied patents both in the Netherlands and in Venice — a place where, it seems, almost anything could be patented.¹⁶⁷ And because they could be easily disassembled and shipped as a pair of lenses, early telescopes could have moved easily in and out of areas covered by patents (had they received any). The massive smuggling between Switzerland and France in the eighteenth century of watches mixed into fish shipments from Geneva, shows that some instruments could travel even better than books.¹⁶⁸

But if certain instruments, especially mathematical ones, were comparable to books in terms of mobility and reproducibility, the limited size of their market and of their production runs was too marginal to justify the costs of a privilege application. Indeed, before 1600 there were only a few cities in Europe where instrument making could be a full-time profession, for a handful of people. Furthermore, patenting expenses were high in some countries (with the exception of the Hapsburg empire, which might help to explain the anomalously large number of instrument patents found there around 1600).¹⁶⁹ The pendulum clock patent obtained by Royal Society in 1664 included many heterogeneous inventions because, as Moray relayed to Huygens: "Patents are very expensive here, but at least we can put a hundred different things in the same patent."¹⁷⁰ (Huygens's response that in the Netherlands he had "obtained them at little cost but most of the times gratis" reflected the power of his father's connections more than the actual costs of patenting on the Continent.¹⁷¹) Patenting fees remained high in England in the eighteenth century — around £100 in 1750.¹⁷² That was about twice the annual salary of a skilled London artisan.¹⁷³ Although the English instrument market was already substantial by the time Dollond patented his achromatic lenses in 1758, he could not afford the patenting expenses and (like several other instrument makers) took in a partner for that purpose.¹⁷⁴

Some instruments, therefore, were caught between a rock and a hard place. Their mobility and material features made them as difficult to protect as books, while the marginality of their market prior to 1700 did not make obtaining and enforcing privileges look like a viable business strategy. As I discuss in a subsequent article, similar issues can be found behind Galileo's decision not to seek a patent for his geometrical and military compass.¹⁷⁵ But as soon as he realized that the satellites of

Jupiter he had just discovered (with the telescope) could function as astronomical clocks to solve the very expensive problem of longitude determination, he quickly tried to enter into patent-like agreements with the Spanish and the Dutch.¹⁷⁶ In doing so he joined the longitude ‘bandwagon’ which was responsible for such a large share of all early modern instrument patents.

However, this does not mean that, operating beyond the reach of legal protection, all instruments close to the ‘book pole’ ended up causing the financial ruin of their makers. For sure that was not the case with clocks, watches, or ivory sundials. The mobility and reproducibility of these instruments did make them hard to protect, but their substantial market allowed for the development of specialized guilds (such as those established in London and in Nuremberg) that provided protection, if only locally. The presence of a sizeable market also explains the many patents for clocks and watches that were issued later on, when the power of the guilds declined. Things did not look too bad at the other end of the spectrum either, that is, among the makers of expensive ‘one-off’ instruments. Most of the early modern gilded brass instruments we admire today in science museums did not suffer intellectual property troubles.¹⁷⁷ Custom made and often gorgeous, these instruments shared in the luxury goods economy of high-end artisanal and artistic products. As such, they had little need for patents.

IN THE BEGINNING WAS PRINT

With these issues in mind, we should look at a deceptively inconspicuous market for instruments — one that was parallel to, but radically different from, the one occupied by expensive custom instruments. Many mathematical instruments that circulated in this market were identical to their expensive brothers (and could in fact be produced by the same makers), except that they were made of paper. Furthermore, they were protected not by patents but by the kind of privileges that covered books and prints.¹⁷⁸ These were astrolabes, logarithmic scales, squares, sundials, quadrants, and globes printed on book pages from woodcuts or, more frequently, from copper plates.

After purchasing such books, readers would cut out the paper templates (about nine for an astrolabe), glue them on cardboard, pasteboard, or wood, and then assemble the various parts. These instruments were much cheaper than their metal siblings, but the cost of their protection was marginal. In larger European cities, printers belonging to guilds were automatically granted printing privileges if their manuscripts or images were approved for publication by the licensers. Because these instruments were highly perishable and more likely to be used than collected, they have left very little direct evidence about the size of their markets. Still, if we put together the range of paper instruments still extant with what we know about the size of early modern print runs, we can guess that thousands of these instruments were produced in the sixteenth and seventeenth centuries.¹⁷⁹ Books carrying these instruments were published in various countries — in Latin or vernacular languages — thus aiming at a wide range of audiences. We know little, however, about the contexts of use of these paper instruments.

In the eighteenth and nineteenth centuries they became used mostly as pedagogical tools, but in earlier periods they were treated as working instruments as well. It has been argued that it was in paper form that astrolabes and other instruments were mostly known and used in the sixteenth and early seventeenth centuries.¹⁸⁰

The existence of parallel markets for paper and metal instruments was made possible by the range of skills typical of mathematical instrument makers. If the production of eighteenth-century instruments required the integration of skills from different trades (turners, clockmakers, glass workers, etc.), sixteenth-century mathematical instrument makers were overwhelmingly located in the printing trades. The same people who produced instruments also cut copper plates for geographical maps, anatomical tables, or any other kind of illustrations. They also printed charts, globes, paper instruments, and of course books — some of them about their own instruments. They cut fonts too. Apian, Regiomontanus, Gemini, Hartmann, Danfrie, and Danti are just a few examples of a community for which printing and instrument making were merely two aspects of the same business.¹⁸¹ In the eyes of these early makers, the great divide we have come to assume between printed matter and machines boiled down to a mundane choice between materials, not between different bodies of knowledge and techniques. As Bennett has put it:

A solid, dense medium is worked on with an engraving tool. If the final product is to be in brass or wood, the instrument is created directly by application of the tool; if it is to be paper, there is an intermediate stage where a print is pulled from a block of wood or a plate of copper. The designs and constructions of practical geometers, the cutting of wood-blocks and copperplates, the printing of books, of maps, of paper instruments on separate sheets, were all related activities that we find difficult to integrate but whose relationship in the sixteenth century is evident in the careers of many mathematicians.¹⁸²

Such a seamless overlap was no news to sixteenth-century buyers who were in fact quite accustomed to look for and purchase both metal and paper instruments in bookstores.¹⁸³

Typically, paper instruments books would include not only the printed templates for the various parts of the instrument, but also instructions about how to assemble and use the device. Peter Apian's 1533 *Instrument Buch* included two sets of identical prints so that the reader would be left with an illustrated instruction manual even after cutting out and pasting the instruments.¹⁸⁴ That about three-fourths of the extant copies lack the second set of prints suggests that most of the book's owners built (or tried to build) the instruments.¹⁸⁵ In his *Folium populi* — a large dial printed on a full folio page — Apian added a description of how to wet the unusually large print with a sponge for several hours so as to transfer it onto its final material base without deformations.¹⁸⁶ Sometimes paper instruments seem to have been included as 'added value' to books that were primarily aimed at teaching practical mathematics, as in Seth Partridge's 1648 *Rabdologia*, where the readers were instructed to make their own logarithmic rulers by cutting out the illustrations and paste them on wooden

rods — a practice already promoted a few years earlier in Edmund Wingate’s book on the same topic.¹⁸⁷ But if the paper instrument was of a well-known type, it might be sold as an individual print (or as a preassembled paper instrument) rather than as part of a book. That appears to have been the case with the astrolabe issued in 1578 by Philippe Danfrie — the leading French maker of both paper instruments and ‘high-end’ metal devices at the time.¹⁸⁸

The use of print to produce instruments was not limited to flat mathematical instruments. In the same years (and regions) that saw the emergence of paper instruments we also encounter the first printed paper globes — terrestrial (in 1507) and celestial (in 1517). This was a dramatic departure from traditional globes produced by engraving maps directly on large brass spheres. Perceived as ‘boundary objects’ between instruments and maps, globes provide excellent food for thought about intellectual property. They could be protected either with printing privileges (as printed maps) or privileges for inventions (as tridimensional objects).

Imperial and Dutch patent rolls contain several patents for globes — such as those awarded to Gemma Frisius and Gaspar van der Heyden in 1531 and 1536–37, and to Gerard Mercator in 1541.¹⁸⁹ But the globe contained in Johannes Schöner’s *Luculentissima quaedam terrae totius descriptio* of 1515 was protected as a print, as stated by the privilege granted by Emperor Maximilian: “No one is to print or have printed these books *with the cosmographic globes.*”¹⁹⁰ Analogous wording is in the privilege granted by Emperor Charles V to Franciscus Monachus’s *De orbis situ ac descriptione* — the first cosmographical text with paper globe printed in the Netherlands around 1526.¹⁹¹ My guess is that Schöner’s and Monachus’s globes were covered by printing privileges because they came as an appendix to a book, while Gemma’s 1536–37 printed globes — being sold already mounted on wooden spheres — were treated as “machines”. Adding yet another twist to such boundary crossings, English patents rolls (not book privileges) list several globes but make no distinction between those printed on paper and those engraved on metal.¹⁹² They are both treated as inventions.

Like instrument makers, globe makers could be also printers and engravers able to produce metal instruments and globes as well as the plates from which to print paper instruments and maps. Globes were printed as flat maps (first from woodcuts and then from engravings) in the shape of gores (usually twelve of them, each covering 30° of longitude) and then cut out, applied on wooden spheres, and sometime hand-painted.¹⁹³ Books that included these gores (like those that delivered paper instruments) also taught the readers to use the instruments that were to be assembled from these paper strips, in this case by instructing them in geography and cosmography.¹⁹⁴ As with paper instruments, the shift from metal to print greatly expanded the market for globes by dropping their price while increasing productivity by a couple of orders of magnitude.¹⁹⁵ The size of editions could easily climb into the hundreds for larger globes and in the thousands for smaller ones, thus matching those of books and sometimes exceeding them.¹⁹⁶

What makes paper instruments and globes so relevant to discussions of intellectual

property is not only that they could be covered by either patents or printing privileges, but that they constituted multiple and virtually identical copies pulled from the same plate. Furthermore, most mathematical instruments were already metal plates with divisions, retes, and other lines engraved on them. Which means that, were it not for the left–right inversion produced by printing, one could have conceivably pulled paper copies directly off most metal instruments. Paper instruments and globes, therefore, were the first instruments in the age of mechanical reproduction — well before the introduction of industrial production techniques of the eighteenth century. In this context, the printing press functioned not as a technology for the mechanical reproduction of images and texts, but rather as the first industrial method for the serial production of paper-based mechanical devices. These devices, however, could be protected by printing privileges, not patents.

While these examples confound, in interesting ways, boundaries between instruments and texts, they also confirm the pedagogical role shared by books and paper instruments. It is well known that paper instruments and paper globes could come with books teaching their readers how use them, and that, in turn, those instruments could function as pedagogical tools for teaching practical mathematics. But to buy a book that taught how to assemble and use an instrument was not like buying a grammar book. As little mathematical education was provided by the university, instrument books should be seen not as textbooks connected to established schools and curricula but rather as part of ‘distance learning’ packages that provided both textual instruction and related material teaching tools. This means that pedagogical goals were coupled to tactics for the marketing of instruments, makers, and teachers. These books, in fact, were not simply aimed at selling paper instruments and instructions but also at expanding the market for instruments by training their buyers. That paper instruments were cheap meant not only that they sold in greater numbers, but also that they could reach first time buyers — people who, knowing little about mathematics and instruments, would not have been likely to buy brass instruments or hire a tutor.

