Time for a Change? Technological Persistence in the British Watchmaking Industry

ALUN C. DAVIES

Résumé

Dans cet article, l'auteur identifie les facteurs qui ont mené au déclin de l'industrie horlogère, autrefois puissante, en Grande-Bretagne. D'une position dominante à la fin du XVIII^e siècle, alors que les horlogers anglais satisfaisaient à la moitié de la demande mondiale, l'industrie britannique est tombée à un modeste niveau dans la période qui a précédé la Première Guerre mondiale. Les producteurs étrangers ont d'abord concurrencé les fabricants britanniques dans les marchés étrangers puis les ont pratiquement chassés de leur propre marché. C'est la persistance de vieilles technologies dans les centres d'horlogerie anglais de Londres, Prescot, Birmingham et Coventry qui a mené à ce déclin fatal. La résistance au changement s'est alimentée à des facteurs économiques, sociaux et culturels. En négligeant d'adopter les innovations techniques mises au point en Suisse et aux États-Unis, et de s'adapter aux conditions changeantes du marché, la technologie raffinée mais périmée de Grande-Bretagne s'est condamnée elle-même à disparaître.

Abstract

In this article the author identifies factors that led to the decline of the once-mighty British watch industry. From a dominant position in the late eighteenth century when English watchmakers supplied half of the world's demand, to a low point in the pre-World War I period, foreign producers at first challenged domestic British manufacturers in foreign markets, then virtually drove them out of their home market. The persistence of old technologies in the English watchmaking centres of London, Prescot, Birmingham and Coventry led to this terminal decline. Resistance to change was fuelled by economic, social and cultural factors. By failing both to adopt technological innovations developed in Switzerland and the United States and to adapt to changing market conditions, the sophisticated but outdated technology of Great Britain doomed itself to extinction.

The commercial and technical achievements of classic British watchmaking were impressive. At the end of the eighteenth century Britain produced about half of the world's output of watches and had a thriving export market. The complex technology embodied in the chronometer represented perhaps the greatest achievement of any handcraft industry. Simultaneously, at the bottom end of the market, thousands of rural clockmakers crafted the simple, cheap, reliable clocks which were among the first consumer durables.[1] But by the eve of the first world war, British watchmaking was in terminal decline. Why?

The Early Industry

Whilst the clockmaking industry was ubiquitous, watch manufacturing was concentrated in a few places, notably London, Prescot (near Liverpool), and Coventry. In the London district of Clerkenwell, hundreds of master craftsmen employed thousands of independent outworkers to produce almost 200 000 watches a year during the 1790s, the peak years of production. Most units employed only a handful of workers. Tools were hand-held and hand-powered, and the structure of the industry remained on the lines evolved by Tompion and others in the late seventeenth century.

There were at least a dozen major branches: makers of dials, pallets, pinions, springs, chains, screws, finishers, and so on. Each specialism was in turn further subdivided. The industry was well described by Aaron Dennison, the father of the American watch industry, but the same account could have been made at any time from the early eighteenth century to the eve of World War I:

> *The party setting up as a manufacturer of watches bought his Lancashire movements – conglomeration of rough materials – and gave them out to A, B, C, D, to have them finished. A, B, C, and D gave out the job of pivoting certain wheels of the train to E, certain other parts to F, and the fusée cutting to G. Dial-making, jewelling, gilding, motioning, etc. to others, down almost the entire length of the alphabet; and how that, taking these various pieces of work to outside workpeople – who, if sober enough to be at their places and were likely engaged on someone's work ahead of them, and how, under such circumstances, he would take the occasion to drop himself into a "pub" and drink and gossip and, perhaps, unfit himself for work for the remainder of the day ...* [2]

This classic method of production and the essential structure of the industry in Britain survived long after new watchmaking methods were evolved elsewhere to make cheaper and, ultimately, better quality watches. Despite its great achievements the system had obvious and considerable limitations. The high cost of a typical Clerkenwell watch was not due solely to low labour productivity resulting from complex handcraft technology. With few exceptions, by 1800 even the least expensive English watches normally included a *fusée*, which European competitors regarded as unnecessary for most ordinary production lines. A *fusée* was a device invented in the fifteenth century to compensate or equalize the uneven force exerted by an unwinding mainspring. It was a cone-shaped pulley with a spiral groove of varying diameter on which was wound a tiny chain with miniscule links.[3]

