The Scientific Instrument Trade in Provincial England during the Industrial Revolution 1760-1851

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Abstract

This investigation into the growth of manufacture of scientific instruments in provincial England outside London during the Industrial Revolution, was prompted by a set of questions posed by the instrument historian J.R. Millburn in 1986, and uses his criticisms of the existing state of knowledge about this subject as an agenda for a way forward. At the start of the Industrial Revolution, it appeared that most of these instruments were made and sold in London, but by the time of the Great Exhibition in 1851, a number of provincial firms had the self-confidence to exhibit their products in London to an international audience. How had this change come about, and why?

Guided by Millburn's queries, this thesis looks at the four main, and two lesser, English centres known for instrument production outside the capital: these were Birmingham, Liverpool, Manchester and Sheffield, with the older population centres in Bristol and York. Using new sources, their growth is charted, together with some characterisation of their products. From contemporary evidence, it is argued that the principal output of the provincial trade (with some notable exceptions) must have been into the London marketplace, anonymously, and at the cheaper end of the market. More generally, how did the Industrial Revolution affect the instrument trade, and did the instrument trade influence the Industrial Revolution at all? This thesis discusses the structure and organization of the provincial trade, and looks at the impact of new technology imported from other closely-allied trades. New information is provided on some aspects of Millburn's agenda, especially marketing techniques, sources of materials, tools and customer relationships. However, the nature of the evidence has meant that there are still some lacunae, particularly where the size of individual workshops are concerned, and for most of the financial aspects of the trade.

Contents

Author's Declaration

This thesis is the result of my own work and includes nothing which is the outcome of work done in collaboration, unless acknowledged as such. Some material has been published in the course of writing this thesis, and these articles are included in the Bibliography under my name.

Acknowledgements

Firstly, I must acknowledge my institution, the National Museums of Scotland, which not only allowed me to devote 20% of my working life (a day a week, nominally, but in the later stages a much more outrageous proportion) to this project, but also underwrote it to the extent of paying 80% of my fees. An institution which is prepared to allow one of its staff to further herself through scholarship is these days an unusual place, and one to be cherished. I am indebted to the far-sightedness of my senior management, which can see beyond the mundane to the lasting importance to that institution, of scholarship, research and publication. I hope that this piece of work fulfils their expectations, and will bear the fruit they wish.

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Illustrations and Tables

Introduction

Subject and reason for this work

This thesis has developed as a logical extension to earlier projects in instrument history undertaken with colleagues in the course of my work as a museum curator.[1] Since it is a function of curators to collect, their research is done to inform future collecting as well as to understand and contextualise material already in their care. My specific job responsibilities, as a curator in Scotland's national museum, are towards the collection of instruments (known as 'scientific instruments' to differentiate them from musical instruments) from their beginnings to about 1900, with special reference to items used or manufactured in Scotland. It became apparent in the course of research into the history of Scottish and Irish instruments that the trade in these localities was bound up closely with that of England, and in particular, during the early modern period, with that of London. However, during the Industrial Revolution it appeared that the powerful influence of London waned, and some new locations in the English provinces, specifically, four: Birmingham, Liverpool, Manchester and Sheffield - became important in providing instruments on an international scale. Why should this have been, and how had it happened?

No complete survey of this industry, either temporal or geographical, had been published when I started this thesis, partly because of the difficulty, diffusion and scarcity of source material, but also because the instrument-making workforce was never very large. This meant that the industry had not been perceived as particularly important, either in economic or social terms. It had had its beginnings in England in late Tudor times, reached an international standing during the eighteenth century, and encountered growing foreign competition from the mid-nineteenth century. In its older form - the traditional staple of optical instruments - it declined steeply after the Second World War, although British manufacturers are still producing instruments for the experimental, usually state-subsidised, part of the market: in vacuum science, MRI (magnetic resonance imaging), and mass spectrometry, for example.[2] Currently, most of the instrument types covered by this thesis have either been technically superseded, or are manufactured by German or Japanese firms. Apparently only of antiquarian interest, it would yet seem that the English trade and manufacture of

[1]. Burnett and Morrison-Low (1989); Clarke et al. (1989).

[2]. Much of the chronology of the British instrument industry for the twentieth century can be traced through the Journal of Scientific Instruments, published by the Institute of Physics from 1922-1967, subsequently continued as the Journal of Physics E: Scientific Instruments.

scientific instruments was important to the economic upheaval which historians call the Industrial Revolution. Instrument-making brought varied skills together into a single trade which produced items that assisted change in many economic activities. The trade itself was a small, albeit significant, section of the skilled metal trades, in which specialist craftsmen produced relatively expensive commodities initially for the luxury end of the market. In due course, however, it was the more practical and useful items which formed the bulk of the trade's production. For example, increasing numbers of surveying instruments were needed to expand and develop the transport system of late eighteenth century England, beginning with the canals, but extending to the road system and eventually helping to create the railway network. A large demand for navigational instruments was created by increasing overseas trade connected with imperial expansion, and with the growth of a merchant navy to carry these goods, and of the Royal Navy to defend them. Technological change in the making of instrumentation, such as the introduction of the dividing engine,[3] may have meant that this growing demand was largely met. Considerable numbers of scientific instruments, across a broad spectrum, from very cheaply-produced pieces to bespoke individual items, appear to have been exported, while the London shops were also able to supply a healthy home market. A closer examination of this business, using an economic history approach, could lead to a better understanding of this specialist trade, its networks and its more general effects.

Thesis definitions and parameters

The major problem of this topic centres around defining the nature of change in the trade and manufacture of instruments during this period, from about 1760 to about 1850. The evidence is fragmentary, scattered and often hard to find. There is also a subset of questions, relating to the connections between the four provincial centres and London, long acknowledged by instrument historians to be the world centre of the precision instrument trade at this time. These include: how to characterise the differences and links between each centre; particular methods of marketing, and distinctions between closely allied trades, such as horology or cutlery, which were also using technically-skilled metal workers. Where did the demand for these instruments come from, and how did the provincial centres supply it, particularly in face of competition from London? Here is a paradox between the physical survival of many hundreds, if not thousands, of instruments and the

[3]. A device which marks out circular or linear scales into degrees or measured intervals: see

paucity of documentary information about the economics of their construction and marketing. In chapter 1 this discussion is set in the context of the economic history literature on the nature of industrialisation and technological change. Although this thesis is about instrument making in 'provincial England', characterised for the first time in chapter 2, the international context of the London trade means that a broader European picture has to be sketched, together with some explanation of the relative positions of the trade of other countries at different times, and this is examined in chapter 3.

The topic covers a wide range of craft and manufactured products which were used in a variety of disciplines. The raw materials of construction - mostly brass and optical glass - are of some importance, and their manufacture and supply to the provincial instrument trade is discussed in chapter 4. At the time, there were no such classifications as 'precision instruments' or 'scientific instruments', which are late-nineteenth century descriptions.[4] These terms have come to mean specific historic categories for the historians of instruments: 'precision instruments' now means a finely-divided, usually London-made, probably large astronomical or first-order surveying item which was made by a front-ranking craftsman and would have proved expensive in time and materials. 'Scientific instruments' were made in London, too, and provided the everyday trade which allowed the 'precision' items to be made in terms of expertise and cash flow; but whereas 'scientific instruments' began to be made in increasingly large numbers in the provinces, it was only by the mid-nineteenth century that 'precision instruments' could be produced there. Why was this and how did it come about?

Contemporaries classified instruments by their use, as 'mathematical', 'optical' and 'philosophical' instruments, and examples of each can be identified illustrated in the trade- card of J.M. Hyde of Bristol, in business between 1841 and 1855 [Fig. 1]. Historically, mathematical instruments were the first to be developed, and included such items as sundials, logarithmic scales and sighting instruments. Any device which had a graduated scale, which was used to measure angles or distance, or perform calculations, could be regarded as a mathematical instrument: thus both maker and user had to be both numerate and literate. Optical instruments were

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Chapman (1995).

4. For discussions of this problem, see Warner (1990) and Turner (1993).

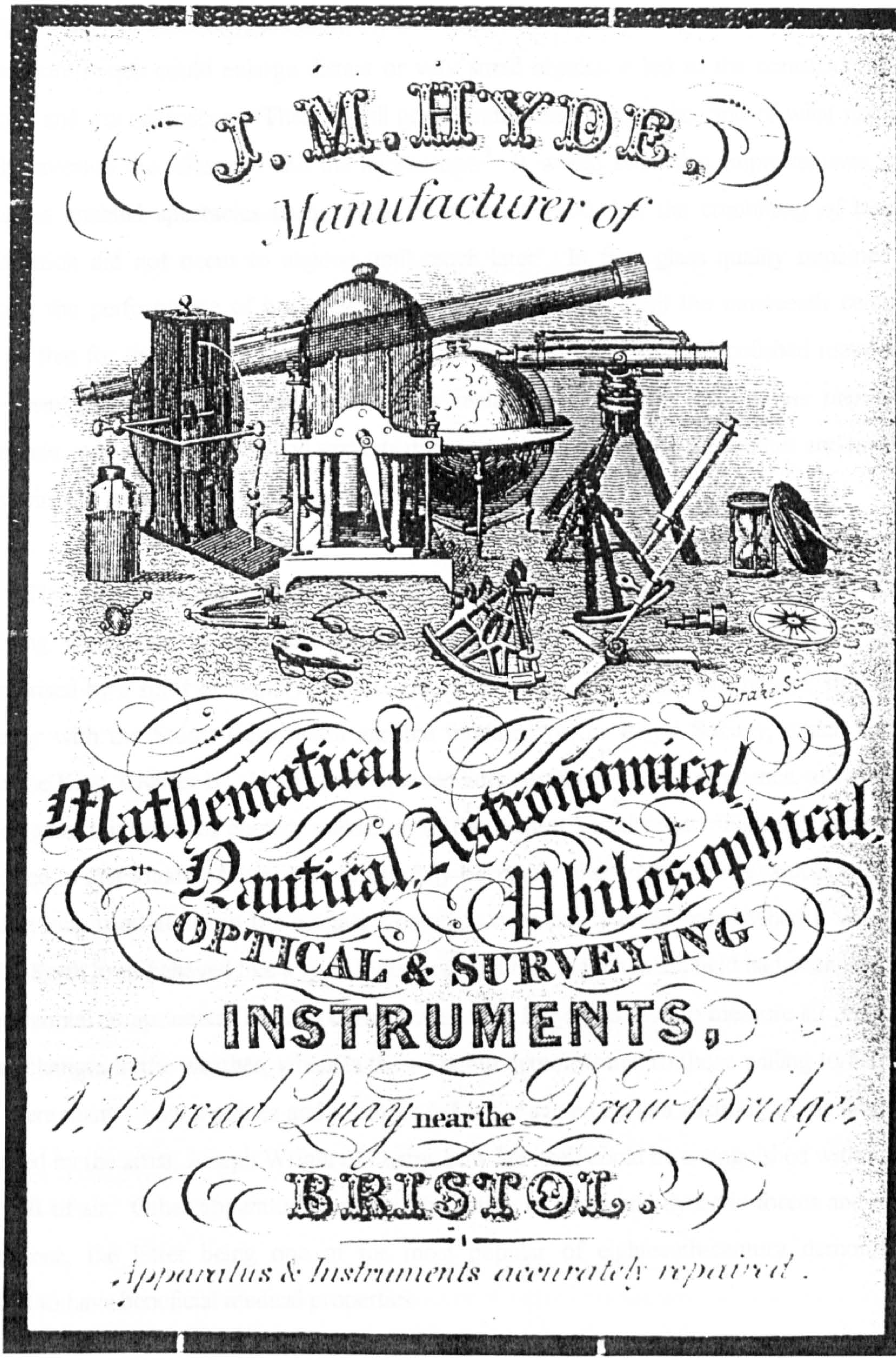

Fig. 1:1 Trade card of J.M. Hyde, Bristol, 1841-55.
Reece Winstone Archive & Publishing.

developed after the discovery, probably in the Netherlands at the end of the sixteenth century, that two or more lenses could enlarge distant or very small objects: it led to the construction of the telescope and the microscope. There is still great controversy about who, and of what nationality, actually invented the telescope and the microscope.[5] It would seem that improvements in glass production enabled spectacles to be made from about 1300, but the combining of lenses for magnification did not occur to anyone until much later. In fact, glass quality remained poor, inhibiting the performance of both telescopes and microscopes until the nineteenth century, so much so that for the eighteenth century the larger aperture telescopes had polished metal mirrors rather than glass optics. Optical components replaced open sights on various mathematical instruments, such as the octants and sextants used in navigation, and the theodolites and levels used in surveying, to improve pointing accuracy.

The third grouping, 'philosophical' instruments, dates from the mid-seventeenth century, coinciding with what is often described as the Scientific Revolution, or the New Science, characterised by a spirit of enquiry into the natural and physical world. In England, this occurred politically with the Stuart Restoration and the founding of the Royal Society, which had as its patron the King, Charles II. Although he showed little sustained interest in science, as royal patron Charles gave this spirit of enquiry validation of the highest social order. New instruments were developed to investigate or demonstrate naturally-occurring phenomena. For example, magnetism, although long used at sea in the mariner's compass, was newly investigated when it was realised that the Earth itself behaved like a giant lodestone, and that the magnetic field had changing vertical and horizontal components. The barometer, invented in Italy, was used to measure air pressure and predict changes in the weather, whereas the air pump demonstrated to those willing to listen - and there were many - how a guinea and a feather fell at the same rate in a vacuum; or, as dramatically portrayed by the artist, Joseph Wright of Derby, how life itself could be extinguished without God's great gift of air. Other apparatus illustrated the action of static and dynamic forces and electrical phenomena, the latter being one of the most popular of eighteenth-century demonstrations, believed to have beneficial medical properties.

This variety of instrumentation resulted in a correspondingly wide spread of different types

[5]. Discussed by van Helden (1977). More recently, see the meeting report 'Was there an

of customer. The eighteenth-century market for instruments was identified in the 1960s by Silvio Bedini as threefold: first, there were the men of science, the philosophers who performed experiments, and who needed new apparatus to help them in their investigations. Although a proportionally small part of the market, this important relationship between maker and user was on a one-to-one basis, and the technology thus developed helped to increase scientific understanding, while the scientific ideas brought technological improvements. It helped develop the instrument-maker's skill, and if the device was published by the user, thus stimulating interest in the demonstration, then it could be produced by the maker in larger numbers. A second, and somewhat larger group of customers, were the dilettanti; that is, the gentlemen with sufficient disposable income to be able to buy the latest fashionable microscope (for instance), either as an amusement or to entertain and impress friends. Bedini's third and largest group can be identified as the so-called 'mathematical practitioners', those who required instruments for practical use in everyday life.[6] Substantial collections of all these categories of complex items have survived as material evidence, some of it accessible for study in public museums.[7] It is worth stressing that this material can be used as a three-dimensional archive because careful examination of individual items often reveals information about its manufacture or subsequent history. Objects can be used as historical evidence just as material culture is used in archaeology. There is therefore scope for analysis of its manufacture, the workshop organisation of the trade and the market development during this period. For example, individual surveying instruments were assembled in small groups or batches, but because the parts were only approximately interchangeable, each was identified by a number within the batch, so that all components with a particular number could be finely-adjusted to fit that individual instrument: only by dismantling such instruments do these numbers come to light, but they give an idea of the size of batches produced in an individual workshop.[8]

Elizabethan Telescope?' with further references and contributions from Ronan et al. (1993).

[6]. Bedini (1964), 3-13.

[7]. In the United Kingdom, the major collections of such material are held at the Science Museum, London; the National Maritime Museum, Greenwich; the National Museums of Scotland; and the university museums at Oxford and Cambridge, respectively, the Museum of the History of Science and the Whipple Museum of the History of Science. Much of the material is published in catalogue form, and currently more of it is being made accessible on the Web; however, there are no substantial collections of English provincial instruments. Abroad, the principal collections are to be found in the Deutsches Museum, Munich; Musée National des Techniques, Paris; Museum Boerhaave, Leiden; Museo de Historia della Scienza, Florence; and the National Museum of American History, Washington D.C.