The point is that, no matter how much paper instruments may look like free standing, industrially manufactured instruments one could literally buy off the shelf, they were, in fact, objects entangled in a variety of relations.¹⁹⁷ It is not clear, for instance, that all those who bought paper instruments could actually assemble them or, once assembled, could learn how to use them by reading a book. This means that at least some of these readers-buyers ended up in an instrument maker’s shop to have their paper instrument assembled, fixed, or perhaps upgraded to metal ones. It is equally likely that other readers ended up taking tutorials from mathematical practitioners whose names, perhaps, they picked up in instrument shops or bookstores. In sum, while one could view paper instruments almost as consumer commodities circulating in a modern-looking economy of multiples protected by intellectual property (even before patents had become commonly applied to instruments), they could also be seen as ‘cheap bait’ to attract buyers into a traditional, labour-intensive economy of artisanal and pedagogical services.

These tensions help to explain a genre of publications that would otherwise seem paradoxical from the point of view of intellectual property: the sixteenth- and seventeenth-century “*usus et fabrica*” books.¹⁹⁸ Written by mathematical practitioners in England, Germany, France, and Italy, these books taught readers from a variety of socioprofessional groups the construction and use of instruments in great detail, and in a variety of languages. For example, John Palmer’s 1658 *The Catholique planisphaere* — a book on Gemma Frisius’s astrolabe — instructed readers eager to construct the instrument that “the Mater ... must be well-polished: but it may very well be made of a fair past-board, pasted on a Massie board: for thereon the Lineaments may be distinguished with inkes of several colours, which cannot be if it be made in metall”.¹⁹⁹ The instructions remained detailed throughout the book: “Then with your Graver [a tool] you shall make there the shape of a Star”, or “The cutting of this Network [rete] requires much labour and care. Be sure you use no punches nor Chisils, nor adventure to stamp your figures, lest you spoile all. But get your Gravers Drils and Files...”²⁰⁰

Detailed descriptions like these are quite common in the genre, making it seem that the “*usus et fabrica*” books are out to defy assumptions about both artisanal secrecy and economic logic.²⁰¹ While paper instruments books sold the devices they disclosed, the “*usus and fabrica*” books taught how to build instruments they did not even sell. And did so with a level of detail that exceeds both late eighteenth-century patent specification requirements as well as the conventions of ‘virtual witnessing’ of seventeenth-century natural philosophers.²⁰² Clues to the specific economy in which these books circulated come from their tendency to inform the readers about where they can purchase the instruments whose construction and use they describe.²⁰³ Also telling is the fact that these authors rarely refer to themselves as the suppliers of these instruments, although they might occasionally offer their services as tutors to those readers who may not have fully grasped the “*usus*” part of the book.²⁰⁴

For instance, Ottavio Fabri’s 1615 *L’uso della squadra mobile* mentions that the instrument (whose construction the book describes) can be competently made by Master Battista, the clockmaker in Venice’s Spaderia quarter, but also by Master Enea Sartis, son of Master Christopher.²⁰⁵ Similarly, Edward Worsop’s 1582 *A discoverie of sundrie errors and faults daily committed by lande-meaters...* informs the readers that

Scales, compasses, and sundry sorts of Geometricall instruments in metal, are to be had in the house of Humphrey Cole, neere unto North dore of Paules, and at the house of John Bull at the Exchange gate: in wood at John Reade in Hosier Lane; at James Lockerson’s dwelling neer the Conduite at Dowe Gate, and at John Reynolds at Tower Hill.²⁰⁶

Typically, the author of a “*usus et fabrica*” book was a mathematical practitioner. While this figure is encountered (plus or minus some local traits) in most European countries after 1550, it has been studied in greater detail in England, where many of the “*usus et fabrica*” books were published. The wide range of professional activities

of the “mathematicalls” included managing technical projects, instrument design (but rarely construction), and teaching (either through books, lectures, or private classes).²⁰⁷ As shown by Turner and others, the demand for education in practical mathematics and instruments use grew among gentlemen in the late sixteenth and seventeenth centuries.²⁰⁸ Some of the “mathematicalls” were gentlemen themselves (Digges or Blagrove are examples) while others styled their texts to make them (and their authors) palatable to upper-class audiences and students.²⁰⁹ For instance, one of these “usus et fabrica” books — Thomas Hood’s 1592 *The use of both the globes, celestiall, and terrestriall* — is staged as a dialogue between a polite mathematical practitioner and an equally polite student who wants to learn cosmography so as to be able to say the right things in the right places:

My desire is to be instructed by you in the use of the Globe: and that so much the rather, because lately ... there have bin two Globes set forth, and for so much as they are now in the handes of many with whome I have to do, I would not be altogether ignorant in those matters.²¹⁰

Writing about instruments one had not produced was a practice that went hand in hand with the near-gentlemanly image the mathematical practitioners wished to project.

But while one could think that the “mathematicalls” were fashioning themselves as gentlemen at the expense of the instrument makers whose trade secrets they were so thoroughly disclosing, we have no evidence that the makers actually saw things that way. Practitioners and makers seemed to have developed a symbiotic (rather than adversarial) relationship. The former wrote about instruments, taught them, and made them more socially acceptable, while the latter made and sold them. Both practitioners and makers were trying to spread their small markets through publishing and teaching or by selling instruments, including cheap paper ones.

The frequent inclusion of instrument makers’ names and addresses in the books authored by the “mathematicalls” should not be seen as a form of direct advertisement, but rather as a modest attempt to expand the overall market.²¹¹ We should take seriously Worsop’s remark that “I have thought good to give advertisement hereof, because many who that would provide such things knowe not where to have them”.²¹² Unable to find a supplier, potential buyers and students could have simply drifted away. And that would have been bad for both the “mathematicalls” and the makers.

As we have seen, the case of paper instruments and globes has very intriguing intellectual property implications. But we should not put too modern a gloss on it, casting these instruments as copies of an authorial original protected by something like a “copyright”. Printing privileges did indeed protect the makers of paper instruments and globes as well as the authors of the “usus et fabrica” books. But, in the end, both makers and mathematical practitioners made a living primarily from the labour, services, and the other products they bundled together with the prints of instruments and globes, or with mathematical textbooks. That is why disclosure was not particularly damaging in “usus et fabrica” books and paper instruments alike.

Still, these arrangements may relate directly to intellectual property issues, though

not of the kind found in legal textbooks. The recent success of free software and open source models has shown that profitable knowledge-intensive businesses do not need to be rooted in the ownership of intellectual property. For instance, people may provide access to software without payment while earning a living by charging for assistance, maintenance, and documentation.²¹³ This model seems to match some key elements of the economy of instrument makers and mathematical practitioners around 1600. Like open source code, the overwhelming majority of paper or metal instruments were not protected as intellectual property although they circulated in a commercial rather than non-academic environment. And like open source code, these instruments were copied, circulated, ‘patched’ and developed by a variety of practitioners. While it is true that instrument makers received income from making and selling instruments (unlike modern hackers who neither buy nor sell their code), intellectual property concerns were not central role in their businesses. The open source model fits the mathematical practitioners even better: they designed instruments but made a living by publishing and teaching their operations, that is, by assisting their users.

MAKING A LIVING V. PROTECTING PROPERTY

It seems that today the notion of “making a living” or “having a career” in knowledge-based fields is becoming increasingly equated to the protection and development of one’s intellectual property. This view is often internalized by historians of science and technology who then tend to ask what tools for the protection of intellectual property were available to the historical actors. Some of the questions asked in this essay, I admit, do not escape that kind of anachronism.

But it is one thing to start with an anachronistic question, and another to end up with anachronistic conclusions. Perspectives grounded in contemporary notions of intellectual property seem to apply reasonably well to late eighteenth-century scenarios that, at least in England, already bear a family resemblance to modern contexts: instruments were produced in a semi-industrial fashion, instruments were patented, patents were used as business tools, patents were litigated, etc. But the complexities of earlier scenarios, the peculiar logic of the privilege system, and especially the evidence provided by the “*usus et fabrica*” books and the production of paper instruments and globes shows that, in these contexts, ‘intellectual property’ can be invoked only as a short-hand designator, not a legal doctrine. Depending on their uses and material features, instruments were entangled in so many different economies that it would seem hopeless to try to fit them within one specific intellectual property framework. If, as legal scholars teach us, property is a “bundle of rights”, it would take a very large bundle to hold together all the ways in which instruments were protected in early modern Europe. The evidence, I believe, also shows that the traditional distinction between secrecy and openness, between philosophical and artisanal ethos needs to become substantially more nuanced to be able effectively to describe the movement of instruments and knowledge about instruments.

The search for evidence about the patenting of instruments has been rewarding

by forcing questions not only about what makers did when they patented, but also about what they did when they did not patent. Even more importantly, tracing such questions has ended up uncovering what early modern patents were not. It is not that early patents were basically like modern patents except that early patentees had a tendency to be foreigners. The difference is substantially more radical: privileges were primarily aimed at establishing manufactures or making machines and skilled bodies move across geographical and political boundaries, but not about protecting intellectual property rights vested in an author.

Thinking of the intellectual property features of early modern instruments by placing them on the continuum between the ‘book pole’ and the ‘machine pole’ is, I think, also heuristically useful. But such a spectrum should not be recoded as a trajectory or, worse, as a progressive path toward the ‘machine pole’ leading to the inevitable widespread patenting of instruments. While some of the evidence about early modern instrument making resonates with standard narratives about the industrial revolution — larger non-local markets, bigger workshops, increased division of labour, capital investments, and patenting — such analogies may be shallower or more limited than they seem. Most of trends discussed here, in fact, have to do with the material features of specific instruments, their markets, mobility, and reproducibility in certain places at certain times. It is by no means automatic to recast such trends as a chapter in the industrial revolution. For instance, it is worth asking what scenarios would have come into being had the determination of the longitude not been the crucial international commercial and military problem it was, and had it not created such a large market for certain kinds of instruments. Quite possibly, the history of early modern instrument patenting might have looked like little more than the history of eighteenth-century clock and watch patenting in England.

This essay opened with a question concerning the changing nature of the credit attached to instrument making and design — its oscillations between credit systems based on priority and publication (rewarded with philosophical credit), and those based on the exchange of objects or labour for money. Several pages later, we see that not only did instruments move back and forth between these two credit systems, but they also moved, materially and legally, between categories of books and machines as well as across the boundaries we now place between copyrights and patents. Instruments were not so much the well-delineated objects contemplated by intellectual property law, but rather moving nodes in networks of relations among makers, designers, users, collectors, and teachers. I find no good reason to believe that things have changed much since then.