There was general agreement that if one discounted cost and complication of assembly, a *fusée* was a superior device to its alternative, the going barrel. *Fusées* were invariably used in the best chronometers, for example. But it was an additional complication, and therefore an additional expense. Its chain could and did frequently break, necessitating irritating and expensive repairs. A going barrel simply dispensed with this potential source of trouble: a sufficiently long mainspring was inserted, geared directly onto the wheel train, and only a portion of its potential unwind was used. It kept time adequately for most purposes, and was cheap and simple. Moreover, a *fusée* took up room inside the movement and necessitated a fatter watch case (thereby also increasing the amount and cost of the gold or silver used). Thick, heavy watches also became less fashionable than thin, light ones. Despite this, a *fusée* remained a quintessential feature of Clerkenwell's best watches.

New Swiss Technologies

The new watchmaking technologies which challenged the old came from Switzerland at the end of the eighteenth century and from the United States in the middle of the nineteenth. The first challenge came from the Swiss Jura at the very time that the English horological industry seemed in the ascendancy. Swiss watches had been produced by a putting-out system similar to that in England.[4] In Geneva the watchmaking industry had grown from a production of about 5000 watches a year in 1685 to some 85 000 almost a century later. During the 1770s, however, production methods were revolutionized when Georges Frédéric Japy devised a system which, in effect, mass produced the rough movement or *ébauche*.[5] By 1777 Japy had designed machine tools and a production line that required only semi-skilled labour. Annual output from his works reached 100 000 movements by 1800. Geneva finishers flourished thanks to the availability of cheap *ébauches*. But there were also other reasons why watches from the Jura and Geneva were cheaper than British watches. Just as important as standardized *ébauches* and lower labour costs was the adoption by Swiss and French watchmakers of the going barrel instead of the *fusée*, and a new, simpler and cheaper way of arranging the parts of the movement into a different pattern, or *calibre*, devised in the 1770s by Jean-Antoine Lépine.[6] Lépine's layout became the standard for European watches; it was especially suitable for the new generation of watches whose rough movements originated in Japy's factories. These features helped Swiss makers to tap the new mass markets for watches which were developing in the early nineteenth century as a result of rising incomes.

A cheap Swiss watch with a going barrel instead of a *fusée* kept time to an adequate level of accuracy. For most Britons and others,

especially first-time buyers, it represented much better value for money. Sales of smuggled Swiss watches in Britain were at first measured in tens of thousands, but after 1850 the lowering, and then the disappearance, of tariff barriers swelled imports to millions.

The American Challenge

After 1858 the British watch market was also penetrated by the products of a quite different horological technology which had emerged in the United States. This was the method of making clocks, and then watches, by what became known as the "American system." This reduced the hand-crafting techniques characteristic of classic horological technology to a minimum and then disposed of it almost entirely. To use Eugene Ferguson's widely accepted definition, the American system involved the "sequential series of operations carried out on successive special-purpose machines that produced interchangeable parts."[7] Its origins lay partly in developments in the New England clock industry in the early years of the nineteenth century, and partly in simultaneous developments in the region's small arms industry. Professor Hounshell has traced the diffusion of these production techniques into various other consumer and producer goods industries, and Professor Rosenberg has stressed the importance of the emergence of a separate, specialized machine tool industry by the 1840s.[8]

The American system achieved considerable successes in the production of wooden and metal clock movements. But factory production of watches was much more difficult. The tolerances required for watch parts were mostly beyond the capacity of the first generation of specialized horological machine tools; precision to 1:1000 inch and better was needed. The first successful steps towards such accuracy in the machine part production and watch assembly in factories was taken by the Waltham company in the early 1850s. Progress was slow, however.[9] In addition to technical problems there were financial and managerial crises, and the first examples of Waltham watches imported into Britain were contemptuously dismissed by Clerkenwell's craftsmen.[10]

Twenty years later, new generations of improved machine tools had turned the infant American watchmaking industry into a formidable giant and Clerkenwell was reeling under the impact. By 1880, for example, an American worker with a twenty ton punch could blank out about 10 000 wheels a day. Yet loyalty to the traditional technology persisted in Clerkenwell where wheels were still hand cut and finished. In the United States' watch factories, balances and springs as close to the desired standard as possible were made in vast quantities in large production runs. Hairsprings were sorted by strength and then matched to balance the wheels.[11] In Clerkenwell, the old technology of fitting a hairspring to a balance wheel was a highly skilled, specialized task.