[8]. Clarke et al. (1989), xi.

Had the nature of the instrumentation changed by the mid-nineteenth century? There was certainly a wider variety of choice, demonstrated by the contents of the catalogues of available items supplied by individual firms, and there were entirely new classes of instrument, for example, in telegraphy and photography. However, the markets appear to have remained substantially the same. Willem Hackmann has stressed (as has J.A. Bennett) that the market in precision instruments (principally astronomical) was stimulated in the late eighteenth century by three London institutions, and thus by the State: these were the Royal Society, the Board of Longitude and the Royal Observatory.[9] In time, the powerful influence of these bodies waned. The Royal Society became more of a gentlemen's club and less a focus for scientific work, until reformed in the late nineteenth century.[10] Once John Harrison had effectively 'solved' the problem of longitude, the Board's purpose changed, and it was finally wound up in 1828.[11] During the nineteenth century, the effect of the long incumbency of the seventh Astronomer Royal, George Biddell Airy (1801-1892), saw the pre-eminent firm of Troughton & Simms regarded 'as his personal mechanics for any small task, from repairing spectacles to making up some gadget from his scribbled sketch.'[12]

Indeed, by the early decades of the nineteenth century, the scientific input into the British Industrial Revolution was perceived by some contemporaries to be 'running out of steam'.[13] The mathematician Charles Babbage (1791-1892) was one of the most vocal of this point of view, publishing in 1830 a famous essay on 'The Decline of Science in England', arguing that this trend could be reversed only if the State rewarded scientists properly for their endeavours, instituting research grants, and providing an effective system of scientific education.[14] Hackmann goes on to demonstrate that in some ways the Great Exhibition of 1851 vindicated Babbage's point of view: 'the organizers who were keen to show the triumph of British industrial power, in the end demonstrated that Britain might be eclipsed by the technical capabilities of her faster-growing European rivals.'[15]

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9. Hackmann (1985), 58; Bennett (1985), 14.
10. Hall (1984).
11. Andrewes (1996); Landes (1983), 143-157.
12. McConnell (1992), 39.
13. Hackmann (1985), 61.
14. *Ibid.*, quoting Charles Babbage, *Reflections on the Decline of Science in England, and on Some of its Causes* (London, 1830).

Hackmann has analysed the contents of the Great Exhibition's Class X, Philosophical Instruments, together with relevant Jury reports: the English entries took the majority of the prizes, as might have been expected. However, on closer inspection, this was less impressive: 'it is difficult to identify national trends in these awards, except that a great deal of energy was devoted in England to the new field of electric telegraphy which had much trade potential, while French makers developed their market for well-made optical instruments.'[16] It was felt by Babbage and others that the trade itself required better rewards, together with some form of technical education for skilled workmen, as by this time the apprenticeship system in the London craft guilds was clearly inadequate. Such attempts to move in this direction - by the London-based Society of Arts, founded in 1754 (as the Society for the Encouragement of Arts, Manufactures and Commerce), by the Mechanics' Institutes movement, dating from the 1820s, or by the British Association for the Advancement of Science, founded in 1831 - proved to be insufficient for the demands of industry: State-organised scientific and technical education did not come to England until the 1870s.[17] This was to prove the market growth area in the latter part of the nineteenth century, and large numbers of provincial instrument firms were to benefit from the captive markets in schools both at home and in the colonies.

The problem

An agenda for an analysis of the instrument trade during this period was set in 1985 by an exhibition in Cambridge entitled 'Science and Profit in 18th-Century London'. This was accompanied by a collection of essays under the same title on aspects of the eighteenth century London trade: 'The Economic Context', by Roy Porter, 'The Scientific Context', by J.A. Bennett, 'Scientific Instruments and their Public', by Simon Schaffer, and 'The Instrument-Making Trade' by Olivia Brown.[18] Generally, this was received more or less favourably by curators and historians of science, but there was some criticism from the respected instrument historian, John Millburn, who took the monograph to task for being:

[15]. *Ibid.*, 65.
[16]. *Ibid.*, 64.
[17]. *Ibid.*, 66-67.
[18]. Porter et al., (1985).

> altogether too complacent and uncritical. Reading this, one would never guess that little is in fact currently known about the detailed structure of the instrument-making trade in the eighteenth century, or about the lives of the individuals around whom the whole fabric of the exhibition is constructed ... Detailed studies of individual instrument-makers - their finances (this exercise is supposed to be about profit as well as science), their marketing techniques, their sources of materials and components, their tools, their relationships with their workmen, subcontractors and each other - are, with very few exceptions, non-existent. For example, almost nothing is known for certain about the size of the individual instrument makers' workshops, or how many specialist craftsmen were involved in the construction of different types of instrument, apart from what can be deduced from numbers of apprentices bound and a few isolated 'facts' such as the claim that Ramsden employed 50 men. Economic historians resort frequently to citing two major business archives that happen to have survived, the Wedgwood papers and the Boulton/Watt papers, though in the absence of similar material on their competitors it is debatable whether the conclusions drawn are reliable. Historians of scientific instruments in the eighteenth century have no such convenient stores to draw upon. The relevant information must be painstakingly extracted piece by piece from a variety of sources ..., a daunting task but one which nevertheless must be undertaken before a reliable and comprehensive synthesis of the trade in the 18th century can be constructed.[19]

This thesis is a response to Millburn's challenge, and will attempt to measure up to the agenda he set. What Millburn wrote in 1986 was a fair statement of the status quo, and that he felt he was the proverbial voice crying in the wilderness is shown by a later article, which had more of his thoughts along these lines.[20] This gave advice about where clues to the structure of the trade might be uncovered, but as individual examples of particular instances. He maintains the agenda he set in 1986 by publishing critically-argued detail. However, he provides no synthesis, and his principal objection to Porter et al. is that they purport to give an analysis of the trade which is not based on data, because that data has yet to be captured.[21] Such an analysis would involve extracting as much detailed information about the nature of each firm and its products as is to be found in archival and printed sources, and in the evidence provided by the instruments themselves. This thesis aims to make a start towards this objective, by providing an outline of the changing size of each provincial centre over time, and giving some characterisation to the nature of the trade.

'The trade' is a term which embraces both named manufacturers and retailers, and can even be extended to encompass all who participated in the making or selling of 'scientific' instruments; in

19. Millburn (1986c), 84.
20. Millburn (1989).
21. Among Millburn's most detailed work is his publications on the London lecturer and

view of the recent historiography debating the parameters of the Industrial Revolution, this should certainly look at the roles of women and children, and consider to what extent this particular business was a family enterprise. 'Provincial England' may appear on the surface to be a prejudicial term, but it merely means 'outside London'; and the places in which the trade operated were quite discrete:

> ... instrument making in the British Isles outside London was a provincial activity at least until the latter years of the 19th century. It was provincial in that London was the centre of activity, with manufacture in other towns and centres largely a peripheral activity.[22]

However, no instrument historian appears to have asked why this was so, nor how it came to have changed by the late nineteenth century.

In contrast to the situation in some other manufacturing industries, London never ceased producing instruments and instrument parts during this entire period: chapter 3 discusses how important London became in international terms, and the reasons for this. Some indication of how it maintained and then subsequently lost its pre-eminent position will be given; and how provincial centres of instrument making interacted with London producers and retailers. The four major provincial centres - which were the centres of most vigorous activity - are described in chapter 2. These centres were Birmingham, Liverpool, Manchester and Sheffield, although some activity elsewhere has been noted during this period, in particular in Bristol and York, and this is described for comparative purposes. There is evidence of instrument production in all four major provincial centres throughout the period of the Industrial Revolution, and the size of the trade in each location will be estimated, compared with that of London, together with some identification of the nature of provincial input to the London trade. All four centres were ones which showed considerable population growth at this time. However, not all new industrial population centres became bases for instrument making: particular conditions had to be in place before a provincial centre could flourish. Was this because the instrument trade fulfilled the conditions of a 'proto-industrial' trade? As economic historians have come to an appreciation of the slower rates of economic growth at this time, it has led to discussions about the period and conditions before industrialisation, through the concept of 'proto-industrialisation'. Although this term was first coined in 1972 by Mendels to connect areas of rural manufacture with growing populations which could not be sustained solely

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instrument maker Benjamin Martin: see Millburn (1976), (1986a) and (1986b).

22. Bryden (1984).

by local agriculture, it has proved a useful theoretical tool, by trying to show that there was a more evolutionary form of capital accumulation and technological change, with emphasis as much on cultural changes and labour organisation, as on mechanical innovation.[23] The symbiosis of agriculture and industry across the seasons, the co-ordination of rural industries by urban merchants and the dependence of those industries on distant markets has been supported by evidence in some regions, and especially in metal-working trades.[24] However, the concept of proto-industrialisation is not always appropriate, as Coleman has pointed out, for out of ten English regions which experienced it, six did not move on to experience the 'Industrial Revolution' proper.[25] Coleman also stresses the precondition of coal resources as a more important factor: Hudson shows that quite other factors, such as the gender division of labour and the complexity of the development of industrial capitalisation which varied in each specific instance, were crucial in the industrialisation of the textile industries.[26] Unfortunately, the model does not work for instrument manufacture because, particularly in the case of Birmingham, the trade - as a component of the metal trades based there - was so nationally and externally oriented for the marketing of its products, it had clearly developed along lines of its own.[27] Even the case of Sheffield, which appears superficially to have some of the characteristics of proto-industrialisation in that makers of instruments appeared to support themselves with seasonal agricultural work, yet their products were also sent to distant markets and there was no accompanying population explosion. In both cases, the manufacture of instruments or their components remained a small-scale, family-run enterprise, in which aspects of production were farmed out to subcontractors.

The term 'Industrial Revolution' has a long history, dating back to the end of the nineteenth century, and has recently been a hotly-contested area of discussion amongst economic historians. Together with related arguments over the rise of mass markets and consumerism, and the perceived eventual decline of Britain's world economic domination, the recent literature where it relates to instrument production will be discussed in chapter 1.

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23. Berg et al. in Berg et al. (1983), pp.1-32.
24. Hey (1972); Rowlands (1975); Berg (1991), pp.3-26; Berg (1994); Crafts, (1985).
25. Coleman (1983).
26. Hudson (1992), 111-120.

Instrument history

The traditional literature in this area concentrates on museums' and collectors' interests, and studies have tended to dwell on how and why an instrument works, and on the origins of its inventiveness.[28] In addition, the literature tends to be internalist and self-reflecting. The two pioneering monographs on the people who made up the trade were written by a geographer, E.G.R. Taylor: *The Mathematical Practitioners of Tudor and Stuart England 1485-1714* (Cambridge, 1954) and *The Mathematical Practitioners of Hanoverian England 1714-1840* (Cambridge, 1966), and for thirty years Taylor's volumes (or at least the biographies published in them) were adopted uncritically as a ready means of identifying the personalities within the trade. Since then, a burgeoning literature for scientific instruments has developed. However, the historiography of instruments has to some extent been 'demand-led': to date, the people who have wanted to know about instruments were museum curators, antiquaries, collectors, and latterly, auctioneers and dealers. (The priority of this last category often being uncritical dating, upon which to base their pricing, which is what makes the Antiques Roadshow such rivetting television.) It is hardly history in the round. It has led to an over-emphasis on the 'maker', and generated some biographical discussion, with a reliance on directory-type secondary sources, without pushing further into any historical considerations, or social or economic contexts.[29] The emphasis on the signature or 'name' has led to a lack of understanding of the structure of the trade and how it might have functioned. A long-cherished perception that a named craftsman constructed all the items bearing his signature through all stages of manufacture has obscured the nature of the enterprise: together with the lack of archival records, instrument history has in some instances become straightforwardly misleading. Recent historiography of this subject since the 1960s is outlined in chapter 1. This thesis is adopting a different approach: that of examining Millburn's challenges in a social and economic context.

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27. Berg (1991), 173-201.

28. There is an extensive literature covering the history of the development of instrumentation, which tends to be antiquarian in its approach. Much of this is captured in a series of bibliographies: Maddison (1963); Turner (1969a); Turner (1983b), and the bibliography produced annually (since 1983) by the Scientific Instrument Commission of the International Union of the History and Philosophy of Science, the first thirteen recently published together as Turner and Bryden (1997).

29. An example is the ill-conceived, self-published work by Banfield (1991), which uncritically assembles dates and 'facts' from a series of secondary works, without checking the original sources, thus compounding any errors.

Methodology and sources

The most obvious source to uncover the numbers of instrument-making firms has been the local street directories, which started to appear as increased commercial activity spread throughout the English provinces. Often the information found in these has been taken at face value, despite the knowledge that there are a number of inherent problems.[30] Among these, there is a lack of knowledge concerning the motives of the contributors, the topicality and veracity of the information, and whether entries had to be paid for. Directories, produced intermittently, are a flawed source, yet remain the most important starting point for uncovering the names and probable longevity of businesses, and have been used as such here. Even so, the first extensive directory-based listing of the instrument trade was published only as recently as 1995, and although the last twenty years has seen individual lists published for Scotland, Ireland and Victorian London, nothing has been produced for the rest of provincial England.[31]

This *Directory of British Scientific Instrument Makers 1550-1851*, by Gloria Clifton is the culmination of over a decade of research by Project SIMON (Scientific Instrument Makers, Observations and Notes), set up in 1984 by Professor G.L'E. Turner, to create a national database of instrument makers and sellers. Signed instruments survive in reasonably large numbers, because they are considered beautiful as well as functional. Yet the signature indicates only the point of retail, usually in London (for reasons which will be discussed in chapter 4). Early items with provincial signatures are most unusual, yet it is apparent from contemporary street directories and other archival sources, that instruments were being produced in the provinces, especially in what were later to become the major provincial centres, from a reasonably early date. The first research officer of Project SIMON was Michael Crawforth, assisted by his wife Diana, and this post was subsequently filled after Mr Crawforth's death in 1988 by Gloria Clifton.[32] Trawling through London guild records, Corporation of London records, trade directories, parish records, wills, insurance registers, advertisements, trade cards and inscriptions on instruments, they compiled

[30]. These are discussed in Goss (1932); Norton (1950); Shaw and Tipper (1988). See also Shaw (1982).

[31]. Bryden (1972) (revised as Clarke et al. (1989)); Burnett and Morrison-Low (1989) and Downing (1984). Clifton (1995) looks in particular at London instrument makers within the London guilds, but takes provincial instrument-making only partially into account, using some provincial directories.

[32]. Clifton (1993a), 341, n.1; Clifton (1995), xi-xv.

different fields in a database:

> Each maker has a separate entry - completed as far as possible - comprising name and working dates, trade, addresses with dates, and such guild details as apprenticeship, master, freedom and apprentices, all with dates. Then come such associated names as family relations in the trade, partners, employers and employees, predecessors and successors, followed by miscellaneous information, types of instruments made and advertised, and - most importantly - references to the sources of information.[33]

The emphasis of this whole work - correctly - has been on the centre of the trade: London. Much of the Scottish and Irish material has been supplied by earlier publications produced by the National Museums of Scotland, and some raw data from research for this thesis was also fed in for Birmingham, Sheffield, Manchester and Liverpool makers. One of the aims of this thesis was to supplement the Project SIMON database. Thus broadly similar comparisons can be made between the London trade and that in the provinces. However, the principal difference between the figures obtained by Project SIMON and those in this thesis is that SIMON contains all named individuals (including apprentices and otherwise unrecorded signatories of instruments), whereas this thesis looks at numbers of businesses as a starting point.