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 14. On the Venetian case see Brown, *The Venetian printing press* (ref. 9), 50–72, 92–95. The farming out of the licensing process to the Printers’ Guild (or equivalent bodies such as the Stationers’ Company in London) is found in France and England as well.
 15. See the charts and globes by Harris, Senex, and Wilson patented on 7 July 1721 (*AIPI*, 252, 508, 625) and Haywood’s and Jefferys’s 17 November 1775 patent for non-cartaceous globes (*ibid.*, 260, 302).
 16. Cases in which the fit between legal categories of intellectual property and techno-scientific products has been either unclear or problematic include Daniel Kevles, “Of mice & money”, *Daedalus*, cxxxii (2002), 78–88; Sheldon Halpern, Craig Allen Nard, and Kenneth Port, *Fundamentals of United States intellectual property law: Copyright, patent, and trademark* (The Hague, 1999), 11–16, 229–31; James Boyle, *Shamans, software, spleens* (Cambridge, MA, 1996), 97–107; Glenn Bugos and Daniel Kevles, “Plants as intellectual property: American practice, law, and policy in world context”, *Osiris*, vii (1992), 75–104; Jack Kloppenburg, *First the seed: The political economy of plant biotechnology, 1492–2000* (Cambridge, 1988); James Boyle, “Enclosing the genome: What the squabbles over genetic patenting can teach us”, <http://www.law.duke.edu/boylesite/low/genome.pdf>; Glenn Bugos, “Intellectual property protection in the American chicken-breeding industry”, *Business history review*, lxvi (1992), 127–68; Henry Fountain, “DNA ditties”, *New York Times*, 31 March 2002, “Week in review” Section (my thanks to Michael Papish for this reference).
 17. Berveglieri, *Inventori stranieri a Venezia* (ref. 9), 90. Of the few known instrument makers in Italy in the seventeenth century, several of them operated in Venice (Daumas, *Scientific instruments* (ref. 4), 63–67).
 18. Francesca Trivellato, “Scienziati, artefici, corporazioni e privilegi nella Venezia di tardo Settecento”, in Paola Massa and Angelo Moiola (eds), *Dalla corporazione al mutuo soccorso: Organizzazione*

- e tutela del lavoro tra XVI e XX secolo* (Bologna, 2004), 381–8. Part of Trivellato’s argument is that, by that time, the economic importance of glass production — especially of a technical kind like this — was not sufficiently important to the Venetian economy to justify a patent. On Selva see Alberto Lualdi, “La famiglia Selva, ottici del ’700 veneziano”, *Nuncius*, xvi (2001), 531–46. Lualdi does not focus on the issue of the patent, but indicates that Selva did not actually make flintglass, but managed to produce excellent achromatic telescopes with flintglass imported from England.
19. Blaise Pascal, 1649, “Arithmetical machine” (Michel Guern (ed.), *Pascal, Oeuvres complètes* (Paris, 1998), ii, 346–8); Christiaan Huygens, 1665, “Seagoing clocks” (*HOC*, xvii, 177, note 6); Christiaan Huygens, 1675, “Spring watch” (*HOC*, vii, 419–20); Père Cherubin, 1670 (c.), “Binoculars” (Daumas, *Scientific instruments* (ref. 4), 74; Cherubin D’Orleans, *Effets de la force de la contiguité des corps ...* (Paris, 1688), 413–14). Early modern French patents were issued by different administrative bodies and no comprehensive patent rolls have been published for the ancien régime. Archival research may uncover several more instrument patents than those listed here.
 20. Pablo Pérez, “Los inventos llevados de España a las Indias en la segunda mitad del siglo XVI”, *Cuadernos de investigación histórica*, vii (1983), 35–54, pp. 46–47. On Spanish longitude prizes see Derek Howse, *Greenwich time and the discovery of the longitude* (Oxford, 1980), 10–12. By contrast, Spain had substantial patenting activity in other areas of technology during the sixteenth and early seventeenth centuries (Nicolas García Tapia, *Patentes de invención españolas en el Siglo de Oro* (Madrid, 1990)).
 21. Hubert van Houtte, *Histoire économique de la Belgique à la fin de l’ancien régime* (Gand, 1920). Rolls from the 1515–80 period are in Doorman, *Patents for inventions in the Netherlands* (ref. 10), 81–89.
 22. Creutz, “Die Herausbildung des Erfindungsschutzes in Sachsen im 15. und 16. Jahrhundert” (ref. 11), 109.
 23. Hulme, “The history of the patent system under the Prerogative and at Common Law: A sequel” (ref. 10), 51. The grant’s title suggests that the patent concerns mathematical instruments, but its description indicates otherwise: “Another water-rising device, obtained by ‘long and painful study of the mathematical sciences’ by the petitioner, a Cambridge Master of Arts.” The term “mathematical instrument” is found in an April 1706 patent concerning a gearbox, thus indicating its broad semantic range (*AIPI*, 379).
 24. Worcester, Edward, Marquis of, #131, 8th February 1661, “Making a watch or clock to go for several weeks without spring, chain, or other method of winding-up” (*AIPI*, 637).
 25. Smethwick, Francis, #149, 14th May 1666, “Grinding optical glasses in figures which are not spherical”, and Quare, Daniel, #342, 2nd August 1695, “Making a portable weather-glass or barometer” (*AIPI*, 523, 463). Smethwick’s and Quare’s instruments were submitted to the Royal Society for approval (Bryden and Simms, “Spectacles improved to perfection and approved of by the Royal Society” (ref. 4), 2–3, 31–32). Contrary to what we find in eighteenth-century France, such submissions had no direct legal relevance to the patent application process.
 26. Michael Hunter, *The Royal Society and its Fellows, 1660–1700* (Chalfont St Giles, 1985), 70, 200.
 27. David Landes, *Revolution in time* (Cambridge, MA, 1983), 147–8; *AIPI*, 155, 184.
 28. *AIPI*, 572. This is what became known as the “cylinder escapement” perfected by Tompion’s assistant and successor, George Graham (R. W. Symonds, *Thomas Tompion: His life and work* (London, 1951), 242).
 29. Pohlmann, “The inventor’s rights in early German law” (ref. 10), 135–9.
 30. On Josua Habermehl see Ernst Zinner, *Deutsche und Niederländische astronomische Instrumente des 11. – 18. Jahrhunderts* (Munich, 1967), 346–6.

31. The patent might relate to Bürgi's instrument reproduced in J. A. Bennett, *The divided circle* (Oxford, 1987) at p. 46. On Rueckert see Zinner, *Deutsche und Niederländische astronomische Instrumente* (ref. 30), 239, 331, 604.
32. I have not been able to find any information about Elias Huetter or Melchior and Caspar Strobel. The Imperial rolls list Huetter as having received three patents from 1582 to 1595 for a hydraulic device, a gun-lock, and a planetarium (Pohlmann, "The inventor's rights in early German law" (ref. 10), 137–8). The range of these inventions suggests that he might have been an investor rather than a maker.
33. By the time he received the patent in 1602, Bürgi was not yet in Rudolph's employ but he was well known to the Emperor for the work he had done for Duke Wilhelm IV of Hesse-Kassel. Bürgi moved to Prague in 1603. On Markgraf see H. von Bertele and E. Neumann, "Der kaiserliche Kammeruhrmacher Christoph Margraf und die Erfindung der Kugellaufruhr", *Jahrbuch der kunsthistorischen Sammlungen in Wien*, lix (1963), 39–98, which reproduces the privilege at pp. 94–96, and various images of his clock-based automata. More images are in Kunsthistorisches Museum Wien, *Prag um 1600: Kunst und Kultur am Hofe Kaiser Rudolfs II* (Vienna, 1988), ii, 262–4. Some of Markgraf's instruments owned by Rudolph are listed in Beket Bukovinska, "Scientifica in der Kunstkammer Rudolfs II", in John Robert Christianson *et al.* (eds), *Tycho Brahe and Prague* (Frankfurt, 2002), 270–5. On Schissler see Maximilian Bobinger, *Christoph Schissler der Ältere und der Jüngere* (Augsburg, 1954). The patent concerns Schissler senior.
34. MacLeod, *Inventing the Industrial Revolution* (ref. 10), 28–30. Eric Ash, *Power, knowledge, and expertise in Elizabethan England* (Baltimore, 2004), 33–34.
35. Nicolas García Tapia and Jesús Carrillo Castillo, *Tecnología e imperio* (Madrid, 2002), 79–112.
36. Père d'Orleans, *Effets de la force de la contiguité des corps ...* (ref. 19), 413–14. The privilege was awarded gratis.
37. Christiaan's father — Constantijn Huygens — was one of the most influential politicians in the Netherlands at that time. In the documents related to the clock and watch patents, Christiaan is often referred to as Constantijn's son. Pascal's case is comparable. The text of Louis XIV's letter patent makes apparent the King's respect for Blaise's intellectual qualities and mathematical skills, but it is also quite emphatic about Louis's friendship with his father — a royal official.
38. "Privilège pour la machine d'arithmétique de M. Pascal", in Guern (ed.), *Pascal, Oeuvres complètes* (ref. 19), ii, 346–8. The best discussion of the "Pascaline" is Guy Mourlevat, *Les machines arithmétiques de Blaise Pascal* (Clermont-Ferrand, 1988). Pascal's path to the patent is sketched out in Louis Lafuma, *Controverses Pascaliennes* (Paris, 1952), 105–20.
39. The privilege mentions that Pascal has already produced fifty somewhat different prototypes. It does so, I believe, to imply that the Pascaline comes in many shapes and forms — all of which, however, instantiated the claim covered by the privilege. Pascal's strategy, ratified by the text of the privilege, is to put forward a very general central claim that can be reduced to practice in many different ways — several of which have already been actualized in prototypes prior to the privilege application. By mentioning so many Pascalines already in circulation, Pascal also maximizes his chances of winning later infringement cases. With so many different prototypes in circulation, it would have been relatively easy to argue that many competitors had been inspired by them. Furthermore, that all of Pascal's prototypes were covered by the privilege would have given him the opportunity to argue that calculating machines by other people (whatever they might have been) resembled some aspect of one of his many Pascalines, and thus infringed on his privilege.
40. *HOC*, v, 254, 256–7, 264, 279.
41. Iliffe, "'In the warehouse'" (ref. 1), 45–46.
42. Examples of such strategies are in Achille De Rubertis, "Bernardo Buontalenti inventore di strumenti per mulini", *Rivista d'arte*, xii (1930), 555–63; Molà, "Artigiani e brevetti nella Firenze del