In the manufacture of screws, which accounted for perhaps one quarter of the parts in a watch, Waltham's productivity increases were prodigious. Donald Hoke has recently explained how, under the American system, methods of producing screws changed from cutting each screw by hand.[12] In 1850, daily output per worker amounted to about 1200 to 1500. Several generations of screw cutting machines were subsequently developed. By 1885, one operative at Waltham could look after six machines and produce 50 000 to 60 000 screws per day. In 1854 it had taken 24 work days for Waltham to produce a watch; by 1907 it took 1.37 working days and, as Hoke stresses, the quality of the product was greatly improved.

British reactions to the Swiss challenge were organized by the Clockmakers' Company. Time after time the guild tried to persuade the government to protect the industry by enforcing trade laws aimed at preventing smuggling. But watches were notoriously easy to conceal, the smuggling trade was well organized, difficulties of enforcement were prodigious, and the penalties for smuggling were derisory. Indeed, so trivial were they that the cost of insuring against potential seizure and fines became a small extra charge factored into the purchase price. British consumers wanted cheap watches and British shopkeepers were willing to deal in them. Moreover, the British government moved away from protectionism after 1820 and lacked the will – as well as the capability – to control illegal watch imports.[13]

For 30 years the Clockmakers' Company fought a hopeless rearguard action as the tide of smuggled Swiss watches rose. The idea that domestic production methods should be modified to enable British makers to compete on similar terms with the Swiss was dismissed out of hand. Among the most prominent reasons advanced in favour of retaining the old technology was national security. Only classic watchmaking technology, it was argued, could produce an adequate supply of marine chro-

nometers for the Royal and merchant navies: it was necessary therefore to preserve and protect existing handcrafting skills. To reject classic technology might mean throwing out the baby with the bathwater. It was powerfully persuasive argument at the time. Other arguments stressed the evils of factory production and the dehumanizing features of factory labour.[14]

The Ingold Episode

The loyalty of Clerkenwell's independent, self-employed craftsmen to the old technology can be seen in the Ingold episode of 1842–43. A turning point in the history of British watchmaking, it marked a decisive rejection of new ideas in favour of old methods. The episode concerned attempts by Pierre Frédéric Ingold, a Swiss watchmaker, to establish factory production of watches.[15] Born in Bienne in 1787, Ingold had served his apprenticeship with the great Abraham-Louis Bréguet and had subsequently developed a number of machines to make watch parts. His first ventures to establish "factories" in Paris, Versailles and London during the 1830s had failed. In 1842 he tried again in London. His prospectuses for his proposed "British Watch and Clock Company" announced that he aimed to raise about £250 000 to buy and equip a factory in Soho, London. Using machine tools to produce watch parts, he planned an output of about 300 watches a day – or between 70 000 to 100 000 a year, approximately half the United Kingdom's then annual output of watches. Ingold's proposed watches resembled Swiss models in style and layout rather than English models: they were "quite slim for the period," and they did not contain a bothersome *fusée*.

After a long and bitter dispute and despite the powerful support lent to it by the young rising star at the Board of Trade, William Ewart Gladstone, the bill which would have established the company was defeated in parliament. After the defeat Ingold went to the United States where, curiously, he seems not to have had any connection with later American watchmaking developments. Finally returning to Switzerland, he died there, an old man, in the early 1870s, and is now mainly remembered for one of his machines, the *Ingold fraise*.

Ingold's failure meant that the attitudes of craftsmen became even more entrenched at the very time when they might have taken a lead in developing new technology. Ingold's proposals united even Clerkenwell's fiercely independent outworkers. Exhibiting classic Luddite reactions, some of them stormed the proposed factory premises and broke windows. They well understood the potential threat posed by the proposed developments. Subsequently, expert analysis of Ingold's patent applications and some of the surviving prototype machines has shown that he could not immediately have produced a complete machine-made watch. His machine tools were essentially variations of existing tools, such as a turret lathe, and a press and stamping machine which cut blanks for cogged wheels and balance wheels from a strip of metal. Had his proposals been implemented, however, they would have enabled their operators to produce more quickly than contemporary techniques allowed, and would have yielded parts for most of the watch. The final springing and adjustments would still, at first, have needed to be done by hand: an element of craftsmanship would have survived. It is probable that production from the original machines would not have been trouble free, but it is likely that improvements and solutions would have emerged to overcome the difficulties.[16] Later versions of the machine tools would no doubt have proved superior. At the very least, centralized production on one site would have increased labour productivity.