In trying to answer Millburn's agenda, a range of quantitative and qualitative questions emerge: what was the size, scale, structure of the trade? Conventionally, the economic historian would turn to relevant business archives to answer these questions. However, few business archives of this type of enterprise have survived. That of the firm of Kelvin & White of Glasgow is lodged in Glasgow University Archives; that of Berry & Mackay of Aberdeen is to be found in Aberdeen University Library. It seems that nothing survives from the early years of Ireland's only instrument makers with an international clientele, the telescope makers Howard Grubb, formerly Thomas Grubb and latterly Sir Howard Grubb Parsons of Newcastle. In England, apart from the archive from the businesses of Thomas Cooke of York, and the associated London firm of Troughton & Simms (now in the Borthwick Institute, University of York), and some early records associated with the London firm of William Elliott (currently held at GEC Rochester, Kent), and later stockbooks from 1866-1944 of J.H. Dallmeyer, there are otherwise no substantial business records known to survive from this type of firm at this period.[34] In their absence, other methods

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33. Bennett (1995).

34. Use of the records of Kelvin & White and Berry & Mackay was made by Clarke et al. (1989); Grubb is discussed in Burnett and Morrison-Low (1989), 89-117 and Glass (1997). McConnell

have to be used.

Even looking at the rate of success or failure is complicated: surviving English bankruptcy proceedings are hard to find, as the official papers relating to this were destroyed earlier this century.[35] The bankruptcy papers from only two English instrument-making concerns have survived, both London-based, and one of these has recently been scrutinised in some depth.[36] Other sources - probate, insurance records, wills, bank accounts and rate books - can be used to fill out the detail of business biography necessary to provide the picture capable of the synthesis required by Millburn.[37] Millburn has made a start by looking at the records of the Board of Ordnance at the Public Record Office, to work out how lucrative the royal appointment holders found their contracts during the French and Napoleonic Wars, and his data will be more closely examined in chapter 6.[38]

The very nature of the business undertaken was technologically sensitive in that the major London workshops were producing the most highly sought-after precision instruments, at the industry's leading edge, and there was a government embargo on information about production until the 1820s. The men who ran these firms in any case wished to keep their competitors, whether foreign or provincial, in the dark about their innovations. Unsurprisingly, no English descriptions of the workshop floor appear to have been made, apart from George Adams's brief and general description of subcontracting in the London trade of the 1740s, which was really a personal reassurance of quality control to prospective customers:

> In the construction of all the Machines I have ever made, my first and greatest Care hath been to produce good Models and Drawings, several of them I have imitated from the best Authors, as well as Foreigners, as those of our own Country. I have altered and improved others, and have added many new ones of my own Invention ... That their Exactness may be particularly attended to, I always inspect and direct the several Pieces myself, see them all combined in my own House, and finish the most curious Parts thereof with my own Hands.[39]

(1992) made extensive use of the Vickers Archive; early Elliott records were used by Holland (1993). The Dallmeyer stockbooks were consulted by Williams (1994).

35. Marriner (1980).

36. McConnell (1993b); McConnell (1994a); an overview of the instrument trade and bankruptcy is given by Morrison-Low (1994a).

37. Westall (1984).

38. Millburn (1988a); Millburn (1992a); Millburn (1992b) Millburn (1992c).

39. Adams (1746), 224.

Other accounts of the English trade come from travellers from abroad: the eighteenth-century London trade was examined by G.L'E. Turner, seen through the eyes of impressed visiting foreigners.[40] Given the dearth of contemporary descriptive documentation by its own practitioners, the diaries and letters of foreign visitors can shed fresh insights on to what was then seen as a reasonably 'secret' activity; for example, the career of the Dane, Jesper Bidstrup (1763-1802) has recently been outlined to throw new light on technology transfer from London to Europe, but it also supplies badly-needed details of London trade organisation, and this will be further examined in chapter 3.[41] Anthony Turner has placed the London trade into a European context by demonstrating the smallness and weakness particularly of the French trade compared with its thriving London counterpart, and his work is outlined in chapter 1.[42] Anita McConnell has looked at some of the major London makers' problems responding to market demands and the resulting effects this had on the nature of their business. She found that by the late eighteenth century:

> the major instrument makers responded to increased demand by specialising either as retail suppliers of a wide range of small or medium sized apparatus, or as precision engineers, concentrating on the production of large apparatus to order, supplemented by retail trades.[43]

The London trade, with its components of 'precision' and 'scientific' instruments, and its relationship with the trade in the English provinces, will be more closely examined in chapter 3.

The nature of the trade: 1760 and 1851

This recent work suggests that we have some idea about the organisation, structure and external pressures upon the English instrument trade at the dates generally taken to mark the start and end of the British Industrial Revolution. In addition, there are some similarities with other trades, in particular those which shared some of the characteristics evident earlier, such as clockmaking or printing and the book-trade. These included methods of passing on craft skills through formal apprenticeship in the older centres of population, where such structures could be enforced, and long-established lines of communication into the provinces where the products could be sold.

40. Turner (1979).
41. For a general overview of foreign espionage and British industry, see Woolrich (1988), Harris (1998), and more specifically for the instrument trade, Christensen (1993).
42. Turner (1987), especially chapter 5; Turner (1989) and Turner (1998).
43. McConnell (1994b), 50.

Initially, the instrument trade catered largely for the luxury end of the market: it was primarily based in London, where the richest people were located. It was largely a hand-crafted industry, in which an apprenticeship had to be served, in order to be initiated into its particular skills of brasswork, glasswork, precision engraving and generally the application of numeracy and literacy. There is not much evidence of mechanisation, or of power being applied to tools, and although foot-operated lathes and grinding machines were available, these simple devices were driven by human muscle power. Skills were learned 'on the job', and attempts to codify experience and disseminate it, along the lines of the French *Encyclopédie*, were doomed to failure as the 'knowhow' had to be taught by one-to-one transmission. Hence the attempts by foreigners to bribe workmen about current shopfloor practice, discussed further in chapter 4, and the sad comment from the young James Watt in 1755 on finding that the London instrument trade was a closed shop to outsiders: 'I have not yet got a master', he wrote despondently to his father in Greenock, 'we have tried several, but they all made some objection or other. I find that, if any of them agree with me at all, it will not be for less than a year; and even for that time they will be expecting some money.'[44]

The trade appears to have been very much an enclosed family enterprise, in which women and children participated, although there are no figures which show to what extent this was the case, as might be expected during this period. (Even by the time of the first Census to record occupations in 1841, this information was not necessarily recorded). This will be discussed further in chapter 4. As Alice Clark and Ivy Pinchbeck make clear, this characteristic of family enterprise, including women and children in the instrument trade was common to most craft-based industries, and like them, there were also a number of other shared features.[45] Thus, it was rational that scientific instruments were included by the Skilled Workforce Project, which ran as part of the Achievement Project.[46] This addressed overlapping trades and crafts in the London and Paris metropolitan areas in the early modern period, and stressed the interdisciplinary nature of the workforce, markets and products. Over time, this model eventually breaks down, as economic

44. Quoted in Smiles (1865), 102.

45. Clark (1982); Pinchbeck (1981).

46. This five-year research project (1990-5), concerned with the period 1500-1750, based at the Centre for Metropolitan history, University of London, sponsored by the Renaissance Trust, has published the results of a number of its findings, e.g. Mitchell (1995), Fox and Turner (1998). The project looked at overlapping areas of the skilled workforce, such as textiles, gun-making, bookselling, printing and scientific instruments to see if these specialisms could inform each other:

forces, such as rental levels within the city and better transport to and from a previously less accessible hinterland, dictate that work goes out to the provinces (where overheads may be lower), so that more co-ordinating control is ceded to provincial entrepreneurs who then have the freedom to develop their own markets.

During the period covered by this thesis the workforce was transformed from one being competent in a series of craft-based skills, to becoming more reliant on some of the machine tools which were then being developed. Often these tools evolved, and, with the addition of steam-power, came to be used with great effect in heavy engineering.[47] However, their early appearance and initial development within precision instrument-making, was important for the development of the trade. These 'tools to make tools' included the lathe, the dividing engine and the precision screw, and these and their impact will be discussed in chapter 4. Their use led to a greater accuracy within the instruments themselves. It is also important to remember that, as Raphael Samuel has demonstrated, hand technology existed successfully side-by-side with mechanisation well into the mid-Victorian period, and it is clear that instrument production remained mainly a hand technology manufacture until the late nineteenth century.[48]

Did the instrument trade, especially in the provinces, move into 'factories', as did the textile industry at this period? David Landes has defined the factory as a 'concentration of production and maintenance of discipline'.[49] The answer appears to be 'only partially', as instances can be discovered, in particular in Sheffield, where water power could be supplied to individual buildings to shape the wood for telescopes, or to grind the glass for optical components; and clearly some form of discipline was in place to keep the workforce to task.[50] However, the pattern in Birmingham, Manchester and Liverpool appears to have remained that of small workshops, in which - particularly in Birmingham - entrepreneurs managing such small-scale metal workshops were able to produce other commodities, and not solely instruments.

In the manufacture of instruments during this period, the major technological

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see *The Achievement Project Newsletter*, 1991-1994.

47. Rolt (1965), 33-39.

48. Samuel (1977).

49. Landes (1969), 121.

breakthroughs were in two areas: the better understanding of the materials of construction, and the radical improvement of some machine tools used to produce the instruments. On the materials side, there is some literature on brass and glass manufacture,[51] and this will be looked at more closely in chapter 4. In particular, there has been some discussion about the introduction of the achromatic lens (which uses discs of different-density flint and crown glass) and the patent litigation which stemmed from it.[52]

As so often with 'invention', a number of people arrived at a similar practical solution to a specific problem almost simultaneously. The winners, as always, were the lawyers. Mechanical improvements to machine tools - Henry Maudsley's lathe, Jesse Ramsden's dividing engine, the precision screw - have been reviewed more as part of engineering history than as instrument history.[53] The introduction of lens-grinding machinery and the application of power to some of the processes of instrument manufacture, which appear to have been introduced (unpatented) during this period in the English provinces, does not seem to have been discussed, either by contemporaries or more recently, but was surely of economic importance, as more standardised components could be produced more rapidly.

The line between engineering production and the precision mechanics which is a part of instrument-making is a fine one (and possibly an artificial one of twentieth-century devising), and one which people like John Smeaton and James Watt were able to cross, leaving instrument production behind them. During this period, these distinctions were not economically important, as it was possible to alter direction within a trade. By 1850, systems for classification were being developed. For instance, the Great Exhibition set up a large classification scheme for the 'Work and Industry of All Nations', in which elements of specialisation were becoming clearer. New areas had appeared in instrumentation since 1760, notably photography and telegraphy: the London firm W.& S. Jones was able to offer 436 priced items in 1838, compared with 342 in 1794: but fashion (and obsolescence) had dictated that only 228 items survived from the earlier list into the later catalogue. How the trade responded to this growth, which took into account scientific discoveries,

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50. Morrison-Low (1994b).
51. For brass, see Day (1984); and for glass, see Thorpe (1929).
52. Robischon (1983).
53. Rolt (1965); Brooks (1989); Chapman (1995); Woodbury (1972); Floud (1976) deals with a

technological change as well as fashion, must be investigated. A scrutiny of the Jones's catalogues which survive between 1792 and 1855 demonstrates that the prices of individual items remained more or less static, and this will be further examined in chapter 3.[54]

Conclusions

The instrument trade changed greatly during the period of the Industrial Revolution: it moved from being a small, London-centred craft, commanding international markets, to one which (as Clifton has indicated, and chapter 2 of this thesis will confirm) trebled in size,[55] with strong roots in the English provinces which fed some of its products into the London market but was also prepared to look further afield. Clouds were, however, gathering on the economic horizon, with the strongly commercial industries in France and Germany, which had more state backing through technical education for workmen from an earlier date. Keeping Millburn's critique as a guide, this thesis will attempt to sketch a 'structure of the instrument-making trade ... [and say something] about the lives of the individuals'. Providing details of 'their finances' has proved next to impossible, although occasionally Probate details have been uncovered; 'their marketing techniques', although ephemeral, have proved easier to establish, where evidence has survived, and are outlined in chapter 5; 'their sources of materials and components, their tools, their relationships with their workmen, subcontractors and each other' are sketched in chapter 4. But where Millburn notes that 'almost nothing is known for certain about the size of the individual instrument makers' workshops, or how many specialist craftsmen were involved in the construction of different types of instrument', it must be admitted that with the period's lack of source materials, official and business, this remains a matter for speculation in most cases, although some evidence has been discovered for two or three previously unknown substantial provincial factories, and these are discussed in chapters 2 and 4.

The instrument trade has previously been studied almost entirely from the perspective of the end-products. These can often be appreciated as items of beauty as well as of utility. However, their creators were making them for economic reasons: they needed to be successful at what they did, they required to reach and expand their markets, they had to have business acumen, and they

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later period.

54. Some of these catalogues are listed in Anderson et al. (1990).

55. Clifton (1995), xiii, citing nineteenth century Census figures.

had to make a profit and pay their workmen. In short, they had to survive. This thesis will try to explain how they attempted to do this, in a time of great economic and technological change, population flux, and a prolonged period of war. It will also look at the larger question, of whether the trade, small as it was, effected any influence on the Industrial Revolution and its course.

Chapter 1: The Instrument Trade and the Industrial Revolution: a bibliographic survey

British instrument history 1760-1850: a bibliographic survey

The literature produced in the last fifty years or so concerning the instrument trade in England during the Industrial Revolution, as defined in the Introduction, has been mostly descriptive and self-contained in its nature, and only consulted within the museums profession or antique collectors' marketplace. It has been produced, in the main, by curators, working backwards from the end-products in their care. Much ground has been covered, but it has been characterised by the discovery of facts, and has lacked contact with other relevant historical disciplines which might have helped it become more reflective and self-critical. For reasons hinted at in the Introduction, issues important to instrument historians were not embraced until recently by historians of science, whose post-war work focused on issues more closely akin to those of philosophers and historians of ideas. The methodology of the history of scientific instruments has therefore hardly moved since the war; hence Millburn's dissatisfaction. Some facts, in the form of informational detail have been added, of which more could be made if different methodologies or interpretation were applied, especially by economic historians.

The starting point for discussion of post-war literature about the instrument trade (as opposed to the development of particular instruments over time) has to be E.G.R. Taylor's two monographs and for this period in particular, her 1966 book, *The Mathematical Practitioners of Hanoverian England 1714-1840*, which has an excellent and under-valued introduction, followed by an alphabetical directory of short biographies of individual 'mathematical practitioners'.[1] These biographies, often just a line or two, are given with minimal references, and unfortunately this work was used heavily in a manner which the author had not intended. Until recently, Taylor has been over-relied upon for accuracy and veracity, especially where dating is concerned.[2] Taylor's treatment tends to trail off by the end of the eighteenth century, and her coverage of provincial makers is scanty: biographies of 36 Birmingham makers, 43 from Liverpool, 15 from Manchester, 27 from Sheffield and 99 from other provincial centres (220, or about 10%, out of a total of 2282

[1]. Taylor (1966); the timespan of Taylor's excellent earlier monograph, Taylor (1954), rests largely outside the period of this thesis.
[2]. See Crawforth (1987a) for a corrective of Taylor.

numbered individual biographies). As a biographical study, Taylor has chosen 1840 as her terminal point, linked loosely with the ascent to the throne of Victoria. The depersonalisation and fragmentation of the subject through changed circumstances forced her to conclude that:

> ...as the years passed the [British] Association [for the Advancement of Science] tended to promote sectionalism, and to treat applied science as the poor relation of pure science. Such changes were fostered inevitably by the transformation of the craftsman into the factory-hand, of the instrument-maker into the retailer, of the man of science into the salaried professor. The old personal links and the identifications of inventor, maker and user were lost.[3]

One of the limitations of her biographical approach is that it precluded an elaboration of the causes of these changes.