- Cinquecento” (ref. 11), 68. Galileo’s attempts to enlist the Medici’s help to secure printing privileges for the books published by the Accademia dei Lincei from other princes falls in the same category.
43. See ref. 7 above.
 44. Huygens applied for a privilege on 5 February and obtained it on 15 February (*HOC*, vii, 401, 419–20). English patents took about one to two months to issue (MacLeod, *Inventing the Industrial Revolution* (ref. 10), 76).
 45. On English inventors who pursued titles or employment in the royal service see MacLeod, *Inventing the Industrial Revolution* (ref. 10), 34. An example is Joseph Moxon whose newly designed globes earned him the title of “Royal Hydrographer”. Moxon’s inventions are not listed in the English patent rolls. Similarly, Thomas Bedwell did not patent his carpenter’s rule and gunner’s rule but managed to become the “Keeper of the Ordnance Store” at the Tower of London in 1589 (Stephen Johnston, “Mathematical practitioners and instruments in Elizabethan England”, *Annals of science*, xlviii (1991), 319–44). Johnston analyses Bedwell’s creative alternatives to secure his intellectual property in his instruments at pp. 327–8.
 46. Crawford, “Evidence from trade cards for the scientific instrument industry” (ref. 4) argues that patents were used as “badges of honour” in advertisement (p. 455), but lists only a few examples (Fenn (p. 505), Ould (p. 521), and Mcculloch (p. 516)). Later in the article the author acknowledges that such use was, in fact, relatively rare (p. 460). We also need to notice that only few of the patented instruments were advertised as such. A discussion of patents’ double role as business protection and advertisement later in the century is in Bertucci, “A philosophical business” (ref. 1), 47–49.
 47. Sorrenson, “Dollond & Son’s pursuit of achromaticity” (ref. 1), 36–38.
 48. Christopher Steadman, quoted in Sorrenson, “Dollond & Son’s pursuit of achromaticity” (ref. 1), 52, note 31.
 49. On the price increases see Sorrenson, “Dollond & Son’s pursuit of achromaticity” (ref. 1), 39. André Danjon and André Couderc, *Lunettes et télescopes* (Paris, 1935), 658 reports that in 1772 the price of achromatic telescopes went from 21 to 16 shillings/foot.
 50. The historiography on trademarks is quite limited but see Frank J. Schechter, *The historical foundations of the law relating to trade-marks* (New York, 1925).
 51. It seems that the vast majority of the instruments submitted to the Académie for approval — an early step in the patent application process — were actually never patented, suggesting that they were pursued as endorsements and badges of honour rather than as legal intellectual property titles. In a tightly controlled mercantilistic economy, titles issued by a royal institution like the Académie (and the connections they enabled) seemed more valuable than intellectual property. Examples are in Hahn, *Anatomy of a scientific institution* (ref. 12), 69–72, esp. p. 70; and Catherine Cardinal, “Ferdinand Berthoud and Pierre Le Roy”, in William Andrewes (ed.), *The quest for longitude* (Cambridge, MA, 1996), 282–92. Several of Berthoud’s and Le Roy’s instruments were submitted to the Académie’s approval, but were not patented. See also ref. 66 below.
 52. A. J. Turner, *From pleasure and profit to science and security* (ref. 4); and Maurice Daumas, “Le corps des ingénieurs brevetés en instrument scientifiques (1787)”, *Archives internationales d’histoires des sciences*, v (1952), 86–96.
 53. Two patents (one by the States General and one by States of Holland) were granted to Salomon Coster for Huygens’s first pendulum watch in 1657. Huygens took a patent (from the States General) in 1664 for his remontoir seagoing clock and two more (from the States General and States Holland) for the spring watch in 1675. Simon Douw took out two patents (from the States General and States Holland) for an improvement on Huygens’s 1657 clock. Douw’s patents were strenuously opposed by Coster and Huygens (Doorman, *Patents for inventions in the Netherlands* (ref. 10), 146, 147, 150, 153, 179, 180, 184).

54. Peter de Clercq, *At the Sign of the Oriental Lamp: The Musschenbroek workshop in Leiden, 1660–1750* (Rotterdam, 1997), 39.
55. Clock patents are also mentioned in the secondary literature about the patent system in Florence and Venice: Molà, “Artigiani e brevetti nella Firenze del Cinquecento” (ref. 11), 72; and Berveglieri, *Inventori stranieri a Venezia* (ref. 9), 21.
56. The absence of philosophical instruments from Dutch patent rolls is remarkable given the production of those instruments in the Netherlands.
57. Quare, Daniel, 2nd August 1695, “Making a portable weather-glass or barometer”, in *AIPI*, 463. The dispute between Quare and the London’s Clockmakers’ Guild over this patent is discussed in Joyce Brown, “Guild organisation and the instrument-making trade” (ref. 4), 32. On Quare’s interaction with the Royal Society see Bryden and Simms, “Spectacles improved to perfection” (ref. 4), 31–32.
58. John R. Millburn, “The Office of Ordnance and the instrument-making trade in the mid-eighteenth century”, *Annals of science*, xlv (1988), 221–93.
59. Crawforth, “Evidence from trade cards for the scientific instrument industry” (ref. 4), 474.
60. John Heilbron, *Elements of early modern physics* (Berkeley, 1982), 70; Daumas, *Scientific instruments* (ref. 4), 228–45; Anita McConnell, “From craft workshop to big business: The London scientific instrument trade’s response to increasing demand, 1750–1820”, *The London journal*, xix (1994), 36–53; Jim Bennett, “Shopping for instruments in Paris and London”, in Pamela Smith and Paula Findlen (eds), *Merchants and marvels: Commerce, science, and art in early modern Europe* (New York, 2002), 370–98; Gerard L’E. Turner, “The London trade in scientific instrument-making in the eighteenth century” in *Scientific instruments and experimental philosophy, 1550–1850* (Aldershot, 1990), 1–21; Bryden, “Evidence from advertising for mathematical instrument making in London, 1556–1714” (ref. 4), esp. pp. 322–36; Crawforth, “Evidence from trade cards for the scientific instrument industry” (ref. 4), 453–554. On the turn toward ‘industrial’ instrument making in eighteenth-century England, see Allan Chapman, “Scientific instruments and industrial innovation: The achievement of Jesse Ramsden”, in R. G. W. Anderson, J. A. Bennett, and W. F. Ryan (eds), *Making instruments count* (Aldershot, 1993), 418–30.
61. John Hadley was awarded a patent on 22 November 1734 for a “Quadrant for taking at sea the altitude of the sun, moon, or stars, and also any other angles; level to be fixed to a quadrant, for taking meridional altitudes at sea” (*AIPI*, 238).
62. See Culpeper’s plea to clients not to show his instruments to other London makers in Crawforth, “Evidence from trade cards for the scientific instrument industry” (ref. 4), 463.
63. It may be interesting to map the distribution of patents between the London ‘west-end’ makers of philosophical instruments and the ‘east-end’ mathematical instrument makers to compare patenting patterns in different branches of the business.
64. Stewart, “Science, instruments, and guilds in early modern Britain” (ref. 4), 392–410, and MacLeod, *Inventing the Industrial Revolution* (ref. 10), 137. Michael Berlin’s work supports such positions by showing that, since the seventeenth century, the London guilds relaxed their power to search the shops for ‘quality control’ purposes. The clockmakers (which included many instrument makers) dropped it altogether in 1750 (Berlin, “‘Broken in all pieces’” (ref. 4), espec. p. 87). The guilds’ declining ability to enforce their rules could be a factor behind the increased patenting of instruments (often by guild members) in England after 1700. These readings, like those by Daumas on instrument making in eighteenth-century France (Daumas, *Scientific instruments* (ref. 4), 90–106) and by Karel Davids on the relationship between thriving patent activity in the Netherlands and permissive or weak local guilds (“Technological change and the economic expansion of the Dutch Republic, 1580–1680”, in Karel Davids and Leo Noordegraaf (eds), *The Dutch economy in the Golden Age* (Amsterdam, 1993), 79–104, pp. 94–95) indicate that most studies of early modern patenting (including those related to instruments) do not participate in the

- recent historiography that tries to revise the received consensus about the guilds' technological conservatism. Despite the available literature (see ref. 4 above) too much is still unknown about the relationship between instrument makers and guilds (especially outside of London) and how that may have impacted instrument patenting. But even the evidence from England is not so clear cut. A few instrument patents were opposed (Quare's, De Duillier's, Dollond's), but many more were not, even when the patentees belonged to the guilds. And in Dollond's case, the litigation resulted from the unusually large market potential of achromatic lenses, not from an anti-patent policy by the guilds. The same applies to the guilds' successful attempt to void the patent granted to Fatio de Duillier *et al.* on rubies as clock bearings. Like Dollond's, that patent seemed to impact too many clockmakers for the guild not to react.
65. A reading of the brief descriptions of patents in *AIFI* indicates that as differences among instruments of the same kind began to make a bigger difference, the language of English eighteenth-century instrument patents began to sound like modern 'patentese', with a more careful wording of the specificity of patent claims.
 66. The Académie des Sciences of Paris was charged with the examination of patent applications, but its role was neither exclusive — the Crown could chose other examiners — nor conclusive — a positive report from the Académie did not imply the issuance of the patent (Hahn, *Anatomy of a scientific institution* (ref. 12), 60–65). Inventors, however, submitted their work to the Académie not only to pursue a patent, but also in the hope of receiving a positive endorsement. The Académie published many of the approved inventions in M. Gallon (ed.), *Machines et inventions approuvées par l'Académie Royale des Sciences, depuis son établissement...* (Paris, 1735–77), in seven volumes covering the 1666–1754 period.
 67. "Chambre obscure de nouvelle construction", and "Machine pour tailler les verres de lunettes", in Gallon (ed.), *Machines et inventions approuvées* (ref. 66), vi, 125–8.
 68. *AIFI*, 152, 395, 236; Bertucci, "A philosophical business" (ref. 1), 41–58. De Magellan, was not an instrument maker but an agent, purchasing instruments in London for Van Marum in the 1780s (Gerard L'E. Turner, "The London trade" (ref. 60), 13). His role in this patent, therefore, may have been that of the financial backer.
 69. George Adams in 1750; Robert Blair in 1785 and 1791; Hugh Dixon in 1785; Christopher Irwin in 1758; Henry Pyefinch in 1770; Cater Rand in 1792; Thomas Short in 1774; and William Storer in 1780 (*AIFI*, 2, 51, 162, 297, 463, 466, 515, 547).
 70. By George Lindsay in 1743, William Storer in 1780, and Hugh Dixon in 1785 (*AIFI*, 340, 547, 162).
 71. Hilaire-Pérez, "Invention and the state in 18th-century France" (ref. 12), 915.
 72. Mandich, "Venetian patents" (ref. 9), 167, note 1A.
 73. *Supplica* is the Italian term found in Venice and elsewhere to designate the request of a privilege.
 74. France introduced the notion of the author as holder of intellectual property rights with the Revolution. Article 1 of the 7 January 1791 law states: "Toute découverte ou nouvelle invention, dans tous les genres d'industrie, est la propriété de son auteur; en conséquence, la loi lui en garantit la pleine et entière jouissance, suivant le mode et pour le temps qui seront ci-après déterminés" (quoted in Yves Plasseraud and François Savignon, *L'état et l'invention* (Paris, 1986), 186). Other European countries took longer to pass similar legal codifications, while Britain started moving earlier in that direction, prodded along by industrial and commercial developments rather than political revolutions. In the Kingdom of Piedmont and Sardinia (soon to become the Kingdom of Italy), the shift from "royal favour" to "inventor's rights" happened only in 1855 (Vittorio Marchis, Luisa Dolza, and Michelangelo Vasta, *I privilegi industriali come specchio dell'innovazione nel Piemonte preunitario* (Turin, 1992), 118). Switzerland and the Netherlands, however, chose to go without a national patent system until the twentieth century (Eric Schiff, *Industrialization without national patents: The Netherlands, 1869–1912; Switzerland, 1850–1907* (Princeton, 1971)).