Ingold's defeat was decisive: the classic methods of production remained essentially unchanged in Clerkenwell up to the first world war. The only London firm to use machine tools to any extent was that of the Swiss brothers P. & A. Guye.[17] By about 1890 their 100 workers had the use of 80 to 90 "automatic machines," with which they made watch parts. But the finishing, springing and timing of the Guyes' watches were still done by hand; they were consequently expensive. Their output of about 500 watches a month was but a fraction of the 1000 or more watches a day being produced by contemporary giant American factories.

The remainder of Clerkenwell's independent watchmakers stubbornly opposed the introduction of any aspect of the American system. In 1858 they had formed the British Horological Institute (B.H.I.) to defend their interests, partly because of the inability of the Clockmakers' Company to do so, and partly because they recognized that the rising tide of imports represented a powerful commercial threat. But despite the valiant efforts of a few reformers, the B.H.I. itself mirrored the views

and prejudices of the great majority of craftsmen and masters in Clerkenwell. So great was its loyalty to the old and hostility to the new, that the B.H.I. rejected the idea that its own sponsored classes instruct apprentices in the use of machine tools.[18]

Other Experiences

Outside Clerkenwell there was also much evidence of the persistence of old horological technology and the failure to successfully transplant new methods of production. In the other centres of horological manufacture, Prescot and Coventry, as well as in Birmingham (the location of many small industries), some attempts to introduce new production methods were made. Very little information about the first efforts has survived. For example, a firm named the English Watch Company was founded in Birmingham during the 1870s, and survived for a year or two.[19] It had emerged from the ashes of an earlier speculation, the Anglo-American Watch Company, about which even less is known. These were the first explicit endeavours to copy the American system of watchmaking by buying-up and installing machines from a defunct American watch factory. A little later a German immigrant in Birmingham, William Ehrhardt, fared somewhat better.[20] He managed to persuade some horological outworkers to come together in a factory building, thereby effecting several simple economies of scale and organization. He introduced machines gradually. By 1899 he employed 400 workers and made about 600 watches a week. Further introduction of machinery resulted in a reduction in the number of employees rather than in an increase in aggregate output. Like the Guyes in London, Ehrhardt made more use of machinery to make watch parts, but the end product was still assembled and finished by hand. Neither Ehrhardt nor the Guyes really adopted the essential features of the American system, although it is interesting to observe that the Americans also finished and assembled by hand.[21]

The Persistence of Old Technology

The most notable examples of the persistence of old watchmaking technology occurred in Coventry and Prescot, revealing the depth of social and cultural – as well as economic – resistance to the adoption of new machines and methods. In Coventry the most conspicuous feature of watchmaking in the last third of the nineteenth century was the persistence of scores of small firms which hung onto old methods of production, in cut-throat competition amongst themselves.[22] This was despite several attempts to come to terms with new machine tools, of which the most notable was made by Rotherham, the city's oldest and biggest watchmaking firm.[23] The company's exposure to the reality and implications of new American technology came through John Rotherham (1838–1905). In 1856, at the age of 18, he had been sent to the United States by his father and grandfather to find out why the firm's American export market was declining. (Until about 1850 about half of Rotherham's watches had been exported, with the United States taking the largest share.) John's later account of his trip pointed with painful accuracy at the reasons for the collapse of the export market:

> *I called on the large merchants in New York, and they showed me drawer after drawer of Coventry watches, not one of which would go. They had been sent out with insufficient care, and the cost of repairing them out there was so great that they simply lay there, and the people who bought them were disgusted, and so was I.*

Chastened, the young Rotherham then visited the newly established Waltham watch factory and returned home to alert English watchmakers to the threat posed by new American production methods. His warnings went unheeded. This was partly because the collapse of American export orders was temporarily offset by a new market in Australia, created by the gold rush. But John Rotherham was henceforth conditioned by his first view of the American system, and when he eventually took control of his family's firm he determined to introduce machine tools into the production process. In 1880, after further examination of Swiss and American machines and methods, he installed some new watchmaking machinery. American design influences could be seen in a new cutting engine ("for cutting a stack of escape wheels at a time"), which was "nearly identical with one which had been exhibited at the (London) 1885 Inventions Exhibition by the Waltham Company." At first the strategy seemed successful, for business expanded. Within ten years the factory employed 400 workers, including 100 women.