The work of Maurice Daumas, as a curator at the Conservatoire National des Arts et Métiers in Paris during the 1950s and 1960s, concerns an earlier period and emphasises the French input, although there is a short chapter on late eighteenth-century English (meaning London) workshops. His important contribution to Charles Singer's multi-volume *History of Technology* concerns innovations in tools which enabled instrument makers to create late eighteenth-century instruments, and the subject has only recently been reassessed by Randall Brooks, John Brooks and Allan Chapman: more will be said about this in chapter 4.[4]

G. L'E. Turner, also a museum curator, has provided two useful bibliographies on instrumentation, and these include items which examine aspects of the trade during the period of the Industrial Revolution.[5] A further bibliography compiled by Turner in conjunction with D.J. Bryden, also with a museum background, covers articles and monographs produced internationally between 1983 and 1995, capturing particularly exhibition catalogues, those most ephemeral pieces of literature which often contain new information or ideas.[6] However, the majority of contributions are what one would expect: scholarly but often minutely-focused contributions, lacking a broader perspective. Business histories of individual London firms have appeared during the last forty

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[3]. Taylor (1966), 105.
[4]. Daumas (1972); Daumas (1958); Brooks (1989); Brooks (1992); Chapman (1995).
[5]. Turner (1969a); Turner (1983b).
[6]. Turner and Bryden (1997).

years, among them works about Benjamin Martin;[7] Troughton & Simms;[8] James Short;[9] and R.B. Bate.[10] Each of these provides a different success story, or one of ultimate economic failure. Martin was a successful self-publicist: some of his advertising methods will be examined in chapter 5. However, he died bankrupt, a probable suicide, and his business went not to his son, but to his rivals, W. & S. Jones. Troughton & Simms managed to align themselves with a government institution, weather a change of direction, but in the end were forced into a convenient business partnership with a provincial manufacturer, Thomas Cooke of York. Short's business lasted until his death, when his heirs proved to be unbusinesslike failures. Bate coped by pushing his business out on a number of different fronts, and won government contracts (through family contacts) with a number of government agencies, subcontracting on a grand scale, perhaps the grandest seen to date. Yet his business did not survive his death, either.

Lacking English eye-witness accounts, G. L'E. Turner has provided an overview of the eighteenth-century London trade described by suitably-impressed contemporary visiting foreigners,[11] whereas Anthony Turner has provided another view, placing the London trade into its European context, showing that the guild structure failed to allow Parisian makers to flourish on an international scale.[12] Dan Christensen has looked at the problems encountered by a Danish instrument maker who came to London at the end of the eighteenth century in order to learn the trade and transfer it to his native land, which he attempted with only limited success.[13] G. L'E. Turner, author of a number of monographs on instruments, in particular the development of the microscope, produced his *Nineteenth Century Scientific Instruments* in 1983, which surveyed a century of instrumentational development: this was very much an artefact-based study, with some new and interesting contributions to make to the area under discussion.[14] For instance, he drew out new areas of instrumentation which developed during the nineteenth century in the fields of electricity, acoustics, photography and telegraphy. Turner considered that the Great Exhibition of

7. Millburn (1976); Millburn (1986a) and Millburn (1986b).
8. McConnell (1992).
9. Bryden (1968); Turner (1969).
10. McConnell (1993a).
11. Turner (1979).
12. Turner (1987), especially chapter 5; Turner (1989) and (1998).
13. Christensen (1993).
14. Turner (1983a).

1851 was 'an international occasion [that] was the peak of the Industrial Revolution, the triumph of steam-power technology and machine-tool engineering', and extracted the names of all instrument makers who had exhibited there.[15] Turner highlighted material hitherto considered 'too modern' as being worthy of consideration by the instrument historians, and generally led to an awareness of a period which had been neglected. More recently, Anita McConnell has studied some of the main late eighteenth-century London makers' problems in meeting market demands and the resulting effects this had on the size of their premises. It appears to have meant a decision to specialise either as retail suppliers of small off-the-peg instruments, or as precision engineers of large bespoke items. This resulted in the latter moving to larger premises; however, none moved out of London at this time.[16]

Guild structure, always stronger in London than in the provinces, has been closely scrutinised. Originally the means by which a craft ensured its skills were protected from infringements by outsiders of any sort, in London it became a method of trade succession, in which skills were passed down through a codified series of rituals: indenture, apprenticeship, freedom. More will be said about the transfer of skills in chapter 4. The trade of mathematical instrument making developed too late to have a guild formed around it, and instead its practitioners emerged from or were obliged to join other guilds. Instrument historians realised during the 1970s that instrument makers had not only joined the most likely guilds, such as the Clockmakers' or Spectaclemakers', but all other guilds, including such unlikely companies as the Broderers' and the Joiners'. Joyce Brown has examined the Grocers' and the Clockmakers' Companies; Allen Simpson has described an important craft succession in the Turners' guild; Michael Crawforth of Project SIMON has published with particular reference to the Broderers' and Joiners' guilds, while Gloria Clifton, continuing with Project SIMON, has produced an essay about the Spectaclemakers' Company.[17] Clifton's completed work on the British trade between 1550 and 1851, published in 1995, attempts to provide some correctives to Taylor's earlier work, has comprehensively mined London guild sources and is strongest on the London instrument trade.[18] By the early nineteenth century, the power of the London guilds was terminally on the wane; and no guild structure

[15]. *Ibid.*, 24, 309-310.
[16]. McConnell (1994b).
[17]. Brown (1978); Brown (1979); Simpson (1985); Crawforth (1987b); Clifton (1993a).

appears to have encompassed instrument making in the provinces, apparently because most English centres were located in areas where the population grew for the first time during the Industrial Revolution, rather than in established medieval centres where guilds were already present. There were, however, formal apprenticeship systems in place in Bristol and York at this time, whose records give some idea of trade succession and continuity in those cities.

Very little instrument history had been produced specifically on the nineteenth-century trade, nationally or internationally, until a symposium held in Amsterdam in 1984. The papers included a number which looked at aspects of the London trade: R.G.W. Anderson discussed the problems. J.A. Bennett looked at institutional change, its effects on the makers and their corresponding change in status. Willem Hackmann examined the trade in natural philosophy instruments.[19] Anderson, indeed, took issue with Taylor's work by asking 'What, then, led to change in the 19th century?'[20] Qualifying his remarks by saying that a definitive answer was currently unavailable through lack of underpinning research, he suggested that Taylor's characterisation of depersonalisation of production was correct, and that it was due to the concomitant massive and comprehensive reorganization of science during the nineteenth century. Anderson suggested that the nature of this reorganisation 'might be crudely categorised under six headings: education, research, scientific institutions and societies, industrialisation, colonial expansion and public health,' but there has been little response to his agenda. Subsequent work on the nineteenth-century trade has focused on the business history-type studies mentioned above, with similar publications for Scotland and Ireland and a single discursive look at the role of women within the trade.[21] Indeed, more substantive work has been carried out about the later nineteenth-century trade, for instance by Mari Williams.[22] There have also been a number of short articles about individual firms, which add factual details to the overall picture of London's nineteenth-century trade, amongst them pieces about Elliotts, Newtons, Bardins, Janet Taylor and W.& S. Jones.[23] These have outlined the dates, addresses, type of output (although not volume, for which

18. Clifton (1995).
19. Anderson (1985); Bennett (1985) and Hackmann (1985).
20. Anderson (1985), 2.
21. Clarke et al., (1989); Burnett and Morrison-Low (1989); Morrison-Low (1990).
22. Williams (1994); Cattermole and Wolfe (1987).
23. Clifton (1993b); Bristow (1993); Holland (1993); Gee (1992) and (1993); Millburn (1992d); Millburn and Rossaak (1993); Alger (1982); Simpson (1993).

there appears to be no source, reliable or otherwise) of these firms, and demonstrated that they remained family businesses throughout this period. Three recent theses have added to our understanding of the London trade at this period.[24] Brian Gee looked at the contribution to scientific development by a particular group of instrument makers, centred around electrical/magnetic science and its instrumentation for the years between 1820 and 1850. Alice Walters examined the links between the booktrade and instrument-making at the end of the eighteenth century, and William Ginn focused on the relationships of a number of individual scientific customers with their chosen specialist suppliers.[25]

On the marketing side, which will be discussed in chapter 5, there has been interest in the ephemera which was associated with the retailing of instruments. A wealthy collector, Ambrose Heal, produced a pioneering general work on tradesmen's cards in 1925, followed only in 1971 by the London Science Museum, which published an illustrated catalogue of their instrument makers' trade card collection.[26] Heal described a trade card as follows:

> the engraving giving the Trader's name, his sign and his address, and the setting forth of the list of his wares occupies the whole of the face of the Bill, except for the well-proportioned margins which are an integral part of the design of all carefully planned pages. This announcement, then, of his shop is the first and principal use of the Tradesman's Card, and much skill has gone into the making of it.[27]

Perhaps the most thoughtful discussion about trade cards, and how they can be used to reveal information about the trade, is to be found in Michael Crawforth's work on the subject.[28] Outside the period under discussion, D.J. Bryden has written two papers which look at advertising at an earlier date, linking the booksellers and printers closely to instrument production and distribution.[29] Trade catalogues, or lists of retailed items with their prices, appear to have evolved during the late seventeenth century and there have been a number of discussions about these, but only one work devoted exclusively to the instrument trade.[30] However, this latter has done little more than try to locate copies internationally, and some interesting work could yet be done with the material

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24. Gee (1989); Walters (1992); Ginn (1993).
25. *Ibid.*
26. Heal (1925); Calvert (1971).
27. Heal (1925), 2.
28. Crawforth (1985).
29. Bryden (1992) and (1997).

assembled there, such as price statistics, availability of particular instruments over time, or change within the repertoire of a single workshop, as has been undertaken by Peter de Clercq for the Dutch firm, Musschenbroek, between 1694 and 1748.[31]

Finally, to turn to the English provincial trade during this period: no overview of the subject has been provided by instrument historians, and very little produced in the way of business history of individual firms or personalities beyond the slight biographies by Taylor, and the factual and cryptic information given by Clifton.[32] Some work, however, has been done on the Manchester trade, particularly by Jenny Wetton, a curator at the Museum of Science and Industry.[33] She has also written about Manchester's most prominent nineteenth-century maker, John Benjamin Dancer, as have others.[34] The Liverpool trade was outlined by Paul Dearden for a visit of the Scientific Instrument Society, and briefly summarised.[35] Another paper has sketched possible connections between the trade in Bristol and Birmingham.[36] In 1984 D.J. Bryden in a short paper entitled 'Provincial Scientific Instrument Making' proposed that:

> ... by the nineteenth century, whilst London retained its technical supremacy, provincial centres like Birmingham and Sheffield were responsible for the mass production of many common instruments - Birmingham part-making folding rules to be finished in London, Sheffield cheap optical instruments for retail in London and elsewhere.[37]

At the time this was written there was almost no supporting evidence for such a view, based on inference from provincial production at a later period.[38] However, this thesis has helped to substantiate it, as have two earlier papers discussing Sheffield instrument making.[39] Yet there remains much to be uncovered about the provincial trade: if and how its character altered between localities, whether its nature was changed at all by industrialisation, and how it related over time to the London trade.

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30. Jones and Taylor (1984); Davis and Dreyfuss (1986); Crom (1989); Anderson et al. (1990).
31. De Clercq (1997), 65-72.
32. Taylor (1966); Clifton (1995).
33. Wetton (1990-91); (1994) and (1996).
34. Wetton (1991); Hallett (1979); Hallett (1986); Nuttall (1980); Butler (1987); Logan (1989); Luther (1992); Bracegirdle and McCormick (1993).
35. Bristow (1992).
36. Bryant (1994).
37. Bryden (1984).
38. J. Rabone, 'Measuring Rules', in Timmins (1866), 628-632; Hallam (1984).
39. Morrison-Low (1994b).

Economic history survey: the 'Industrial Revolution' and instrument production

At present, the 'Industrial Revolution' appears to be something of a battlefield amongst economic historians, in which the estimates for economic growth assembled in 1967 by P. Deane and W.A. Cole have been revised, in particular by N.F.R. Crafts.[40] This has produced a less 'revolutionary' model of the period, in which slower rates of growth than had previously been estimated are put forward for the late eighteenth and early nineteenth centuries, the classic period of the Industrial Revolution. Crafts' somewhat pessimistic picture has been countered by a number of writers, notably Julian Hoppit, Maxine Berg and Pat Hudson, and further newly-calculated rates have been put forward by R.V. Jackson.[41] David Cannadine has suggested that the Industrial Revolution is seen by various generations of economic historians in the light of their own experience, but Berg has retorted that there is a missing dimension which Cannadine has overlooked: the component of the 'hidden' workforce, supplied by unrecorded women and children.[42] Certainly, the women and children who must have worked in a family-based enterprise like the precision instrument trade have gone virtually unnoticed.

How have economic historians seen the instrument trade, and what significance has it had, for them, as factor for change in the Industrial Revolution? As I have adopted Millburn's agenda for this thesis, I should also examine the publication that prompted his critique. The essay written by Roy Porter for the book to accompany the 1985 exhibition 'Science and Profit in 18th-Century London' was entitled 'The Economic Context', and it offers some explanations for the growth in the London instrument trade at the end of the eighteenth century.[43] In it, he gives as his authorities Peter Mathias and T.S. Ashton, that 'no-one ... doubted that high craft skills were indissolubly linked with economic transformation'.[44] These skills, brought in at an earlier date by foreigners, were by the mid-eighteenth century to be found indigenously: Porter quotes David Landes's example of the English invention of jewelled bearings for timepieces, and goes on to remark upon

40. Deane and Cole (1967); Crafts (1985).
41. Hoppit (1990); Berg and Hudson (1992); Jackson (1992).
42. Cannadine (1984); Berg (1993).
43. Porter et al. (1985), 1-4.
44. *Ibid.*, 1, quoting Ashton (1968) and Mathias (1983).

the contemporary awareness of the importance of good design to industry.[45] He notes that in a European context, unlike her neighbours, the English trade flourished 'in economic opportunity, in market openings.'[46]

The patenting of mechanical improvements appears to have been of minor importance at this date, writes Porter (quoting H.I. Dutton), and 'foreigners were staggered by the strength of consumer demand.'[47] Much of Porter's argument is one of the 'consumer revolution' of McKendrick, Brewer and Plumb, and he draws upon their thesis to support his claim for mid-market growth. Porter stresses that this was a London-centred phenomenon, for after 'a through training in basic skills ... almost all [instrument makers] gravitated to London, for only there did a specialist market exist.'[48] Also, there was no guild of instrument makers that might have stifled individualism. However, Porter admits that prices were high, and there was a fear by makers of having too much capital tied up in a large precision piece; those makers who found institutional or government contracts were fortunate. He rounds off his essay with a thumbnail sketch of the career of the London retailer Benjamin Martin (1704-1782), characterising him as a 'dealer...[who] grasped the importance of catalogue selling.'[49] He mentions Martin's large, but relatively cheap ready-made stock, tempting the impulse buyer, and his promotion of wares through books and lectures. Porter does not say that Martin died a bankrupt - as Millburn (author of several monographs on Martin) does in his essay review of this publication - but does suggest that 'in an increasingly competitive market, business enterprise became no less vital than technical skill.'[50]

This is instrument-making seen as helping to create its own demands: nurturing a new middle-class market, which grew as increasingly-wealthy customers, dazzled by entertaining displays disguised as education, or a desire to emulate their betters, provoked increasing public demand. Porter's answer to the economic question is 'consumption'. However, his four pages scarcely allow him to address some of the more intricate problems, for which he and his co-authors

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45. *Ibid.* 2, quoting Landes (1983).
46. *Ibid.*
47. *Ibid.*, 3, quoting Dutton (1984).
48. *Ibid.*, 3, quoting McKendrick (1982).
49. *Ibid.*, 4.
50. Millburn (1986c), 85; Porter (1985), 4.

were taken to task by Millburn.[51] The rise of consumption is clearly part of the economic equation, but not all of it. A recent general survey of the history of technology by Donald Cardwell mentions in the introduction that encyclopaedic studies on the subject, such as the seven volumes of the *Oxford History of Technology* consisted of many contributions by subject specialists, and thus misses the importance of links between technologies:

> Habbakuk, Landes, Musson, Robinson, Rosenberg and other economic historians have made penetrating studies of the circumstances that have favoured particular innovations and the economic and social consequences of those innovations. Usually, and understandably, economic historians have been rather less interested in the technology than in the economic and social factors associated with it.[52]

He goes on to point out the huge rift between historians of science and historians of technology, and a continuing of studies which 'tend to inflict division rather than encourage unification, with the added disincentive that those who elect to study history may well have deliberately rejected science, and vice versa.'[53] What hope is there of any reasonable synthesis, with such disparate historiographies?