75. Parker, *The Bureau of Commerce in 1781* (ref. 12), 59; Roberto Berveglieri and Carlo Poni, "L'innovazione nel settore serico", in Luca Molà, Reinhold Mueller, and Claudio Zanier (eds), *La seta in Italia dal Medioevo al Seicento* (Venice, 2000), 478, 481–2; Carlo Marco Belfanti, "Guilds, patents, and the circulation of technical knowledge: Northern Italy during the early modern age", *Technology and culture*, xlv (2004), 569–89; Josef Ehmer, "Worlds of mobility: Migration patterns of Viennese artisans in the eighteenth century", in Geoffrey Crossick (ed.), *The artisan and the European town, 1500–1900* (Aldershot, 1997), 172–99; Berveglieri, *Inventori stranieri a Venezia* (ref. 9), 33–34; Carlo Marco Belfanti, "Fashion and innovation: The origins of the Italian hosiery industry in the sixteenth and seventeenth centuries", *Textile industry*, xxvii (1996), 132–47, esp. p. 142; Simonetta Cavaciocchi (ed.), *Le migrazioni in Europa, secoli XIII–XVIII* (Florence, 1994). Although the trend tapered off, the use of patents for the importation of technology remained visible throughout the eighteenth century.
76. "El sono in questa Cita, et anche ala zornada, per la grandeza et bontà soa concorre homeni da diverse bande, et acutissimi ingegni, apti ad excogitar et trovar varij ingegnosi artificij ...", cited in Giulio Mandich, "Le private industriali Veneziane (1450–1550)", *Rivista di diritto commerciale e del diritto generale delle obbligazioni*, xxxiv (1936), Part One, p. 518.
77. Thomas Sprat, *History of the Royal Society* (London, 1667), 398–401.
78. Michael Sonenscher, *Work and wages* (Cambridge, 1989), 216. On Court clockmakers' exemption from guild regulations in Paris and Augsburg see Landes, *Revolution in time* (ref. 27), 225–6.
79. On the awarding of patents to foreigners see Berveglieri, *Inventori stranieri a Venezia* (ref. 9); Davids, "Patents and patentees in the Dutch Republic" (ref. 10), 269; Joan Thirsk, *Economic policy and projects* (Oxford, 1978), 24–77; Felicity Heal and Clive Holmes, "The economic patronage of William Cecil", in Pauline Croft (ed.), *Patronage, culture, and power: The early Cecils* (New Haven, 2002), 199–229; Maximilian Frumkin, "Early history of patents for invention", *Transactions of the Newcomen Society*, xxvi (1947), 47–55; Doorman, *Patents for inventions in the Netherlands* (ref. 10), 13–15.
80. Thirsk, *Economic policy and projects* (ref. 79), 55.
81. Examples of these attempts (successful and unsuccessful alike) are in Molà, "Artigiani e brevetti" (ref. 11), 58–59, 63.
82. John Harris, *Essays in industry and technology in the eighteenth century: England and France* (Aldershot, 1992); John Harris, *Industrial espionage and technology transfer: Britain and France in the eighteenth century* (Aldershot, 1998); André Guillerme (ed.), "De la diffusion des sciences à l'espionnage industriel", special issue of *Cahiers d'histoire et de philosophie des sciences*, xlvii (1999); Karel Davids, "Openness or secrecy? Industrial espionage in the Dutch Republic", *The journal of European economic history*, xxiv (1995), 333–49; Karel Davids "Public knowledge and common secrets: Secrecy and its limits in the early modern Netherlands", *Early science and medicine*, x (2005), 411–27.
83. Francis Bacon, *The Advancement of Learning and New Atlantis*, ed. by Arthur Johnston (Oxford, 1974), 230. I read Bacon's line that "These ships are not otherwise fraught than with store of victuals and good quantity of treasure to remain with the brethren for the buying of such things and rewarding of such persons as they should think fit" to refer to bribes for trade secrets (p. 230). The distinctly autocratic and not republic-of-letters-like nature of the House of Solomon was highlighted in John Heilbron, "Why revisit Solomon's House?", in Tore Frangsmyr (ed.), *Solomon's House revisited* (Canton, MA, 1990), 331–42. The autocratic character of the House of Solomon reflects, I believe, the trade policies Bacon had become familiar with at Court.
84. Thirsk, *Economic policy and projects* (ref. 79), 53. Similarly, Felicity Heal and Clive Holmes claim that "Cecil was claimed to have combed England and Europe for new processes and manufactures. He certainly employed a variety of local agents to report on the feasibility of projects" ("The economic patronage of William Cecil" (ref. 79), 199–229, p. 203).

85. David Landes, “The round of horological migrations”, in Simonetta Cavaciocchi (ed.), *Le migrazioni in Europa, secoli XIII–XVIII* (ref. 75), 561–6; Gerhard Dohrn-Van Rossum, “Migrating technicians: Medieval clockmakers”, *ibid.*, 671–76. On early modern artisanal mobility in early modern Europe see also Leslie Page Moch, *Moving Europeans* (Bloomington, 2003); Stephan Epstein, “Labour mobility, journeyman organisations and markets in skilled labour in Europe, 14th–18th centuries”, in Arnoux and Monnet (eds), *Le technicien dans la cité en Europe occidentale, 1250–1650* (ref. 11), 251–69; and Josef Ehmer, “Worlds of mobility: Migration patterns of Viennese artisans in the eighteenth century”, in Crossick (ed.), *The artisan and the European town, 1500–1900* (ref. 75), 172–99.
86. Henry Heller, *Labour, science, and technology in France, 1500–1620* (Cambridge, 1996), 120. On the migration of Huguenot artisans see Warren Scoville, “The Huguenots and the diffusion of technology”, *Journal of political economy*, lx (1952), 294–311. Other examples of forced migrations are discussed in Heinz Schilling, “Innovation through migration: The settlement of the Calvinistic Netherlanders in sixteenth- and seventeenth-century Central and Western Europe”, *Histoire sociale*, xvi (1983), 7–33. Another example is the expulsion of Sephardic Jewish artisans from Spain and Portugal. A reassessment of the non-dramatic causes and greater scale of artisanal mobility in early modern Europe is Stephan Epstein, “Labour mobility, journeyman organisations, and markets in skilled labour in Europe, 14th–18th centuries”, in Mahieu Arnoux and Pierre Monnet (eds), *Le technicien dans la cité en Europe occidentale, 1250–1650* (Rome, 2004), 251–69.
87. Doorman, *Patents for inventions in the Netherlands* (ref. 10), 59. Later examples are Tito Livio Burattini at the Polish court in Warsaw, Jacob Lusuer at the court in Modena, or Joost Bürgi at the Hesse-Kassel and Rudolphine courts.
88. A. J. Turner, *From pleasure and profit to science and security: Etienne Lenoir and the transformation of precision instrument-making in France, 1760–1830* (Cambridge, 1989), 10. Sections of two letters from Cassini to Belsaigne are in Christian Wolff, *Histoire de l’Observatoire de Paris de sa fondation à 1793* (Paris, 1902), 299–300.
89. Marcus Popplow, “Protection and promotion: Privileges for inventions and books of machines in the Early Modern Period”, *History of technology*, xx (1998), 103–24, p. 109. On Venice’s policies see Berveglieri, *Inventori stranieri a Venezia* (ref. 9), 42–44, 49. As peculiar as it may seem, the decision to reward inventors for the inventions they had not invented yet has an analogue at the other end of the spectrum of authorship, where authorial credit transforms into responsibility. Roger Chartier has shown that the first of three categories used by the Spanish Inquisition to classify heretical books included “all the works of the authors considered to be heretics — that is to say, not only the works they had already written but also the works they were to write and publish in the future” (“Foucault’s Chiasmus”, in Mario Biagioli and Peter Galison (eds), *Scientific authorship* (New York, 2003), 13–31, p. 23).
90. Patrick McCray, “Creating networks of skill: Technology transfer and the glass industry of Venice”, *The journal of European economic history*, xxviii (1999), 301–33, esp. pp. 309–16. Bologna had harsher penalties: “Ugolino Menzani was tried in absentia and condemned to death at the beginning of the seventeenth century for having exported equipment for throwing and twisting silk to Venice. A painting showing him hanged upside down remained on public display in Bologna for more than a century” (Belfanti, “Guilds, patents, and the circulation of technical knowledge” (ref. 75), 581).
91. Giuseppe Ceredi, *Tre discorsi sopra il modo d’alzar acque da’ luoghi bassi...* (Parma, 1567), p. 19, quoted in Popplow, “Protection and promotion” (ref. 89), 122, note 51. Ceredi himself had obtained a privilege from his local prince — Ottavio Farnese — in 1566 (a year before he published his book) for an improved version of the Archimedean screw.
92. Quoted in MacLeod, *Inventing the Industrial Revolution* (ref. 10), 11.

93. Leonardo da Vinci, “Codices Madrid”, quoted in Popplow, “Protection and promotion” (ref. 89), 122, note 50.
94. Carlo Poni, “Ricerche sugli inventori bolognesi della macchina seminatrice alla fine del secolo XVI”, *Rivista storica Italiana*, lxxvi (1964), 455–69, p. 458. Other examples are: the Dutch hydraulic engineer Cornelius Meijer who travelled from Amsterdam to Venice and Rome, obtaining patents in each city (Berveglieri, *Inventori stranieri a Venezia* (ref. 9), 43; Klaas van Berkel, “‘Cornelius Meijer inventor et fecit’: On the representation of science in late seventeenth-century Rome”, in Smith and Findlen, *Merchants and marvels* (ref. 60), 277–96); the French inventor François Antola who obtained patents in Lyons, Florence, and Venice (Berveglieri, *Inventori stranieri a Venezia* (ref. 9), 43); and Guidoboni’s and Gabrielli’s scheme to obtain patents in Venice, Rome, and Florence analysed in Molà, “Artigiani e brevetti nella Firenze del Cinquecento” (ref. 11), 66–67. Huygens’s 1664 English patent of the pendulum clock with Bruce could be put in this category as well.
95. A detailed discussion of the career of one of these projectors is Pamela Smith, *The business of alchemy: Science and culture in the Holy Roman Empire* (Princeton, 1994). A discussion of the complex relation between patents and projects is in Thirsk, *Economic policy and projects* (ref. 79), esp. pp. 24–77.
96. A contextualization of Galileo’s invention and use of the telescope within patenting practices is in Biagioli, *Galileo’s instruments of credit* (ref. 5), 77–134, esp. pp. 119–27.
97. The complementarity (rather than opposition) of guilds and patents has been proposed by Belfanti in his “Guilds, patents, and the circulation of technical knowledge” (ref. 75), 569–89, esp. pp. 576–80.
98. Gouk, *The ivory sundials of Nuremberg, 1500–1700* (ref. 4), 52, 63, 66, 77–81, 117.
99. On the Dutch case: “The urban authorities in Delft in 1755 ruled that no craftsman in the faience-making industry who had gone to practice his trade outside of Delft would ever be allowed to get employment in his native city again or to receive assistance from the poor-box.” Karel Davids, “Public knowledge and common secrets: Secrecy and its limits in the early modern Netherlands”, *Early science and medicine*, x (2005), 411–27, p. 419.
100. Belfanti gives the example of a Florentine immigrant to Venice, Cosimo Scatini, who was given a patent for silk dyeing and applied to the Venetian dyers’ guild at the expiration of the patent, promising to teach his technology to local craftsmen (“Guilds, patents, and the circulation of technical knowledge” (ref. 75), 578).
101. MacLeod, *Inventing the Industrial Revolution* (ref. 10), 10–14.
102. Quite common, such training requirements were as much a form of embodied disclosure than a kind of reduction to practice.
103. Early sixteenth-century printing privileges issued by the Pope warned potential Christian pirates that they would be excommunicated. This threat was dropped in later privileges. The peculiarity of early papal privileges does not reflect a change in the logic of the privilege, but rather in the nature of this specific prince — one who claimed a non-secular jurisdiction over all Christians (Pierina Fontana, “Inizi della proprietà letteraria nello Stato Pontificio”, *Accademie e biblioteche d’Italia*, iii (1929), 204–21, p. 207).
104. Frank Prager, “Brunelleschi’s patent”, *Journal of the Patent Office Society*, xxviii (1946), 109–35; Frank Prager and Gustina Scaglia, *Brunelleschi: Studies of his technology and inventions* (Cambridge, MA, 1970), 111–23.
105. Pamela Long, “Invention, authorship, ‘intellectual property,’ and the origin of patents: Notes toward a conceptual history”, *Technology and culture*, xxxii (1991), 846–84, p. 877.
106. The geographical notion of originality survived until the nineteenth century, that is, well after the emergence of author-centred notions of originality. It was dropped only when the development of formalized patent systems led various countries to recognize each other’s patents. For instance,