Yet, for all of John Rotherham's progressive views, crucial features of the old technology

survived. The American system was only half-heartedly embraced. Even after the introduction of machine tools, some watches were still made in the old way, in a part of the factory specially set aside for the hand assembly and finishing of a mixture of machine-made and handcrafted parts. The reasons lay partly in management's concern for their old workers. A benevolent, paternalistic owner-manager, John Rotherham lacked ruthlessness. Old and new systems coexisted for a time. The consequences are well illustrated in a later recollection by Hugh Rotherham – John's son – of what had happened when a very refined machine tool was introduced and standardized measurements of 1/1000 inch were first discussed. An old worker, he said,

> *insisted that it was quite impossible that there would be a thousandth part of an inch, and when I tried to explain it to him, although I took a hair out of his head, put it in a gauge, and showed him it measured 3/1000 thick (sic) he was still incredulous.*

As well as the persistence of such attitudes amongst the old workers, the case of Rotherham shows that there were also fundamental errors of judgement in the management's production strategy. For example, the firm tried to make watches for every sector of the market. The resulting series of models could be seen in the firm's display at the Paris exhibition of 1889. They ranged from very ordinary grades up to those which bore Kew Observatory "A" certificates. By 1890 Rotherham was making 100 watches a day – a significant increase over the 150 a week recorded by Harriet Martineau during her visit to the factory in 1852. Even so, its productivity – and volume of output – was roughly similar to that of the Guyes and Ehrhardt. All were far below that of contemporary American factories.

The Lancashire Watch Company

The story of the Lancashire Watch Company (L.W.C.) is equally revealing of the reasons why old technologies survived the introduction of new ones. The L.W.C. was formed in 1888 in Prescot, near Liverpool, as an attempt to rescue the district's rapidly declining watch-component industry.[24] The enterprise was explicitly modelled after the Elgin National Watch Company's factory in Illinois, which the firm's founder, T. P. Hewitt, had visited on a trip to the United States. Before 1893, when the L.W.C. employed 1000 workers, it produced watches at the rate of perhaps 60 000 a year, and about 50 000 a year between 1893 and 1900. Output – and the firm's fortunes – then steadily declined and the firm was bankrupted in 1910. Thus, a firm which had been set up to produce cheap machine-made watches failed at the very time that Britain's annual watch imports approached two million.

Like Rotherham in Coventry, the L.W.C. was less than wholehearted in its adoption of new technology, and many features from the past persisted. It took in old workers and some of their tools and methods, with ultimately fatal results. For example, to try to overcome initial hostility to the establishment of a factory where, for two centuries or more, independent craftsmen had plied their trade in making parts and movements, Hewitt bought up all the independent businesses and brought the displaced workers and many of their tools into his new factory. Because it took some time for the new machine tools to be delivered and installed when the factory began operations, "much of the early work ... was probably a continuation of making older Lancashire models until new designs could be introduced." Custom died hard and was, in this instance, encouraged to continue.

But it was not just in manufacturing technology that the L.W.C. hung onto the past. Its production and marketing strategies were also antiquated. It allowed the price of its cheapest model, aimed at the bottom end of the market, to be fixed by the price of the competition (such as the Waterbury, "the watch that made the dollar famous") and not by its own production costs. Thus the "John Bull" had a recommended retail price of five shillings; it sold to the trade at 3s. 9d. each. As Professor Alan Smith, the firm's historian, has observed, it was a wonder

> *... how the company managed to produce them at all ... from November 1909 to March 1911 roughly 5000 John Bull watches were sold. At the trade price mentioned this would have brought back less than £1000 to cover overheads, materials, setting-up new tools and the wages of the employees! The John Bull was a desperate last effort to capture the market for cheap watches, and it was a dismal failure. Without the sale of tens of thousands the venture was doomed.*

There were, of course, other reasons for the firm's failure. Like Rotherham, the L.W.C. made too many models. It offered a standard range of eleven different calibres, or sizes, of watches.