Cardwell's *History of Technology* tries to comprehend elements of both economic history and history of science, and concludes that for the Industrial Revolution

> textiles and steam engines combined to stimulate new technologies. One of the most important of these was the design and manufacture of machine tools, or machines to make machines ... 'Mathematical instruments', such as telescopes and sextants, were commonly of brass, a soft metal, and were made in large numbers by the skilled instrument makers of the eighteenth century using small lathes, screw-cutting lathes and drills... But the industrial machine tool working on hard iron or steel was very much a product of the demands of the textile and the steam engine industries.[54]

For Cardwell, an historian of technology, the instrument trade's importance in these years was its role in the creation of machine tools that were later transferred and applied to engineering.

Economic historians, as opposed to historians of science, such as Porter, or of technology, such as Cardwell, have looked at other causes and effects of the Industrial Revolution, and the

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51. Millburn (1986c), 84: see Introduction to this thesis, p.15.
52. Cardwell (1994), 5.
53. *Ibid.*, 7.
54. *Ibid.* (1994), 216.

instrument trade scarcely figures in their accounts. However, to examine the specific role of instrumentation, I would like to look at those that stress technological change as a means of development in industrialisation. I shall look in particular at the work of T.S. Ashton, D.S. Landes, Peter Mathias, Joel Mokyr, Nathan Rosenberg and Maxine Berg.

Ashton's contribution to the historiography of the Industrial Revolution is of the first importance, proved by the fact that his succinct classic essay *The Industrial Revolution* has been in print since it was first published in 1948. In it he shows how in the late eighteenth century, the membership of the Royal Society - including instrument-makers - demonstrated how closely allied were theoretical science and its practice at this time.[55] In the provinces:

> ... the [nonconformist] academies ... at Bristol, Manchester, Northampton, Daventry, Warrington and elsewhere - did for England in the eighteenth century something of what the universities did for Scotland. ... they were nurseries of scientific thought. Several of them were well-equipped with 'philosophical instruments' and offered facilities for experiment: their teachers included men of the quality of Joseph Priestley and John Dalton...[56]

Ashton, as with so many historians of his generation and the next, brings in the complex but heroic figure of James Watt, 'mathematical instrument-maker' at Glasgow University, whose scientific conversations with the great chemist Joseph Black enabled him to understand how to repair the university's steam-engine model and make it more efficient, thus leading to the road south to Birmingham and the wealth that lay in successfully synthesising the works of others and bringing together 'the varied skills required for the creation of a complex mechanism.'[57] Indeed, Ashton goes on to trace the origins of the engineering industry, and shows that the ancestry of the modern fitter can be found in elements of the repairing millwright, 'clock-makers, instrument-makers, ironfounders and cotton spinners, who, during the industrial revolution, turned from using to making the appliances of their trades.'[58] For Ashton, the skills of the instrument trade provided part of pool of skill which was available for new techniques, although he admits that the bottleneck,

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55. Ashton (1968), 13.
56. *Ibid.*, 15.
57. *Ibid.*, 55-58. Recent work, especially by Macleod (1998), on the personality of James Watt, has concluded that his importance has been over-emphasised in the past, through a careful selection of manuscript evidence engineered by his heirs; nonetheless he remains a significant figure, whose apprenticeship in instrument making lay with the London trade.
58. *Ibid.*, 71.

particularly in engineering, was the time spent training even skilled hands.[59]

No less a classic is David S. Landes's *The Unbound Prometheus*. This, too, has remained in print since its first publication in 1969. Despite Landes' emphasis on technological change, instrumentation does not figure in this work at all. He does discuss the crucial importance of machine tools, but stresses the anonymity of the authors of small incremental improvements, and shows that interchangeability of parts took longer to arrive than might be thought: 'Every screw had its individual thread.'[60] For Landes, technological change is an integral part of the economic background and England was especially ripe for technological change, thanks to cultural institutions which allowed the development of an individualistic, and ultimately, capitalist, society.[61] In later essays, his interest in the 'nuts and bolts' aspect of history, in particular the hair spring and escapements of the horologist, becomes more evident, particularly in his *Revolution in Time*, published in 1983. In his preface he explains how an economic historian was seduced by material culture: 'I was smitten - caught by the combination of mechanical ingenuity, craftsmanship, artistry, and elegance.'[62] The whole book, which proposes the thesis set out in the subtitle - *Clocks and the Making of the Modern World* - discusses the evolution of an industry which lent much of its technology and organisational change to that of the instrument trade. Instruments themselves, however, are mentioned only once, in connection with the Portuguese voyages of discovery in the fifteenth and sixteenth centuries, followed by the scientific revolution of the seventeenth century, which 'was linked closely to the availability of new instruments - telescope, microscope, thermometer, barometer, pendulum - that made possible observations finer than any before and posed issues never suspected.'[63]

In 1993, Landes revisited the territory of *The Unbound Prometheus* with an incisive review of the preceding and intervening historiography, especially those concerning rates of change: 'in the Industrial Revolution debate, as in most ... others, both sides are right: History, of its nature is a

59. *Ibid.*, 96.
60. Landes (1969), 105-7, quote 107.
61. *Ibid.*
62. Landes (1983), xiii.
63. *Ibid.* 160.

constant interplay of continuity and change.'[64] He sees the change as 'essentially technology - the way of doing and making things - with substantial and ramifying effects on productivity, prices, and size of market.'[65] His most recent 'magisterial work' is a discussion of the causes of wealth through examples of world history, where his thesis is that 'human action and human organization seem to be more likely explanations of wealth and poverty than any other variables.'[66] Among the technological changes in the Industrial Revolution in Britain: steampower, waterpower, improvements in iron-smelting, the introduction of powered machinery (particularly in textiles), Landes stresses in metallurgy that:

> most important was the growing recourse to precision gauging and fixed settings. Here the clock and watchmakers and instrument makers gave the lead. They were working smaller pieces and could more easily shape them to the high standards required for accuracy with special-purpose tools such as wheel dividers and tooth-cutters. These devices in turn, along with similar tools devised by machinists, could then be adapted to work in larger format ... [suggesting] in turn the first experiments in mass production based on interchangeable parts (clocks, guns, gun carriages, pulley blocks, locks, hardware, furniture).[67]

At the same date as the publication of Landes' *The Unbound Prometheus*, in 1969, Peter Mathias had voiced similar opinions, in the first edition of his *The First Industrial Nation*, characterising the precision instrument trade as one 'partly the world of the Royal Society; partly that of the Admiralty; partly that of the luxury market for watches and performing dolls.'[68] In relation to technological innovation, Mathias found the high standards of mechanical precision, the complicated division of labour, and the production of specialist tools problematic, in that they had all pre-dated the Industrial Revolution. His answer to the problem of this 'time lag' - the delayed adoption by the textile-machinery builders - is that instrument making was small-scale, at the luxury end of the market, did not use mass production of parts by automatic machinery, and relied for the most part upon human muscle power and was thus extremely expensive, with low productivity per head. Brass was unsuitable for textile machinery, which was large scale, required a massive power source and the skills of the blacksmith, miller and carpenter welded to the accuracy of the precision

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64. Landes (1993), 153.
65. *Ibid.*, 157.
66. Oliver Letwin, review of Landes (1998), in *The Times Literary Supplement*, 14 August 1998.
67. Landes (1998), 191.
68. Mathias (1983), 126.

instrument maker. 'But this did not begin to take place' Mathias states, 'until the development of momentum in strategic industries, such as iron and textiles, created the inducements for businessmen to demand these skills in producing iron machinery and new forms of power.'[69] His subsequent mention of the trade is in 1900, by which time it was clear that the British instrument industry had lost all hope of a European lead to that of the German industry.[70] For Mathias, the scientific instrument trade was not of front-rank significance for the course of the Industrial Revolution.

However, Mathias's interest in the relationships between science and technology during the eighteenth century resulted in a number of essays on this theme. In one, first published in 1972, entitled 'Who Unbound Prometheus?', he discusses the linkages between the two:

> The state actively sought to press scientists into utilitarian endeavour. A long list of instances can be drawn up. Typical examples are ballistics and navigation (improvements in cartography, scientific instruments, astronomy, mathematical tables, accurate time-keeping lay behind this). ... Standardization in production, in dockyards, of interchangeable parts, exact measurement techniques, were much encouraged. Industrial and scientific skills likely to be useful in war received particular attention.[71]

He points out that 'state patronage' after the Stuart Restoration meant the Royal Society. Although this body had virtually no resources, in fact it proved a fertile breeding ground for innovation. And he makes the point that innovation moved 'to the many provincial societies linking amateur scientists with gentlemen-manufacturers', in, for instance, the Lunar Society of Birmingham, and others.[72] The links between amateur science and its practice in industry, which were emphasised by A.E. Musson and Eric Robinson, is acknowledged by Mathias to be unique in Europe at this time. However, he also states that:

> mathematics may well have played a wider role in these relationships than science until the end of the eighteenth century. Navigation techniques and improvements at sea (not only sponsored by the navy), land surveying techniques for estates, accountancy for business, assaying, architectural drawing, spectacle making are examples of practical skills that gained and were seen to gain, from mathematical knowledge. ... The utility of such mathematical expertise, coupled with precision measurement by new instruments, for a trading, industrial, sea-faring nation was sufficient for it to become institutionalized on a

69. *Ibid.*, 127.
70. *Ibid.*, 383.
71. Mathias (1979), 50-51.
72. *Ibid.*, 52; for the Lunar Society see Schofield (1963); for other societies, see Averley (1989).

fairly wide scale in eighteenth-century England.[73]

Joel Mokyr's 1990 work, subtitled *Technological Creativity and Economic Progress* has four indexed references to 'instruments and instrumentmaking', unusual in an economic history.[74] His first mention of these, in a Renaissance context, makes the claim that:

> instrument making in the sixteenth and seventeenth centuries was an art, not a standardized technique ... the Industrial Revolution became possible when mechanics and machine tools could translate ideas and blueprints into accurate and reliable prototypes. Until then, instruments and tools were handmade, expensive to make and repair, and limited in their uses.[75]

Although mass-production, or the 'so-called American system of manufacturing assembled complex products from mass-produced individual components' took place in the instrument industry towards the end of the nineteenth century, Mokyr, like Landes, demonstrates that the idea had occurred to Europeans in the eighteenth century, and was in some instances realized. He temporizes this by observing that 'although in the long run, interchangeability of parts was inexorable, its diffusion in Europe was slowed down by two factors: its inability to produce distinctive high-quality goods, which long kept consumers faithful to skilled artisans, and the resistance of labor, which realized that mass-production would make its skills obsolete.'[76] In an investigation into the factors responsible for technological creativity, Mokyr demonstrates that many microinventions developed during the Industrial Revolution in Britain were inspired by original inventions from the Continent. Despite a lack of formal education, 'as long as technological advances did not require a fundamental understanding of the laws of physics or chemistry on which they were based and as long as advances could be achieved by brilliant but intuitive tinkerers and persistent experimenters, Britain's ability to create or adapt new production technologies was supreme.'[77]

The causes of technological change have concerned the economist-turned-historian Nathan Rosenberg. In one essay, after remarking on the frequency of individual mechanics taking their

73. Mathias (1979), 52-53; Musson and Robinson (1969).
74. Mokyr (1990), 338.
75. *Ibid.*, 72-3.
76. *Ibid.*, 136-7.

'knowhow' with them, he examines the transfer of technology between industries producing 'convergent' products, demonstrating that American consumers were happy to accept

> a homogeneous final product [which] was a decisive factor in the transition from a highly labor-intensive handicraft technology to one involving a sequence of highly specialized machines. Across the whole range of commodities we find evidence that British consumers imposed their tastes on the producer in a manner which seriously constrained him with respect to the exploitation of machine technology.[78]

Resistance to mass-production in a craft industry, such as the instrument trade in Britain, meant problems in subcontracting components, or even the construction of compatible machine tools: 'users of capital equipment such as machine tools' Rosenberg observes, 'often made the tools themselves.'[79] Thomas Cooke of York's earliest surviving trade catalogue lists four pages of 'lathes and tools for ornamental and general purposes, planing and wheel-cutting machines.'[80]

In an essay entitled 'How Exogenous is Science?' given in 1981, Rosenberg stresses the human input into technological development:

> another fundamental way in which technology shapes the scientific enterprise that I can only mention because it is, by itself, an extremely big subject. I refer to the development of techniques of observation, testing, and measurement - in short, instrumentation ... [however,] different instruments may differ enormously in the specificity of their impact upon fields of science. Therefore, any attempt to establish tight links between progress in specific subfields of science and an associated field of instrumentation is doomed to failure.[81]

Rosenberg's understanding of 'scientific instruments' is clearly instruments-for-science, in a late-twentieth century 'Black Box' way, and not the broader, wider-ranging definition of the Industrial Revolution, where practical everyday scientific tools were much less frightening. By 1994, 'instrumentation' has half a column in the index, mostly concerning late twentieth century technologies such as electron microscopes, lasers, particle accelerators or synchrotron radiation: Rosenberg writes that 'the economics of technological change is a subject that is still seriously befuddled by the failure to come to grips with the diversity of the contents of the black box.'[82] His

77. Mokyr (1993), 34-35.
78. Rosenberg (1982), 158.
79. *Ibid.*, 161.
80. Cooke [1863], 13-16.
81. Rosenberg (1982), 158.
82. Rosenberg (1994), 269 and ix.

essay on 'Scientific Instrumentation and University Research' gives a very late-twentieth century, American viewpoint: for instance, the first computer described is the 1946 ENIAC and nothing is said about the wartime conditions that produced Bletchley Park's earlier Colossus.[83]

Maxine Berg has shown that the factory and large-scale firm have dominated considerations of the Industrial Revolution, but that on closer inspection many of the units of production were small scale, especially in the Birmingham and Sheffield metal trades, part of which was formed by the provincial instrument-making trade.[84] 'The specialisation of labour and subdivision of trades in both Birmingham and Sheffield created a niche for the development of the workshop economy ... there appears to be a strong case on the basis of descriptive evidence ... for a workshop economy built on specialisation and the division of labour, on dispersed units concentrated in specific locations and on close networking among these units.'[85] She envisages a stage of 'small producer capitalism', subsequently forgotten, which came before the traumatic introduction of the factory system to the metal trades in Birmingham and Sheffield during the nineteenth century.[86]

In her book *The Age of Manufactures 1700-1820*, Berg notes that the Birmingham and Sheffield metal trades 'really were the locus of Nathan Rosenberg's "continuum of small improvements", or anonymous technical change.'[87] She observes the growth of metal toolmaking trades alongside the smithing trades by the seventeenth century, in London, the Midlands and South-West Lancashire, and with this development came division of labour and specialisation of function:

> The manufacture of watch movements and tools was "put out" as early as the seventeenth century to rural workers in South-West Lancashire by all the big watch firms in London, Coventry and Liverpool [subsequently these were sent back for "finishing"].[88]

Berg stresses the importance of skill, which determined the location of the brass and copper trades: 'by the early eighteenth century many towns carried on the manufacture of brass, with no other

83. *Ibid.*, 259.
84. Berg (1993), 20-21.
85. *Ibid.*, 25.
86. *Ibid.*, 36-37.
87. Berg (1994), 256, quoting Rosenberg.

special advantage than a resident class of artisans already skilled in working in metals.'[89] However, she demonstrates that the perceived 'independence' of metal-working artisans was an illusion: 'capitalist expansion and industrialization in the metal trades found their context not in the factory but in the garret master and other forms of sweating.'[90] Berg found that evidence for industrial growth could be found throughout the eighteenth century, and not just in its final quarter; there was extensive technical change, but this was not devoted exclusively to mechanisation. She found that the organisation of work was one of the keys to understanding industrialisation: 'decentralization, extended workshops, and sweating were equally new departures in the organization of production.'[91] She also found that the impact of technical and industrial change was variable, and did not always lead to growth.