Article 3 of the French patent law of 7 January 1791 reads: “Quiconque approtera en France une découverte étrangère jouira des mêmes avantages que s’il en était l’inventeur”, in Plasseraud and Savignon, *L’état et l’invention* (ref. 74), 186.

107. Berveglieri and Poni, “Three centuries of Venetian patents” (ref. 9), 390.
108. Martha Woodmansee, “The genius and the copyright: Economic and legal conditions of the emergence of the ‘author’”, *Eighteenth-century studies*, xvii (1984), 425–48.
109. While Harris and others have shown that there was widespread “industrial espionage” in early modern Europe, we should add that there was no categorical distinction between such “espionage” and the use of patents to draw artisans and inventors from one country to another. Despite the use of pejorative terms such as ‘espionage’, these practices were not illegal.
110. Iliffe, “‘In the warehouse’” (ref. 1), 29–67.
111. *Ibid.*, 41–52.
112. On Huygens’s ongoing concerns with the determination of the longitude through accurate timekeepers see J. H. Leopold, “The longitude timekeepers of Christiaan Huygens”, in Andrewes (ed.), *The quest for longitude* (ref. 51), 102–14.
113. Iliffe has shown that Hooke and Huygens strove to deliver increasingly more accurate and reliable watches to the King and his counsellors. Oldenburg’s plea to Huygens to send a watch with a hand marking seconds (“‘In the warehouse’” (ref. 1), 50) is obviously not a priority issue but a performance-related argument. No patent for the spring watch (either to Hooke or Huygens) is recorded in the rolls.
114. Furthermore, the inventions covered by these privileges were sometimes put to work in public spaces (canals, public land, or, in Brunelleschi’s case, rivers). In this sense, early patents had more than a passing resemblance with earlier mining privileges.
115. According to U.S. patent law, such specifications need to be sufficiently full and clear to enable a person skilled in the art to make and use that invention (Halpern, Nard, and Port, *Fundamentals of United States intellectual property law* (ref. 16), 235).
116. This does not apply to secret patents concerning, for instance, military technologies (Tom O’ Dell, *Invention and official secrecy: A history of secret patents in the United Kingdom* (Oxford, 1995)).
117. See ref. 82 above.
118. In 1598 Cornelis Meynertsz was asked to provide drawings of the drainage mill he was trying to patent to the Deputies of the States of Holland so that “should the latter find the invention to be new the patent would be granted” (Doorman, *Patents for inventions in the Netherlands* (ref. 10), 174).
119. *Ibid.*, 22–23. When models or drawing were kept by state official, they were not disclosed to the public. Dutch practices were quite similar to English ones, as analysed in Eric Robinson, “James Watt and the laws of patents”, *Technology and culture*, xiii (1972), 115–39.
120. Doorman, *Patents for inventions in the Netherlands* (ref. 10), 175.
121. Hilaire-Pérez, “Invention and the state in 18th-century France” (ref. 12), 919; Hahn, *Anatomy of a scientific institution* (ref. 12), 67.
122. Quoted in Pohlmann, “The inventor’s rights in early German law” (ref. 10), 126, 130.
123. The seven volumes of Gallon (ed.), *Machines et inventions approuvées* (ref. 66), listed the inventions approved from 1666 to 1754 (but were published between 1735 and 1777).
124. Berveglieri, *Inventori stranieri a Venezia* (ref. 9): “purtroppo una descrizione tecnica precisa di ciò che è stato inventato e brevettato manca per la quasi totalità dei brevetti” (p. 26); “Naturalmente non si conosce il principio, oggi sostenuto da alcuni, che concedendo una patente la pubblica autorità deve descrivere l’invenzione che vuole proteggere” (p. 27); “I dossier sono estremamente poveri di illustrazioni” (p. 38).

125. MacLeod, *Inventing the Industrial Revolution* (ref. 10), 49.
126. *Ibid.*, 49.
127. *Ibid.*, 42.
128. “Since official and judicial guidance was lacking for most of the eighteenth century, it is doubtful whether patentees had any clear idea what the function of a specification was or how full and accurate it ought to be. Like most other things about the system, it was left to the patentee’s discretion” (*ibid.*, 50).
129. *HOC*, v, 157.
130. Rupert Hall and Marie Boas Hall (eds), *The correspondence of Henry Oldenburg*, iv (Madison, 1967), 223–4, 235.
131. Sorrenson has argued that when Dollond’s son, Peter, sued for infringement of his father’s 1658 patent for achromatic doublets, the court did not recognize that the invention Peter Dollond was trying to defend was related to, but different from, the one of the 1658 patent: “Rather than questioning what particular kind of achromatic lens it was that the patent covered, the legal proceedings focused on whether or not Dollond’s lens was the first commercially available achromatic lens of any kind” (“Dollond & Son’s pursuit of achromaticity” (ref. 1), 39).
132. *Ibid.*, 37–42.
133. Quoted in *ibid.*, 40.
134. John Milburn, *Adams of Fleet Street, instrument makers to King George III* (Aldershot, 2000), 61; McConnell, “From craft workshop to big business” (ref. 60), 49. The author seems to relate these drawings to a 1775 dividing engine, but that year Ramsden patented an equatorial instrument (*AIPI*, 465).
135. Robinson, “James Watt and the laws of patents” (ref. 119), 125. This is a very important article for anyone interested in the history of disclosure requirements.
136. Mourlevat, *Les machines arithmétiques de Blaise Pascal* (ref. 38), 12.
137. Current U.S. patent law lists two kinds of reduction to practice: constructive and actual. Actual reduction to practice occurs when the inventor constructs the invention (which usually means a prototype), but constructive reduction to practice is deemed sufficient. Constructive reduction to practice was defined in *Fiers v. Revel* (1993) as “While one does not need to have carried out one’s invention before filing a patent application, one does need to be able to describe that invention with particularity” (Halpern, Nard, and Port, *Fundamentals of United States intellectual property law* (ref. 16), 205–7).
138. Jürgen Renn and Matteo Valleriani, “Galileo and the challenge of the Arsenal”, *Nuncius*, xvi (2001), 496, note 36; Berveglieri, *Inventori stranieri a Venezia* (ref. 9), 40.
139. Pohlmann, “The inventor’s rights in early German law” (ref. 10), 126, 129–30; Hahn, *Anatomy of a scientific institution* (ref. 12), 67.
140. Iliffe, “In the warehouse” (ref. 1), 43–48; *HOC*, xvii, 175, note 2.
141. Huygens applied on 5 February 1675 (*HOC*, vii, 401), but had already showed Colbert a model on 31 January (*ibid.*, 407).
142. Biagioli, *Galileo’s instruments of credit* (ref. 5), 120–1.
143. Pohlmann, “The inventor’s rights in early German law” (ref. 10), 129–30.
144. MacLeod, *Inventing the Industrial Revolution* (ref. 10), has found that in late sixteenth-century England, “the consideration or quid pro quo originally demanded was not the disclosure of his secret but the ‘furtherance of trade’ through the effective introduction of a new technique or industry”, p. 13. Reduction to practice requirements in the Netherlands are discussed in Davids, “Patents and patentees in the Dutch Republic” (ref. 10), 267, and the French ones in Hilaire-Pérez, “Invention and the state in 18th-century France” (ref. 12), 923. In Florence too disclosure was replaced by prompt reduction to practice. That requirement could be fulfilled by showing

affidavits by reliable witnesses that the invention was operative (Molà, “Artigiani e brevetti” (ref. 11), 64). Rather than public written disclosure, privileges could include provisions about the training of local workers and artisans into the technology covered by the privilege. In line with the logic of the privilege, the recipients of such “disclosure” were not generic members of society, but the princely subjects who were to use that technology right there and then. On Venetian requirements for reduction to practice (and the cancellation of patents for inventions that failed to meet those requirements) see Berveglieri, *Inventori stranieri a Venezia* (ref. 9), 26–28. On reduction to practice in the Hapsburg Empire see Pohlmann, “The inventor’s rights in early German law” (ref. 10), 129–30.