Indeed, with various permutations, depending upon the numbers of jewels and quality, the company made well over 50 different watch models during its 21 years of existence. As Professor Smith has pointed out, each was available

> *with alternative finishes to suit customers' needs ... To have kept in stock, until the very end, a range of watches and their parts which were going out of fashion fifteen years before seems ... illogical and unbusinesslike ... Had the company concentrated on a few basic designs and sizes and brought the manufacturing costs down to a minimum, they might have succeeded.*

The persistence of old marketing strategies could also be seen in the company's simultaneous production of a range of English wall clocks. They offered these in seven different dial sizes, between eight inches (20 cm) and twenty inches (51 cm), each of them in five different quality grades, with further permutations allowed for the kind of cases and other features. Because of the range of options, prices varied between 23s. 9d. for the smaller, cheaper grades to eight guineas for the best. As if this was not enough, the company also made "electric meters, counters, workmen's time registers, cycle gears, dies, lathes, and every description of small mechanism."

The L.W.C. thus made itself the prisoner of potential demand for an extraordinarily large number of idiosyncratic consumer requirements. This prevented the proper development of new manufacturing technologies and sensible production and marketing strategies. What the firm needed was a small range of standardized, mass produced and saleable products. In reality it was in a hopeless position when competing with companies like the Swiss combines and the giant American watch factories that had jettisoned old production technologies in favour of new ones, and that had modernized their business practices.

The Death of the British Industry

The persistence of old production technologies resulted in the terminal decline of the British watchmaking industry. The 1907 Census of Production revealed that the watches made in British factories and large workshops totalled only 75 000.[25] A further unknown number – perhaps half as many again – were still produced by outworkers using the old handcraft methods in production units too small to be counted by census officials. But even the most generous estimates of their production would suggest that the aggregate output of the British watchmaking industry was far below that achieved during its years of peak production in the 1790s. By 1914 British watchmaking firms supplied probably less than 10 per cent of the domestic market for watches and, at most, accounted for about 20 per cent of its value. Between 1907 and 1914 annual imports rose from 2.5 to 4.5 million pieces.[26] In little more than a century British watchmaking, once the embodiment of contemporary high technology, had become an anachronism. Its surviving practitioners were virtually museum craftsmen in an age of machine-tool, assembly-line production.

A number of lessons can be learned from the failing fortunes of British watchmaking. First, it is clear that no matter how sophisticated its products may be, an old technology is doomed to extinction unless it can come to terms with changing production and market conditions. Clerkenwell's old technology was indeed very complex and, at its best, it produced prodigiously accurate chronometers. It was unable, however, to produce the very large number of cheap watches demanded by a mass market.

Second, resistance to accepting new methods and a long delay in adopting new machines proved fatal. Once the momentum of technical innovation passed elsewhere – as it did after Ingold's failure – it strengthened the resistance and loyalties of those who practiced the old technology.

Third, adopting just a part of a new system was insufficient. In the case of Rotherham and the L.W.C., simply bringing in some of the latest machine tools did not guarantee commercial success. Rather, as these cases illustrate, the realization that they were becoming mere machine minders instead of craftsmen simply deepened the incomprehension and hostility of workers who found themselves de-skilled. Benevolent, paternalistic management attitudes led to the retention of some old workers, old tools and old methods, and failed to placate workers' hostility. Instead they helped to prevent the proper transfer of the entire system of technology which included the adoption of new production technologies, as well as new methods of distribution and marketing.