Conclusions

To a considerable extent, professional historians appear to work in their own particular areas without much reference to what others in closely related disciplines are concluding about the same period. Since the Second World War, economic historians have allowed a considerable amount of technological history to have a bearing on their own work; of necessity, since technological change is seen as one of the 'causes' of the Industrial Revolution, and the reverse can be seen also. Historians of science have become more interested in instrument history, realising that science is not just an abstract, pure mind-game but one which has applications. Yet their interest in instrumentation has centred on the instrument itself, or where it impinges on philosophy or scientific thought.[92] Sadly, instrument historians have, if anything, become more antiquarian in their approach than before. This is possibly because their numbers have risen to become a self-supporting community, and they no longer need to confer with 'outsiders'. It is to be hoped that this will change shortly, as instrument history has become part of the curriculum at the universities of Oxford and Cambridge, and is placed in its scientific, technological and economic context: most importantly, it is taught within the discipline of history.

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88. *Ibid.*, 260.
89. *Ibid.*, 262.
90. *Ibid.*, 274.
91. *Ibid.*, 281.
92. See, for instance, Shapin (1996).

Did the instrument trade have an economic effect on the Industrial Revolution? Instrument historians have not asked this question, but some technological and economic context: most importantly, it is taught within the discipline of history.economic historians have come close to it. In this thesis I shall look at the main headings under which this has appeared - technological change; the transfer of skill, within and without Britain; the rise of new markets through consumerism and education - and try to find some economic explanation for the growth of the trade outside London. I shall try to assess whether the trade contributed at all to the role of Britain as first industrial nation, and if so, how it was driven. My approach is to investigate the structure of the trade in the four cities, which by 1851, had a growing community of instrument producers, using the directories to give an idea of the size in each centre. In some selected cases, I shall look at the unit of production which, following Berg's lines of investigation into provincial metalworking, has proved also to be a family affair.

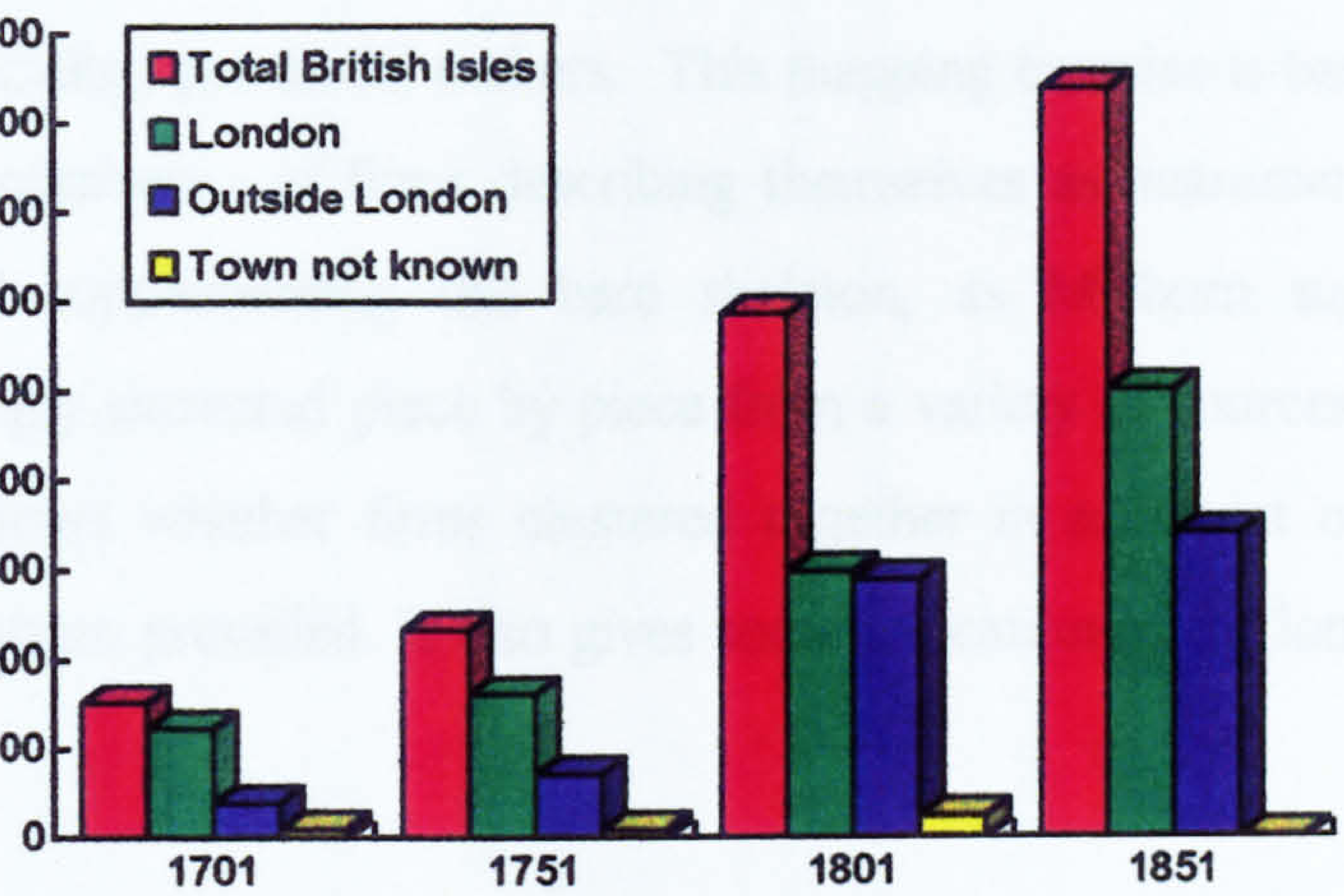
Chapter 2: Mapping the Provinces

Four Provincial Centres of Instrument Production

No overview has been provided, even by instrument historians, of the instrument trade outside London for the period of the Industrial Revolution, such as G. L'E. Turner's account of the London trade during the eighteenth century.[1] Gloria Clifton remarked in the Introduction to her 1995 *Directory* that the numbers of individuals involved were larger than previously thought, and that 'although London remained the principal centre of production ... provincial instrument making was more significant than has generally been assumed.'[2] Her figures for those individuals show increases from 71 outside London (161 within) in 1751, to 287 outside London (297 within) in 1801, to 339 outside London (498 within) in 1851: Clifton's figures are for the whole British Isles, including Scotland and Ireland [Table 2:1].[3] This thesis, by comparison, looks at numbers of firms - rather than of individuals - in specific centres, and tries to match Millburn's agenda by providing further detail about such businesses.

The fieldwork for this thesis covers the four major areas where instruments, or parts of instruments, were produced in England, outside London, during the period between 1760 and 1851. These were Birmingham, Manchester, Liverpool, and Sheffield, all new centres of population whose growth co-incided with the change of pace in the economy at this time. Population growth was not, however, the sole reason for the location for the provincial instrument trade, which quite clearly did not take root in a number of other expanding cities. It would seem that the growth of the trade in specific locations was due to the gradual emergence of an integrated and specialised economy, which gradually evolved throughout England during this period. As Martin Daunton put it: 'Far from producing homogeneity, the emergence of an increasingly integrated economy led to a greater degree of specialisation between regions which were tied together by more efficient transport, marketing and financial systems.'[4] Either - as in the case of Birmingham – the trade reached what Pat Hudson has termed 'the achievement of critical

1. Turner (1979).
2. Clifton (1995), xiv.
3. *Ibid.* xv.
4. Daunton (1995), 279.



Year	Total British Isles	London	Outside London	Town not known
1701	151	123	38	10
1751	232	161	71	9
1801	584	297	287	24
1851	837	498	339	1

Table 2:1 Numbers of individual scientific instrument makers working in the British Isles, including Scotland and Ireland, whose names have been traced (from Gloria Clifton, *Directory of British Scientific Instrument Makers 1550-1850* (London, 1995), xv).

mass'[5] by close association with other similar industries, or – as in the case of Liverpool – the trade relied on a hinterland of expertise from which to draw 'a nucleus of labour for the developing engineering trades', as described by - among others - Sheila Marriner.[6]

This chapter will provide an outline of these four centres, which, by the time of the Great Exhibition, were clearly supplying substantial quantities of instruments in their own right, and trace their newly-found self-confidence from small beginnings, together with some discussion of smaller clusters of (usually specialist) provincial makers. This mapping exercise is based on extracting the names - and thus the numbers - of firms describing themselves as instrument-makers from local street directories, and supplementing this bare skeleton, as Millburn suggested, with other information 'painstakingly extracted piece by piece from a variety of sources.'[7] This produces a local picture which shows whether firms clustered together in a district of a town centre, or whether some other pattern prevailed. It also gives some indication of the longevity of businesses, and entry/exit rates.

What were the reasons for the instrument industry taking root in particular localities? It would appear that certain preconditions were necessary before an ambitious entrepreneur might move to what seemed to him to be an auspicious place. In the abstract, these might be listed as: aristocratic or state patronage; the existence of a pool of skilled labour; nearby sources of essential raw materials of construction; local learned societies; a ready-made sympathetic financial infrastructure; an accessible market; handy transport methods; comparatively low costs of workshop premises; comparative lack of guild control; and possibly an already-existing group of friendly co-religionists or immigrants who would act as a support group should the enterprise fail. These have been tabulated in Table 2:2. Of course, not all these possible preconditions necessarily applied in a single place simultaneously, and there were individuals who began in one location and subsequently moved to another more promising location (for example, the Davis family, who initially settled in Leeds, but moved within ten years to Derby). Some locations, such as Bristol, appear to have prospered with the growth of local trade but waned with it, as Liverpool became

[5]. Hudson (1992), 114.
[6]. Marriner (1982), 55; see also Bailey and Barker (1969).
[7]. Millburn (1986c), 84.

Possible location factors	**Where found.**
1. Aristocratic patronage	London; Bath, Cheltenham.
2. State patronage	London, but still unknown to what extent subcontracting reached provincial trade before 1851.
3. Local learned societies	London (Royal Society 1660); lecturing spreading to all provincial centres from early 18th century.
4. Skilled labour pools in related trades	London (particularly Clerkenwell); Sheffield (cutlery); Birmingham (brass); Liverpool (watchmaking hinterland); Manchester (textile machinery).
5. Accessible raw materials	
(a) brass	Bristol; imported into London from an early date; available cheaply in Birmingham and Sheffield from about 1750.
(b) glass	London glass houses from medieval times; activity centred on Lancashire coalfields from mid eighteenth century, but not produced in industrial quantities until after 1848.
6. Financial infrastructure	Banking well developed throughout the period, but small family businesses still reliant upon family capitalisation.
7. Accessible markets	Items either sold locally e.g. navigation instruments in ports (Bristol, Liverpool, and Hull) or small and robust enough to parcel up and send to more distant markets e.g. telescopes to London (from Birmingham or Sheffield).
8. Transport	All provincial centres connected to London by carrier, subsequently by canal, then railway systems.
9. Low cost of workshop premises	Unknown.
10. Guild control	Ineffective guild control in long-established centres (York, Bristol); none in new centres.
11. Co-religionists or immigrants	Possibly in larger new population centres (with other stronger location factors taken into consideration.)

Table 2:2 Possible factors influencing locations of the instrument trade, and where these might apply between 1760 and 1851.

England's most prosperous Atlantic port during this period. In the following chapter, most of these elements appear in various guises in the provincial centres under discussion.

These centres were selected by working backwards, from an examination of the contents of Class X, philosophical, musical, horological and surgical instruments, of the *Illustrated Catalogue of the Exhibition of all Nations* ... (London, 1852). A total of 751 businesses had displays there. The introduction described 'this Class as representing the culminating point of mechanical skill', and were thus seen to be the makers of their wares.[8] Of these, 108 businesses have been identified by Gerard Turner as instrument makers, of which 53 firms were located in the United Kingdom, but a mere 15 came from outside London.[9] Leaving aside George Yeates of Dublin, Thomas Dunn and James Liddell of Edinburgh, Paul Cameron and Gardner & Co., of Glasgow, this leaves 10 instrument-making firms in England outside the metropolis. These were: Abraham Abraham and Gray & Keen of Liverpool, John Braham and Thomas King of Bristol, Chadburn Brothers of Liverpool and Sheffield, Samuel Sharp of Sheffield; Robert Field & Son and J. Parkes & Son of Birmingham, J.N. Hearden of Plymouth and William Wilton of St. Day, Cornwall. These were not names of first-ranking, international businesses, and we do not even know if the firms were a fairly representative cross-section of provincial English instrument making at this time. All we know is that they were prepared to display their wares in an international forum, and be judged on their own merits. It was also clear from surviving instruments that - although numerically far fewer than those with a London address - instrument makers outside London were by this time confident enough to engrave addresses such as 'Sheffield' and 'Birmingham' on their wares. No work has looked at the contribution of these newcomers to the industry, assessed the impact of their arrival, nor gauged the size of their different centres. Even characterising the differences between the products of new, yet geographically close, instrument-producing centres such as Liverpool and Manchester has not been undertaken.

The four cities thus selected were also, of course, major new centres of industrial population and thus contained pools of skilled and semi-skilled labour, an important pre-requisite for instrument making. Marriner has underlined the existence of skilled metal workers in

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8. *Catalogue....* (1852), 405.
9. Turner (1983), 309-10.

Warrington, making tools: 'watch- and clock-making were extremely important craft industries in Liverpool, Prescot and Warrington, and they spread to other parts of south-west Lancashire such as Ormskirk.'[10] She points out that these skills could be applied to 'making other precision products such as chronometers, sextants and other navigational aids for ships.'[11] Both Liverpool and Manchester, as Hudson outlines, were built on cotton, which brought in 'considerable external economies [which] accrued because of the specialist services of the regional infrastructure.'[12] Instrument-making was able to flourish in these centres because there were supplies of raw materials, a skilled workforce, legal, financial and credit facilities, and a transport system readily available. In Sheffield and Birmingham, which did not follow the 'factory textile' model, the appearance of an instrument-making industry there during this period is perhaps less surprising. The work of Maxine Berg has demonstrated that in Birmingham, where small metal workshops were the norm, the trades had been nationally and externally oriented since at least the seventeenth century, and the instrument trade appears to have become a part of the already-existing structure.[13] In Sheffield, although the metal-workers were cutlers, and thus working in steel rather than brass, David Hey has asserted that the 'structure of the local economy was little affected by new crafts, for they were largely organised on traditional lines.'[14] As a contrast to these 'successful' new centres, instrument activities in two earlier towns with a comparatively large population, York and Bristol, will be outlined as illustrative of the pre-industrial norm. As in London, both York and Bristol retained their guild structures, which although weakening by the end of the eighteenth century, nevertheless were used as a means of transmitting specialist trade skills. York will be contrasted with Sheffield, to show two very different developments within the same region; and Bristol will be contrasted with Liverpool, both as ports clearly supplying a navigational market, yet displaying diverging characteristics with the passage of time.