145. Karel Davids has argued that reduction to practice requirements played a significant role in the decline of Dutch patenting starting around 1640, when inventions became, on average, larger and more complicated, thus requiring more time and capital to develop (“Patents and patentees in the Dutch Republic” (ref. 10), 278–80). The troubles of poor Venetian inventors who did not have sufficient resources to meet reduction to practice requirements are discussed in Berveglieri, *Inventori stranieri a Venezia* (ref. 9), 28–29.
146. See ref. 136 above.
147. Biagioli, *Galileo’s instruments of credit* (ref. 5), 121.
148. Royal Society, “Journal Book”, 16 January 1695, quoted in Bryden and Simms, “Spectacles improved to perfection” (ref. 4), 31.
149. Iliffe, ““In the warehouse”” (ref. 1), 46–52.
150. George Foster, “Izaak Thuret, clockmaker to Louis XIV”, *Antiquarian horology*, iii/3 (1960), 73–75; *HOC*, vii, 399–436.
151. MacLeod argues that, even after the introduction of specification requirements in England in 1723, detailed descriptions of the invention were filed only after the sealing of the patent (*Inventing the Industrial Revolution* (ref. 10), 49, 42). There seem to have been two levels of disclosure: a preliminary summary with the application, and a fuller one after the issuance. This would fit the pattern of inventors’ distrust found elsewhere. Given the enterprising tendencies of many brokers and administrators at the royal court (but — as shown in Ash, *Power, knowledge, and expertise* (ref. 34) — also of the Crown itself), such level of caution on the inventors’ side was probably not paranoid.
152. On 3 June 1663 “Sir Robert Moray ... produced likewise a certain petition lately presented to the king, for a patent to practise a secret of making all grain grow plentifully in any barren ground, without laying on any dung or compost; so that the same land so sown should improve yearly, and bear corn constantly, at the charge of ten or twelve shillings an acre ...” (Thomas Birch, *The history of the Royal Society of London* (London, 1756), i, 252). I have not been able to find this patent in the English rolls. Equally unfitting the image of impartiality that the Society was trying to develop for itself were its plans to demand explicitly higher levels of disclosure from non-members who wished to enter sealed priority claims about their inventions in its archives. At the 16 November 1667 meeting it was discussed that: “Mention being made, that a security might be provided for such inventions or notions, as ingenious persons might have, and desired to secure from usurpation, or from being excluded from having a share in them, if they should be lighted on by others; it was thought good, if any thing of that nature should be brought in, and desired to be lodged with the society, that, if the authors were not of their body, they should be obliged to shew it first to the president, and that then it should be sealed up both by the small seal of the society, and by the seal of the proposer; but if they were of the society, then they should not be obliged to shew it first to the president, but only to declare to him the general heads of the matter, and then it should be sealed up, as mentioned before” (Birch, *The history of the Royal Society of London* (ref. 152), ii, 212).
153. Hunter, *Establishing the new science* (ref. 7), 73–121; K. H. Ochs, “The Royal Society of London’s

- History of Trades programme: An early episode in applied science”, *Notes and records of the Royal Society*, xxxix (1985), 129–58, esp. pp. 146–50.
154. Sprat wrote that “... the Royal Society will be able by degrees, to purchase such extraordinary inventions, which are now close lock’d up in Cabinets; and then to bring them into one common Stock, which shall be upon all occasions expos’d to all mens use” (*History of the Royal Society* (ref. 77), 75). At the 18 May 1664 meeting, Hooke “mentioned that he knew a person, who had the art of softening steel to that degree, that it might be twisted. He was desired to endeavour to get the secret, and to offer a reward for it” (Birch, *The history of the Royal Society of London* (ref. 152), i, 426).
 155. Birch, *The history of the Royal Society of London* (ref. 152), i, 219.
 156. In the first decade or so after its foundation, the Royal Society seemed interested in taking out patents on its members’ work as a way to booster its weak finances. The 1665 patent that included Bruce’s and Huygens’s clock is an example. And the fact that, in February 1675, Huygens offered the English patent for his spring watch to the Society and/or Oldenburg is probably a move inspired by his 1665 experience (*HOC*, vii, 423). Letters between Moray and Huygens in 1664–65 also suggest that Moray (speaking, it seems, in the name of the Society) was interested to share inventions by some members of the Society with Huygens if he managed to take European patents on them. On 5 December 1664 he told Huygens that “Ces Calesches at Chariots [a reference to an invention included in the 1665 Royal Society English patent] seront de grand usage en Hollande aussi. Cest porquoy Je crois que Je vous prieray aussi d’en demander le privilege en ce país là. Mais Je vous entretienderay plus amplement sur ce sujet, lors que les Cahiers de la [English] patente seront dressez” (*HOC*, v, 157).
 157. In the early modern period, trade secrets could be uncovered and used without legal penalties, but not so after a privilege had been issued on them.
 158. Recognized by the law, trade secrets are now regulated by a doctrine that is conceptually distinct from intellectual property (Frank Foster and Robert Shook, *Patents, copyrights, and trademarks* (New York, 1993), 207–15).
 159. Derek Wood, “A state pension for L. J. M. Daguerre for the secret of his Daguerrotype technique”, *Annals of science*, liv (1997), 489–506.
 160. Jim Bennett, “The travels and trials of Mr Harrison’s timekeeper”, in Marie-Noëlle Bourguet, Christian Licoppe, and Otto Sibum (eds), *Instruments, travel, and science* (London, 2002), 75–95. Bennett shows that the discovery of the longitude came to be construed as a double discovery — the discovery of a method to the longitude and the disclosure of such a method in a manner that would allow others to discover the longitude as well. Harrison’s clock was made public in *The principles of Mr. Harrison’s time-keeper, with plates of the same, published by order of the Commissioners of Longitude* (London, 1767), a year after he received £7,500.
 161. *HOC*, v, 271.
 162. Berveglieri and Poni, “Three centuries of Venetian patents” (ref. 9), 390; Ceredi, *Tre discorsi sopra il modo d’alzar acque da’ luoghi bassi...* (ref. 91), 94–100.
 163. Popplow, “Protection and promotion” (ref. 89), 103–24. Comparable examples are in Davids, “Patents and patentees in the Dutch Republic” (ref. 10), 276–8.
 164. Myles Jackson, “Can artisans be scientific authors?”, in Biagioli and Galison (eds), *Scientific authorship* (ref. 89), 113–31.
 165. Iliffe, “‘In the warehouse’” (ref. 1), 38, 45.
 166. Because many of the pre-1700 mathematical instruments were custom-made and required little investment in special equipment beyond the tools of the engraver, their copying could require even less time and capital investment than copying a book (for which one would have to buy expensive paper, fonts, a press, etc.). Optical instruments were a different matter as they required lens-grinding equipment, templates, etc.

167. On the attempted patenting of the telescope in the Netherlands see Albert van Helden, *The invention of the telescope*, American Philosophical Society, *Transactions*, lxvii/4 (1977).
168. Landes, *Revolution in time* (ref. 27), 237.
169. Pohlmann, “The inventor’s rights in early German law” (ref. 10), 131: “A so-called ‘tax’ was levied for an inventor’s privilege. It was payable on delivery of the letters patent and it amounted to 15 Thaler, the equivalent of DM 100 to 150 [in 1961 currency].”
170. *HOC*, v, 168. Some eighteenth-century English instrument patents (such as those by Blair, Dixon, and Storer) list a number of devices, probably for the same reason give by Moray more than a century earlier (*AIPI*, 51, 162, 547).
171. *HOC*, v, 186, and p. 173, note 3.
172. “Between 1750 and 1852 patents could cost anything up to £400, depending on the geographical extent of protection.... The cost of an English patent varied from invention to invention, but was between £100 and £120”, Harold Dutton, *The patent system and inventive activity during the Industrial Revolution, 1750–1852* (Manchester, 1984), 35. Registering additional patents for Scotland and Ireland could cost an additional £225. MacLeod gives comparable figures and discusses the various investments of time and capital faced by applicants, MacLeod, *Inventing the Industrial Revolution* (ref. 10), 76–77.
173. Sorrenson, “Dollond & Son’s pursuit of achromaticity” (ref.1), 52, note 26.
174. *Ibid.*, 34.
175. Biagioli, “Galilei v. Capra” (ref. 2).
176. Albert van Helden, “Longitude and the satellites of Jupiter”, in Andrewes (ed.), *The quest for longitude* (ref. 51), 86–100, esp. pp. 86–92; Silvio Bedini, *The pulse of time* (Florence, 1991), 7–21.
177. Tycho’s instruments are an exception (see ref. 5 above).
178. Berveglieri, *Inventori stranieri a Venezia* (ref. 9), 74; Evelyn Lincoln, “Invention and authorship in early modern Italian visual culture”, *DePaul law review*, lii (2003), 1093–119; Lisa Pon, “Prints and privileges: Regulating the image in 16th-century Italy”, *Harvard University Art Museums bulletin*, vi (1998), 41–64; and David Hunter, “Copyright protection for engravings and maps in eighteenth-century Britain”, *The library*, 6th ser., ix (1987), 128–47; Christopher Witcombe, *Copyright in the Renaissance: Prints and the privilegio in sixteenth-century Venice and Rome* (Leiden, 2004); Michael Bury, “Infringing privileges and copying in Rome, c. 1600”, *Print quarterly*, xxii (2005), 133–8; and Nadine Orenstein, *Hendrick Hondius and the business of print in seventeenth-century Holland* (Rotterdam, 1996), 86–137, esp. pp. 90–94.
179. Besides the paper instruments by Apian discussed below, Georg Hartmann (1489–1564) printed sundials which were then pasted on wood. Besides being much cheaper than the ivory or metal sundials, the printing of paper sundials allowed Hartmann to bypass the regulations of the Nuremberg’s dial-makers guild (Gouk, *The ivory sundials of Nuremberg* (ref. 4), 68–69, 76, 92, 130, 124). Other paper instruments are in the Oxford Museum of History of Science: Inv. #44745 “Paper astrolabe” (Johann Krabbe, German 1583); Inv. #52008 “Paper quadrant” (Oxford, late seventeenth century); Inv. #49296 “Paper astrolabe” (Georg Hartmann, Nuremberg 1542) (different editions of Hartmann’s paper astrolabe were issued between 1531 and 1545); Inv. #91897 “Paper astrolabe” (Hanns Hergahmer, 1492). Philippe Danfrie produced a paper astrolabe in Paris in 1578, reissued it in 1584 (following the adoption of the Gregorian calendar), and probably kept printing and selling it for the rest of his life. Passed on to his heirs, the plates were either sold or rented to other printers, producing more editions around 1625 and again in 1644 (A. J. Turner, “Paper, print, and mathematics: Philippe Danfrie and the making of mathematical instruments in late 16th-century Paris”, in Blondel *et al.* (eds), *Studies in the history of scientific instruments* (ref. 4), 23–41, pp. 31–33). Paper instruments were produced and sold by Joseph Moxon in London (Bryden, “Evidence from advertising for mathematical instrument making” (ref. 4), 330). Jonas Moore’s 1674 paper “Universal dial for all latitudes, being a projection of