NOTES

1. For a discussion of high and low horological technology respectively, see A. C. Davies, "The Life and Death of a Scientific Instrument: The Marine Chronometer, 1770–1920," *Annals of Science* 35 (1978): 509–525; and id., "Rural Clockmaking in Eighteenth Century Wales: Samuel Roberts of Llanfair Caereinion, 1755–1774," *Business History Review* 59 (1985): 49–75.
2. Aaron L. Dennison, quoted in Henry G. Abbott, *The Watch Factories of America Past and Present* (1888), 12–13. On the American wooden movement clockmaking see Donald Hoke, *Ingenious Yankees* (New York: Columbia University Press, 1990).
3. Peter Honig, "History and Mathematical Analyses of the Fusée," in Klaus Maurice and Otto Mayr, eds., *Clockwork Universe: German Clocks and Automata, 1550–1650* (1980), 114–120; and H. Alan Lloyd, "The Origin of the Fusée," *The Antiquaries Journal* 31 (1951): 188–191.
4. On Swiss horology, see Eugène Jaquet and Alfred Chapuis, *Technique and History of the Swiss Watch* (1953; 1970); David S. Landes, *Revolution in Time: Clocks and the Making of the Modern World* (1983), 237–273.
5. Landes, *Revolution in Time*, 261–262; Charles Allix, *Carriage Clocks: Their Historical Development* (1974), 133–137.
6. Adolphe Chapiro, "Jean-Antoine Lépine, 1720–1814: An 'Unknown' Maker," *Antiquarian Horology* 9, (1975): 443–454; and id., "Lépine, Bréguet, and the Origins of the Lever Escapement in France," *ibid.* 14 (1983): 369–396.
7. Eugene S. Ferguson, *Bibliography of the History of Technology* (1968), 298.
8. David S. Hounshell, *From the American System to Mass Production: The Development of Manufacturing Technology in the United States* (1984); Nathan Rosenberg, "Technological Change in the Machine-Tool Industry, 1840–1910," *Perspectives on Technology* (1976): 9–31.
9. Charles Moore, *Timing a Century: History of the Waltham Watch Company* (1945).
10. *Horological Journal* 1 (1858–59): 19.
11. See the discussion by Hoke in *Ingenious Yankees*.
12. Donald Hoke, "British and American Horology: Time to Test Factor Substitution Models," *Journal of Economic History* 47 (1987): 321–327; see also August C. Bolino, "British and American Horology: A Comment on Hoke," *ibid.* 48 (1988): 665–667.
13. S. E. Atkins and W. H. Overall, *Some Account of the Worshipful Company of Clockmakers* (1881) contains reprints of numerous petitions to the government by the guild during this period. For background on free trade in this period see P. J. Cain, ch. 2 of *Economic Foundations of British Overseas Expansion, 1815–1914* (1980). On smuggling Swiss watches, see British Parliamentary Papers vol. 45 (1836) "Report ... on Swiss Trade, Factories, and Industry."
14. See the reports of the debates on the implications of "modernization" conducted by the British Horological Institute, in *Horological Journal* 1 (1858–59) and 22 (1879–1880).
15. R. F. and R. W. Carrington, "Pierre Frédéric Ingold and the British Watch and Clockmaking Company," *Antiquarian Horology* 10 (1978): 698–714. The main papers connected with this episode are in the Guildhall Library, London: MSS. 3943/6–17.
16. Landes, *Revolution in Time*, 283–285.
17. *Watchmaker, Jeweller, and Silversmith* (July 1890): 1–11; *Horological Journal* 35 (Feb. 1893): 85–86.
18. *Horological Journal* 27, (Aug. 1885): 163–164; *ibid.* 47 (Sept. 1904): 2–4.
19. Roy Church, "Nineteenth Century Clock Technology in Britain, the United States, and Switzerland," *Economic History Review* (2nd ser.) 28 (1975): 626; *Watchmaker, Jeweller, and Silversmith* 10 (1884): 1–4.
20. *Horological Journal* 40 (Jan. 1898): 63.
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22. J. R. Bailey, "The Struggle for Survival in the Coventry Ribbon and Watch Trades, 1865–1914," *Midland History 7* (1982): 132–152.
23. The details are fully documented in A. C. Davies, "Old and New Technology in Coventry, 1850–1920," *Antiquarian Horology* 18 (1989): 397–410.
24. Alan Smith, *The Lancashire Watch Company: Prescot, Lancashire, England, 1889–1910* (1973); also A. C. Davies, "Thomas P. Hewitt, 1848–1933," in D. J. Jeremy, ed., *Dictionary of Business Biography* 3 (1985): 186–188.
25. *British Parliamentary Papers* vol. 109: 1 (1912–13), "Final Report of the First Census of Production of the U.K., (1907)," 261–263, 279–281.
26. *Id.*, vol. 83 (1914), Tables 14 and 17: "Imports and Exports of ... Merchandise, 1909–13."