It could be said that instrument making was 'provincial' when it first arrived in England in Tudor times, because for a period this new industry was still dominated by the workshops of Flanders. In due course, men with mathematical and engraving skills moved out of London to find

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10. Marriner (1982), 55.
11. *Ibid.*
12. Hudson (1992), 121.
13. *Ibid.*, 122; Berg (1993).
14. Hey (1991), 136.

new and local markets during the more stable later Stuart period, in the late seventeenth century, to established and growing population centres. Thus Thomas Moone was making instruments in Bristol in 1669 when his fellow Bristolian Samuel Sturmy described him as 'an ingenious smith', and there had been the example of Philip Staynred preceding them both;[15] the brothers John and Robert Roscoe were active in Liverpool from around 1696;[16] and an hour glass-maker, Nicholas Cosens, obtained his freedom in York in 1638.[17]

At the start of the period of the Industrial Revolution, by about 1760, these centres of instrumental activity - and there were few communities of more than a handful of specialist instrument makers to be found anywhere outside London - were located in the major centres of population, because that is where people would buy or use instruments. Even where there were no actual instrument makers resident, the mathematical practitioners - as described by E.G.R. Taylor: the teachers, writers, inventors, surveyors, architects, mapmakers, both amateurs and professionals - were to be found in provincial England from a fairly early date. They would have bought their instruments in London, or made them for themselves. This can be illustrated with the example of two surviving instruments, which date from before 1760. One, a brass rule [Fig. 2:3], marked with various useful scales and with the name of its one-time owner Robert Trollap of York, an architect and builder, is dated 1655, the year in which Trollap designed and built the Exchange and Guildhall, Newcastle. The second item is a boxwood sector or joynt rule, again marked with the owner's name and address 'Robert Hudson, Leeds, 1686', and it includes a perpetual almanac, dialling and trigonometrical scales, as well as timber measures useful for carpenters.[18] Both items were probably - but not irrefutably - London-made, but demonstrate that demand existed outside the metropolis from about the mid-seventeenth century, a demand that came to attract makers away from the south-east to nascent markets in the provinces.

This gradual growth in local market demand led to instrument manufacture - as distinct from importing and repairing - in some areas only. For instance, the practical users - that is, the

15. Taylor (1954), 260.
16. Clifton (1995), 237.
17. *Ibid.*, 66, quoting Loomes (1981), 166.
18. National Museums of Scotland, inventory numbers NMS T.1978.92 and T.1990.88. For Trollap, see Colvin (1995), 989-990.

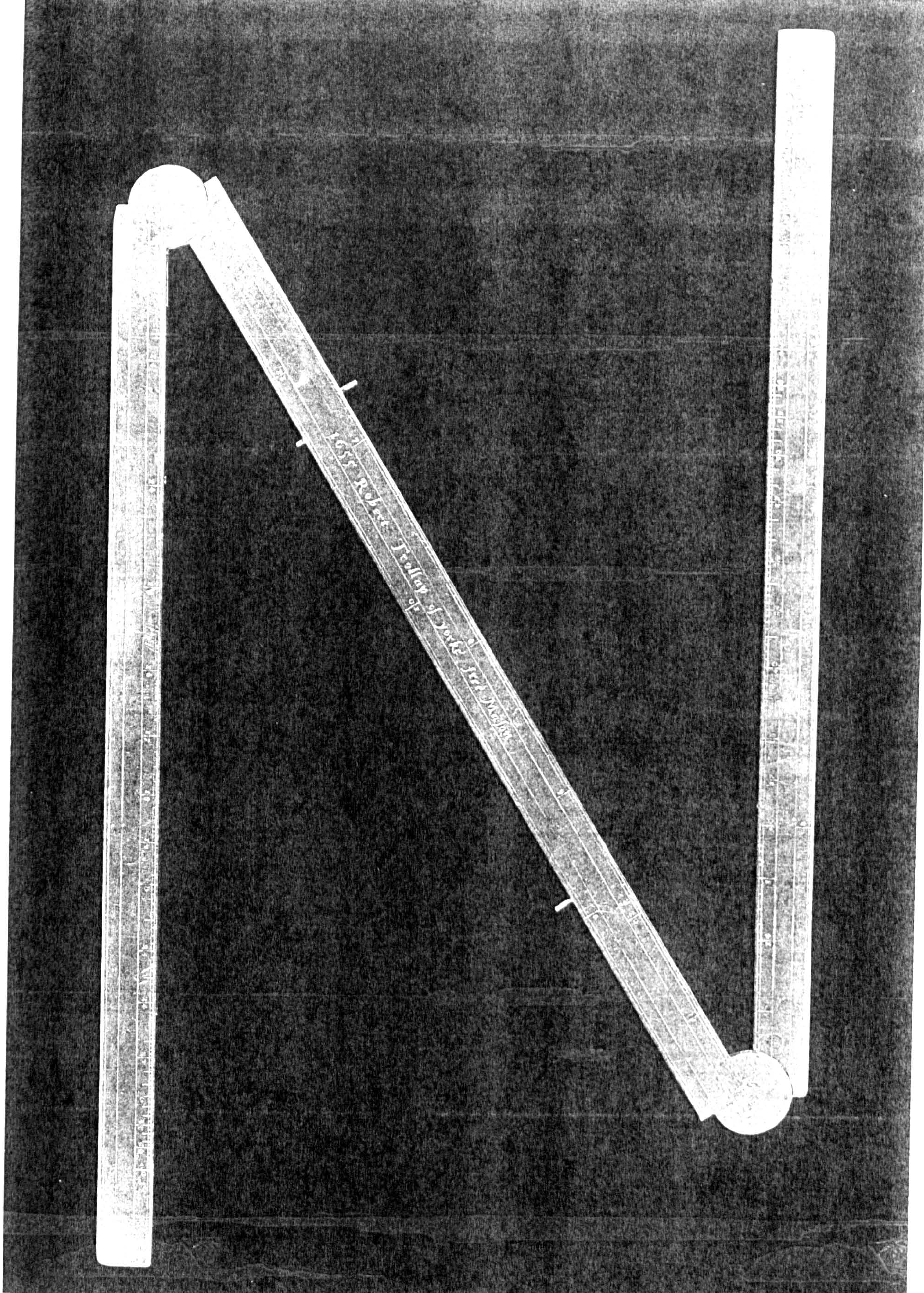

Fig. 2:3 Brass calculating rule, owned by Robert Trollap of York, 1665. National Museums of Scotland.

surveyors, the architects, the carpenters, the masons and other wrights - who were building new towns well away from London, encouraged those with the right skills to move out into the provinces, or, if already there, to diversify into these areas of manufacturing expertise. Repairing was and remained an important function of these new enterprises, however, as the cost and delay, as well as the risk and uncertainty of sending an item back to its London manufacturer often proved unrealistic. Yet it remains very difficult to gauge who was actually 'making' or manufacturing entire instruments in the provinces at all: advertised claims in newspapers and street directories often masked the amount of material bought-in for re-sale, either from London or from other local manufacturers. Despite this, it is clear from examination of the artefacts that the ability to make instruments outside London was there from at least the early eighteenth century. Leaving aside the examples of Scotland and Ireland, which to some extent developed their own indigenous trades (and although outside London, cannot be regarded as 'provincial England'), these pockets of instrumental activity initially remained close to their markets, and these tended to be where there were new population centres.

Table 2:4 shows the number of instrument-making firms to be found in local directories,[19] which gives an idea of trends over much of the period. Unlike the earlier figures provided by Clifton in Table 2:1, these figures show the number of enterprises, rather than individuals. There are also numbers for London makers from the SIMON database, using figures for individuals, to give an idea of the smallness of the scale of the trade outside the capital. Local directories were being introduced from the mid-eighteenth century, and a 'start-date' of 1760 for these places is not possible: Birmingham's first directory was published in 1767; Liverpool in 1766; Manchester in 1772 and Sheffield in 1774. Other substantial provincial cities soon had their own directories, too: Bristol, almost annually from 1775, Newcastle-upon-Tyne from 1778, while others - York, Hull, Leeds - were encompassed in the huge provincial listings undertaken first by Bailey in 1781, and subsequently by Holden, Pigot and Slater.[20]

The directories were produced to satisfy the demands of the rise of commerce, and are a flawed source: as already indicated in the Introduction, their compilers copied from one another,

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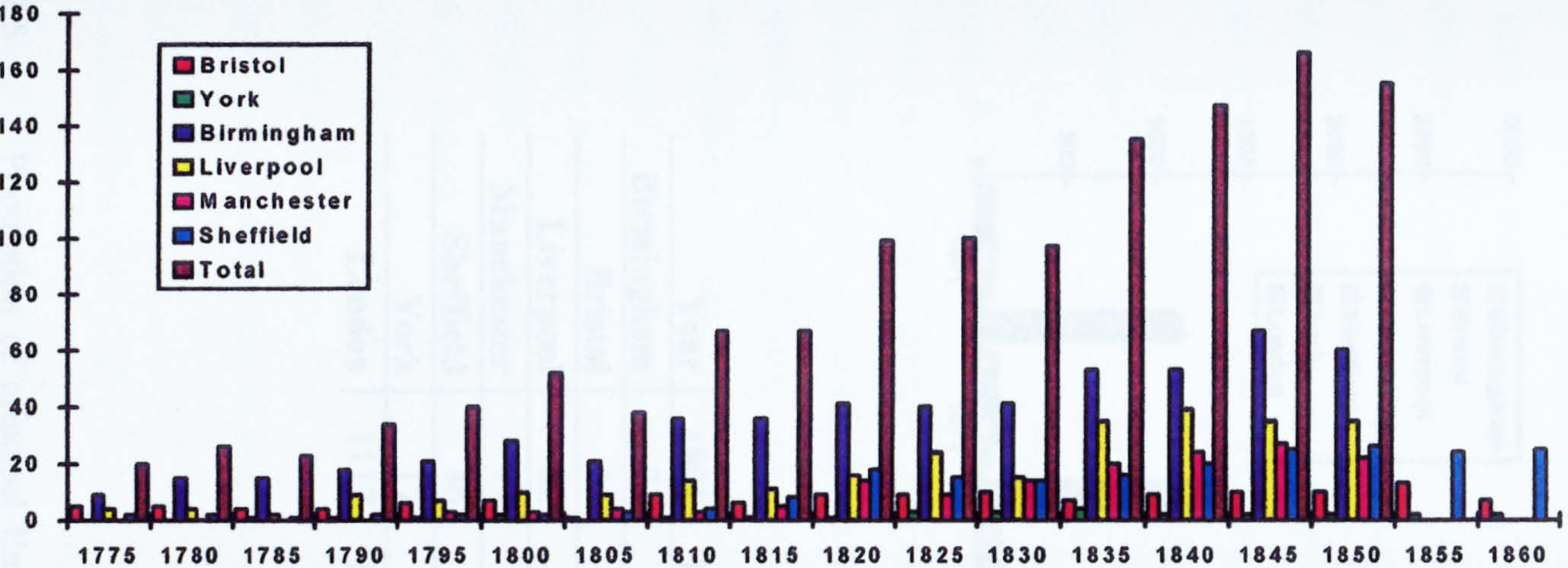
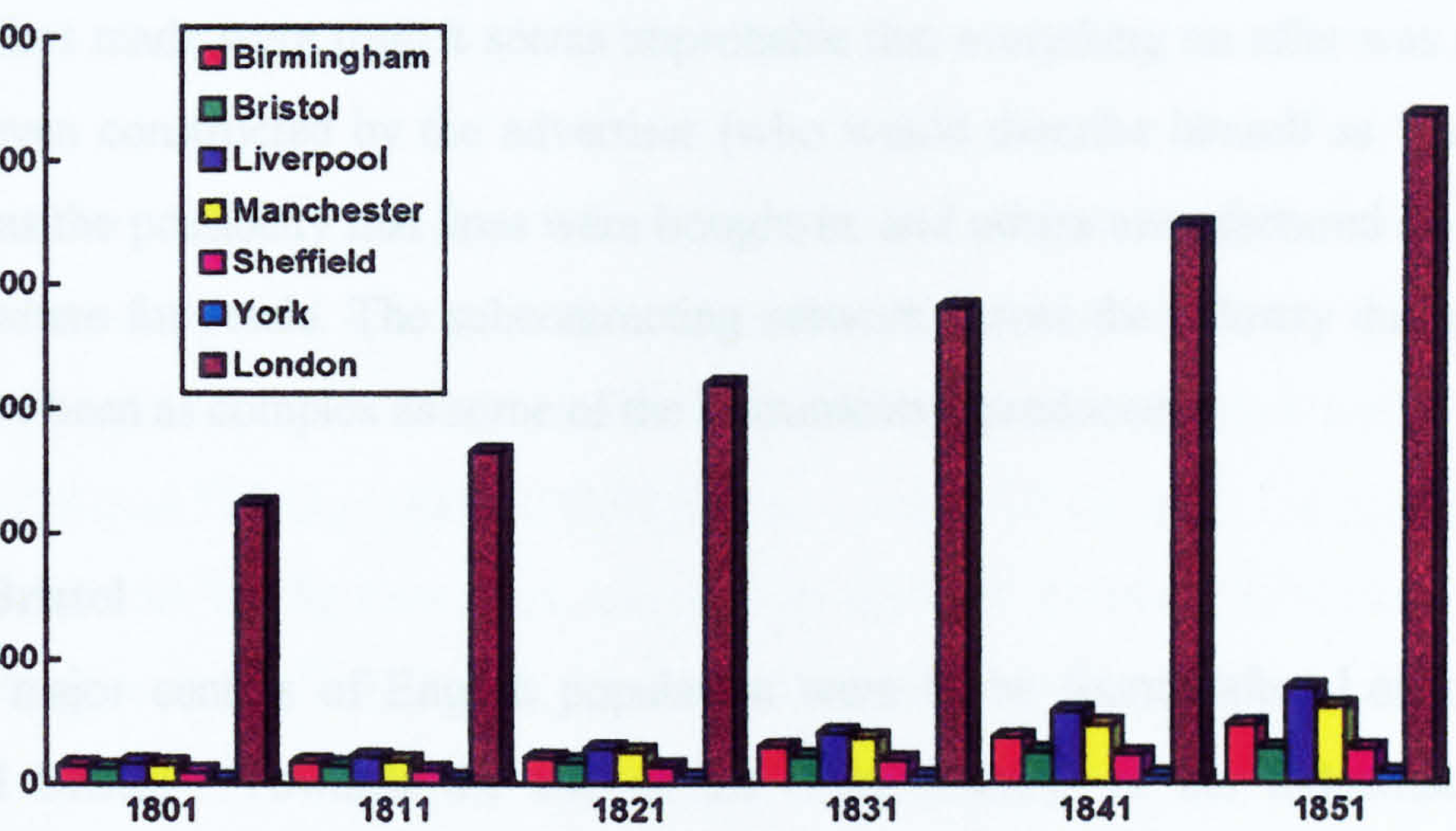
[19]. Despite the problems with these discussed in the Introduction.
[20]. For more detail, see Norton (1950) and Shaw (1982).