- the sphere in plano” is discussed in A. J. Turner, “Mathematical instruments and the education of gentlemen”, *Annals of science*, xxxviii (1988), 51–88, p. 83. On paper logarithmic rules see Bryden, “Evidence from advertising for mathematical instrument making” (ref. 4), 328. More paper instruments are mentioned in Owen Gingerich, “Astronomical paper instruments with moving parts”, in Anderson, Bennett, and Ryan (eds), *Making instruments count* (ref. 60), 63–74. In some cases we find books which include prints of instruments that seem just too detailed and too large to be meant as illustrations. For instance, Bonaiuto Lorini’s 1597 *Delle fortificationi libri cinque* (Venice, 1597) opens with a very large print of the “squadra zoppa” — the moveable square needed to design and survey the construction of the fortifications described in the book. The awkward pagination aimed at maximizing the size of the print and the fact that these pages, if cut out, would not at all damage the content of the book supports the hypothesis that we are in fact dealing with a paper instrument (p. 16). This suggests that there might be more paper instruments in books of practical mathematics that have been mistaken as illustrations. The need to withhold assumptions about what counts as an illustration or a model of an instrument has been stressed in Jim Bennett, “Knowing and doing in the sixteenth century: What were instruments for?”, *The British journal for the history of science*, xxxvi (2003), 129–50, 140–1. While my discussion here is limited to paper instruments that could be built out of prints included in books (not paper devices like pop-up geometrical figures or other pedagogical instruments with moving parts that were part of the textbooks that contained them), there are other hybrid cases that need to be mentioned. These are the paper instruments that, while not meant to be taken out of books, were nevertheless designed and printed with sufficient precision to be used as calculating devices. In this sense, they were both book pages and instruments. Examples are in Gingerich, “Astronomical paper instruments” (ref. 179) and in his “Apian’s *Astronomicum Caesareum* and its Leipzig facsimile”, *Journal for the history of astronomy*, ii (1971), 168–77.
180. “Despite the fact that relatively few paper instruments have survived from this period ... it was probably in this form that the astrolabe and other instruments were most widely known and used. If this be so, and the case of globes where the paper instrument displaced the metal one almost entirely tends to confirm the suggestion, then it entails a considerable revision in our ideas about the distribution and availability of instruments in the late sixteenth and early seventeenth century”, A. J. Turner, “Paper, print, and mathematics” (ref. 179), 32.
181. A. J. Turner, “Paper, print, and mathematics” (ref. 179), 35; Jim Bennett, “The challenge of practical mathematics”, in Stephen Pumfrey, Paolo Rossi, and Maurice Slawinski (eds), *Science, culture, and popular belief in Renaissance Europe* (Manchester, 1991), 176–90, pp. 177–8. In later periods, some makers continued to publish books on their instruments as instructions or publicity. But because of the specialization that resulted from changes in the material characteristics of instruments, we no longer find such a symbiotic relation between printing and instrument making. We could say that if around 1580 it was normal to find instruments in bookstores, around 1750 one found instruction books in instruments shops.
182. Bennett, “Knowing and doing in the sixteenth century” (ref. 179), 141.
183. On the overlap between booksellers and instrument sellers see de Clercq, *At the Sign of the Oriental Lamp* (ref. 54), 23, 27, 32, 68; G. L’E. Turner, “Mathematical instrument-making in London in the sixteenth century”, in Sarah Tyacke, *English map-making 1500–1650* (London, 1983), 93–106, p. 95; and Elizabeth Eisenstein, *The printing press as an agent of change* (Cambridge, 1979), 139, 443. On the continuing presence of instruments in bookstores in late seventeenth-century London see Bryden, “Evidence from advertising for mathematical instrument making in London, 1556–1714” (ref. 4), 329, 331.
184. Peter Apian, *Instrument Buch* (Ingolstadt, 1533).
185. Gingerich, “Astronomical paper instruments” (ref. 179), 71.
186. Peter Apian, *Folium populi: Instrumentum hoc a Petro Apiano iam recens inventum, et in figuram*

folii populi redactum... (Ingolstadt, 1533), at the bottom of the second page of the Latin text.

187. Bryden, “Evidence from advertising for mathematical instrument making in London, 1556–1714” (ref. 4), 328. On Wingate see A. J. Turner, “‘Utile pour les calculs’: The logarithmic scale rule in France and England during the seventeenth century”, *Archives internationales d’histoire des sciences*, xxxviii (1988), 252–70, p. 257.
188. A. J. Turner, “Paper, print, and mathematics” (ref. 179), 26.
189. Peter van der Krogt, *Globi Neerlandici* (Utrecht, 1993), 49, 57; Pohlmann, “The inventor’s rights in early German law” (ref. 10), 136. Doorman, *Patents for inventions in the Netherlands* (ref. 10), lists the following globes: Balochi (1601, p. 101), van Cal (1650, p. 145), Deur (1722, p. 159), Teunisz (1682, p. 186), van Luchtenberg (1684, p. 187), Valck (1701, p. 190).
190. Van der Krogt, *Globi Neerlandici* (ref. 189), 31.
191. Van der Krogt, *Globi Neerlandici* (ref. 189), 43, ill. 2.3.
192. See ref. 15 above.
193. Van der Krogt, *Globi Neerlandici* (ref. 189), 26.
194. The titlepage of Johannes Schöner’s 1515 *Luculentissima quaedam terrae totius descriptio* described the book as a “manual for the use of the solid spherical body, or Astronomical globe and the quick application of it ...” (van der Krogt, *Globi Neerlandici* (ref. 189), 32).
195. Paper technology had the additional bonus of allowing for the production of larger globes. Some prices of Frisius’s and Mercator’s globes are in van der Krogt, *Globi Neerlandici* (ref. 189), 51, 72–75.
196. Martin Waldseemüller’s 1507 *Cosmographiae introductio* (the first book known to include an unmounted paper globe as well as the term “America”) went through several editions exceeding a thousand copies in a few months (Joseph Fischer and Franz von Wieser, *The Cosmographiae introductio of Martin Waldseemüller* (New York, 1907), 2. It was reprinted several times more by 1509 (van der Krogt, *Globi Neerlandici* (ref. 189), 28). The workshop of Johannes Schöner — the leading German globemaker after Waldseemüller — was unable to meet the high demand for printed globes. No one violated his Imperial privilege in the countries that recognized it, but his globes were quickly reprinted and modified in the Netherlands, triggering a long tradition of globe manufacturing (Van der Krogt, *Globi Neerlandici* (ref. 189), 37–82, esp. pp. 40, 47; Antoine de Smet, “L’orfèvre et graveur Gaspar van der Heyden et la construction des globes à Louvain dans le premier tiers du XVIIe siècle”, *Album Antoine de Smet* (Brussels, 1974), 171–82).
197. I am borrowing from Nicholas Thomas, *Entangled objects: Exchange, material culture, and colonialism in the Pacific* (Cambridge, MA, 1991).
198. Examples are: Thomas Hood, *The making and use of the geometrical instrument called a sector* (London, 1598); Ignazio Danti, *Trattato dell’ uso e della fabbrica dell’astrolabio* (Florence, 1569); Philippe Danfrie, *Declaration de l’usage du graphometre...* (Paris, 1597); Edmund Gunter, *The description and use of the sector...* (London, 1624); Leonhard Zubler, *Fabrica et usus instrumenti chorographici* (Basel, 1607); Ottavio Fabri, *L’uso della squadra mobile...* (Venice, 1615); Jean Taisnier, *De annuli spherici fabrica et usu* (Antwerp, 1560); Muzio Oddi, *Fabrica et uso del compasso polimetro* (Milan, 1633); Antonio Lupicini, *Discorso sopra la fabrica e uso delle nuove verghe astronomiche* (Florence, 1582); Baldesarre Capra, *Usus et fabrica circini cuiusdam proportioni* (Padua, 1607). While the genre lasted into the eighteenth century, its function changed as it became increasingly focused on instruments for students and amateurs, not for professionals. An example is Nicolas Bion, *Traité de la construction et des principaux usages des instrumens de mathematique* (Paris, 1709). It covers everything from rulers, squares, sectors (which were more than a century old by the time he described them), to reduction compasses, pantographs, and parallel rulers.
199. John Palmer, *The Catholique planisphaere. Which Mr. Blagrave called The Mathematical Jewel...* (London, 1658), 1.

200. *Ibid.*, 15–16.
201. An example is Fabri, *L'uso della squadra mobile...* (ref. 198). Besides providing prints of the instrument and its parts, the book reviews possible construction materials (cardboard, cypress wood, copper, brass) and gives tips about what construction tasks might be better farmed out to founders and metal workers (pp. 15–18). Similarly, Leonard Digges, *Tectonicon* (London, 1692; original edn, London, 1556), described in great detail the construction of the various components of the “profitable Staffe”, indicating which tasks could be reasonably performed by the reader and which ones, instead, might require the “help of some Craftsman” (p. 23r).
202. Steven Shapin, “Pump and circumstance: Robert Boyle’s literary technology”, *Social studies of science*, xiv (1994), 481–520.
203. Many examples of this trend are discussed in Bryden, “Evidence from advertising for mathematical instrument making in London, 1556–1714” (ref. 4), and, for the earlier periods, in G. L’E. Turner, “Mathematical instrument-making in London in the sixteenth century” (ref. 183), 97–101.
204. For instance, Thomas Hood ended his 1592 *The use of both the globes, celestially, and terrestrially* (see ref. 210), by saying that “if you shall stand in need of my helpe, either through forgetfulness or hardnes of that, which I have taught, you, if you will repaire to my poore lodging in Abchurch lane, you shall find me ready to doe you what pleasure I can”.
205. Fabri, *L'uso della squadra mobile* (ref. 198), 16.
206. Edward Worsop, *A discoverie of sundrie errors and faults daily committed by lande-meaters, ignorant of arithmetike and geometrie...* (London, 1582), “Advertisement to the reader”. See also Cyprian Lucar, *A treatise named Lucarsolace divided into fower bookes...* (London, 1590), 10: “Geometricall tables with their feete, frames, rulers, compasses, and squires are made by John Reynolds, dwelling right against the southeast end of Barking churchyard in tower streete within London, and by John Reade, and Christopher Paine, dwellin in Hosier lane neere unto West smithfield in the suburbs of London: wyer lines like to that above mensioned, may be bought in crooked lane neare unto Eastcheape in London, and you may buy of any painter for a penny 3. or 4. Fine pointed coles or keelers: but for your better instructions, the tipe of every one of the said instruments is to be viewed in the side of paper opposite to this page.”
207. Johnston, “Mathematical practitioners and instruments in Elizabethan England” (ref. 45); Stephen Pumphrey and Frances Dawbarn, “Science and patronage in England, 1570–1625”, *History of science*, xlii (2004), 137–88, esp. pp. 150–64; Ash, *Power, knowledge, and expertise in Elizabethan England* (ref. 34).
208. A. J. Turner, “Mathematical instruments and the education of gentlemen” (ref. 179).
209. Johnston, “Mathematical practitioners and instruments in Elizabethan England” (ref. 45), 327.
210. Thomas Hood, *The use of both the globes, celestially, and terrestrially, most plainly delivered in the forme of a dialogue...* (London, 1592), p. B1.
211. In “Evidence from advertising for mathematical instrument making in London” (ref. 4), Bryden has discussed a progressive shift from late sixteenth- and early seventeenth-century endorsements of specific makers found in the texts of English “usus et fabrica” books, to more distinctly commercial kinds of advertisements found in the late seventeenth and eighteenth centuries (p. 311). This pattern, I believe, matches the trends I discuss here: informal endorsements of makers by mathematical practitioners reflects a context characterized by a small emerging market for instruments. These endorsements do not function as advertisements (as the market is too small to justify it), but rather as tips for buyers who otherwise might not know where to find a reliable maker. The second phase, instead, reflects a context characterized by an established and increasingly competitive market for instruments. At that point, advertisements become just advertisements.
212. Worsop, *A discoverie of sundrie errors and faults* (ref. 206), “Advertisement to the reader”.
213. Eric Raymond, *The cathedral and the bazaar* (Cambridge, MA, 1999), 65–112.