Year	1775	1780	1785	1790	1795	1800	1805	1810	1815	1820	1825	1830	1835	1840	1845	1850	1855	1860
Bristol	5	[5]	4	[4]	6	[7]	1	9	6	9	9	10	7	9	10	10	13	[7]
York		0	1	1	1	2	0	1	1	1	3	3	4	2	2	2	2	2
Birmingham	9	15	15	18	21	28	21	36	36	41	40	41	53	53	67	60		
Liverpool	[4]	[4]	[2]	9	[7]	10	9	14	[11]	[16]	24	15	35	[39]	35	[35]		
Manchester	0	0	0	0	3	3	4	3	5	14	9	14	20	24	27	22		
Sheffield	[2]	[2]	[1]	[2]	[2]	[2]	[3]	4	[8]	[18]	15	14	[16]	[20]	25	[26]	[24]	25
Total	20	26	23	34	40	52	38	67	67	99	100	97	135	147	166	155		

Table 2:4 Numbers of instrument making firms in six provincial centres (figures from local street directories, square brackets for inferred numbers for years where no directory exists)



Year	1801	1811	1821	1831	1841	1851
Birmingham	71	83	102	144	183	233
Bristol	61	71	85	104	124	137
Liverpool	82	104	138	202	286	376
Manchester	75	89	126	182	235	303
Sheffield	46	53	65	92	111	135
York	17	19	22	26	29	36
London	1117	1327	1600	1907	2239	2685

Fig. 2:5 Population of principal English towns, in thousands, 1801-1851 (from B.R. Mitchell, *British Historical Statistics* (Cambridge, 1988), 25-27).

frequently omitted smaller businesses, and left in those which had ceased trading. The accuracy at any given date can only be taken as a rough approximation of numbers within the provincial instrument trade. It does however, give an indication of the underlying trends in specific centres. The newspapers which supply some of the detail are also a flawed source. Advertisements were composed to place the business and its output in the best possible light, and it is extremely unlikely that all the claims made were true: it seems improbable that everything on offer was available off-the-shelf, or even constructed by the advertiser (who would describe himself as 'maker'). Much more likely was the possibility that lines were bought-in, and others manufactured on the premises and sent elsewhere for resale. The subcontracting network across the industry during this period appears to have been as complex as some of the instruments it produced.

Precursors: Bristol

In 1760, the major centres of English population were to be found (after London) in York, Norwich, and Bristol. Towards the end of the 'long century' of the Industrial Revolution, population had grown in the newer centres of Sheffield, Manchester, Liverpool and Birmingham, and in some cases had overtaken the older, medieval wool towns and ports [Table 2:5]. London remained England's major port, the entrepôt for the Empire, although Bristol in the south-west became significant: '... the greatest, the richest and the best port of trade in Great Britain, London only excepted', wrote Daniel Defoe in 1726. 'It is supposed they have an hundred thousand inhabitants in the city, and within three miles of its circumference; and they say above three thousand sail of ships belong to that port.'[21] Here there would be local demand for the supply and repair of navigational instruments, for example the two surviving wooden nocturnals signed by Robert Yeff, dated 1693 and 1702 respectively. There had been instrument making and activities associated with navigation from Tudor times, but not apparently sufficient for a community of specialist practitioners to sustain itself, with skills passed on from one generation to the next.[22] A

[21]. Defoe (1971), 361, 363.

[22]. Nocturnals are time-telling devices, used in conjunction with tide tables, which, as their name suggests, are used at night. The nocturnal by Yeff in the National Maritime Museum is dated 1693, inv. no. N28 A74-2; that in the Science Museum is dated 1702, inv. no. 1903-80; an illustration of this appears in Turner (1987), 72. Robert Yeff's Certificate of the Freedom of Bristol, 1697, is Science Museum inv. no. 1987-61. Yeff is discussed in Clifton (1995), 308. Another instrument by Yeff is a 24-inch Gunter's scale dated 1721 at the Whipple Museum of the History of Science, Cambridge, inv. no. 2823. Other early Bristol makers are

proportion of the goods sold in Bristol must have been associated with London manufacturers, and the cachet of London manufacture can be seen in 1756, when advertisements were appearing in the Bristol press for

> John Wright (From LONDON)... [and at the foot] Gentlemen may depend upon being served with the above, and all other Instruments, made according to the latest Discoveries, JOHN WRIGHT being late an Apprentice to Mr COLE, Successor to Mr THOMAS WRIGHT, Instrument Maker to his Majesty.[23]

Although threatened by competition on at least one occasion, when the London instrument makers James Ayscough and Henry Gregory appointed a local bookseller as an agent for their wares,[24] John Wright appears to have seen them off (he subsequently advertised himself as 'the ONLY MATHEMATICAL, PHILOSOPHICAL and OPTICAL Instrument-Maker in BRISTOL'[25]): he may briefly have been survived by his wife, Susanna, as a backstaff with her signature has been recorded.[26] His shop, however, 'At Hadly's [sic] Quadrant ... Lately the SHOP of Mr JOHN WRIGHT' was being run by Joshua Springer by 1759, implying a firm trade succession: Springer may well have learned his trade in Wright's workshop.[27] By 1774 Springer was to be found in premises at no 2 Clare Street[28] - an address which was to be used in turn by R. & C. Beilby from 1808,[29] and subsequently by John King, who advertised as 'late foreman to C. Beilby'[30] - in a direct line, confirmed by newspaper announcements, which continued until well after the Great Exhibition of 1851. Where a family succession failed through death, lack of inclination or provision of heirs, it seems that a trade succession was the next preferred option. This pattern is most clearly seen in Bristol, where much more modest expansion in the trade occurred.

Joshua Springer may have inherited Wright's premises and commercial goodwill, but in

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mentioned in Barry (1985) are: J. Willis, T. Wells, T. Plummer, E. Woolfe. A backstaff, marked 'Made by Tho^{s} Plumer in Bristol' was offered for sale by Sotheby's, 20 May 1992, Lot 388.

23. *Felix Farley's Bristol Journal*, 13 March 1756.
24. *Ibid.*, 20 November 1756.
25. *Bristol Weekly Intelligencer*, 1 January 1757.
26. Sotheby's, 20 September 1983, Lot 104: 'Made at Sus^{a} Wright^{s} in Briftol'.
27. *Felix Farley's Bristol Journal*, 29 September 1759.
28. *Ibid.*, 10 September, 1774.
29. *Ibid.*, 9 July 1808.
30. Undated trade card, Blaise Castle Museum, Bristol, inv. no. TA 5109.

1774 he also found himself with competition, in the person of Henry Edgeworth, who described himself as 'The only Person in this City, who served a regular Apprenticeship' in instrument-making.[31] Edgeworth appears to have arrived in Bristol from Dublin, where he may have served an apprenticeship with John Margas, formerly of London, until his bankruptcy in 1758.[32] In 1790, Richard Rowland advertised that he had 'succeeded to the business of the late Mr HENRY EDGEWORTH, which he intends carrying on in all its branches'.[33] Again, in partnership with his sons Edward and Thomas Rowland, and long after his death, the firm also survived to beyond the Great Exhibition, apparently still run by family members.

Numbers of firms of instrument makers or retailers in Bristol remained small and relatively static: at around five in 1775, rising to seven or eight in 1800, and to nine in 1810, at which figure it remained until after 1850 [see Table 2:6]. The longevity of the firms, provided they survived the first two or three years, appears to be relatively stable, extending over a number of generations or trade successors.[34] Among contributing factors - other than the obvious one of supplying and repairing navigational instruments - must have been the long-established large houses and estates around Bristol, and a steady market for the supply of quality items: the fashionable spa of Bath was merely a few miles away, while larger landowners with their surveying and building requirements were to be found in the surrounding countryside.[35] Unsurprisingly, early Bristol instrument makers had their premises close to the quays, where their customers could find them without too much trouble [Fig. 2:7]; however, by the mid nineteenth century, there had been a distinct move into the centre of town where the main shopping area was to be found. Nor was the production of instruments by now exclusively for a maritime market.

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31. *Felix Farley's Bristol Journal*, 25 June 1774.

32. Clifton (1995), 92, 178.

33. *Felix Farley's Bristol Journal*, 6 February 1790; Edgeworth's death was announced *ibid.*, 23 January 1790.

34. Numbers gleaned from Bristol directories, which run almost annually from 1792.

35. Bath managed to support a handful of resident instrument retailers during this period including, at different times, Jacob Abraham (who also had a shop in Cheltenham), Lyon and Thomas Davis, James Field, Henry Oakley, John Orchard, Peter Salmoni, Benjamin Smith and Henry Tulley: for whom, see Clifton (1995). William Herschel was of a different stature: see below.

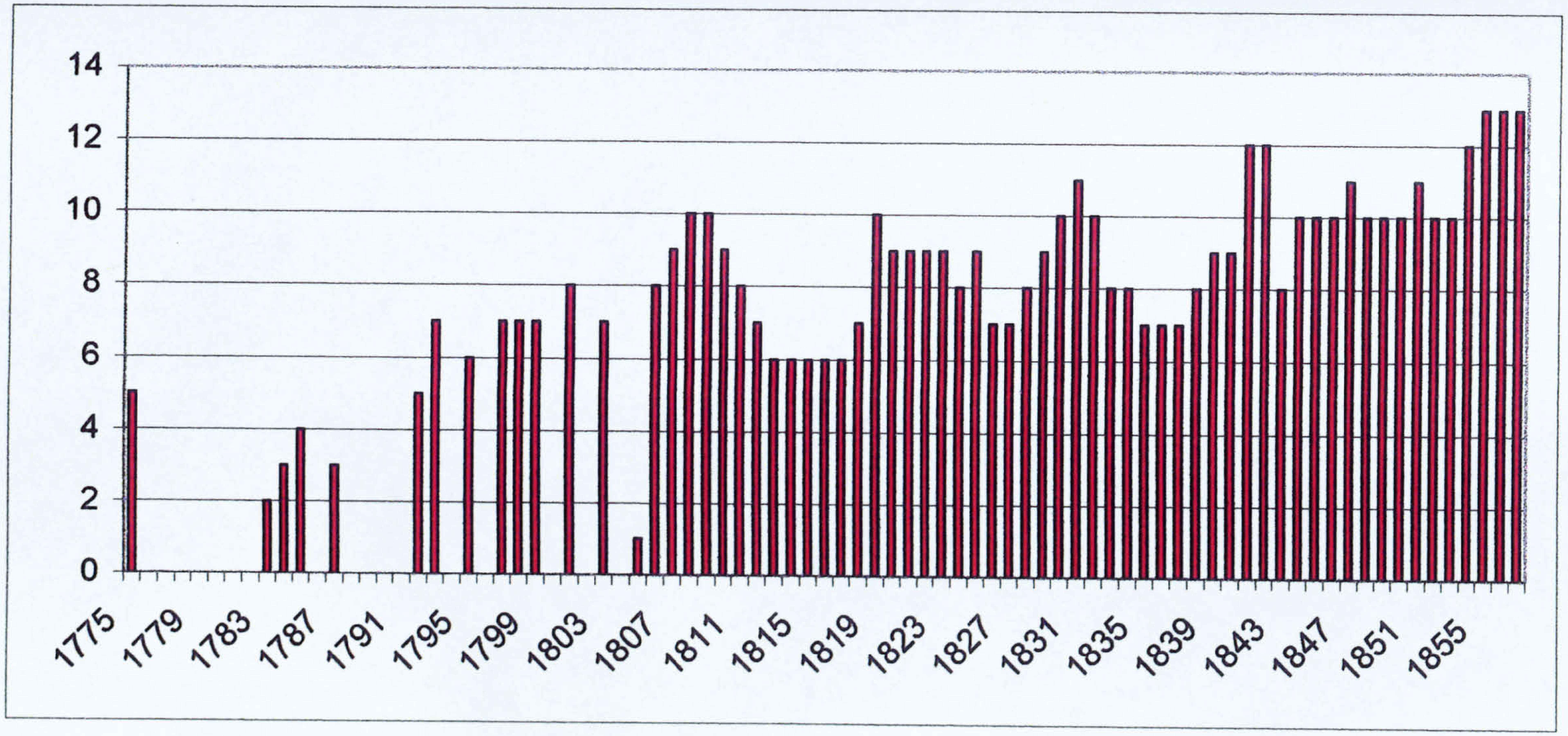

Table 2:6 Bristol 1775-1866 : Numbers of instrument making firms from local directories

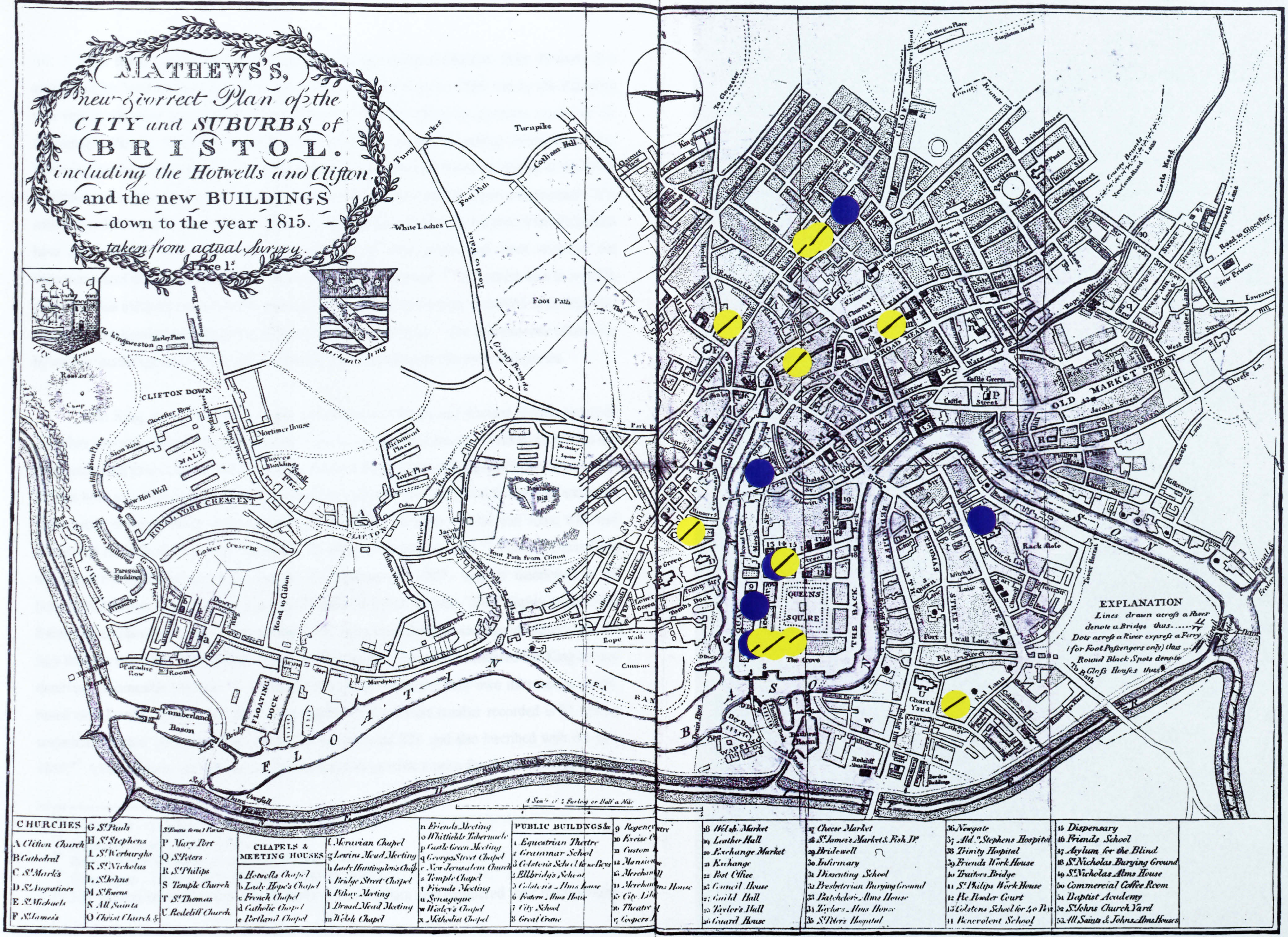

Fig. 2:7 Map of Bristol for 1815, showing locations of firms in 1775 and 1850

Two Bristol instrument makers exhibited at the Great Exhibition. John Braham first announced his 'mathematical instrument warehouse' in Clare street in 1828, but by the following year was in the more fashionable College Green. In the early 1830s his premises moved to St. Augustine's Parade, where he managed to acquire the agency for selling Admiralty charts. However, he was clearly finding that optical material was most lucrative as his display at the Great Exhibition was almost entirely composed of spectacles, and the Jury was most unimpressed: 'It is with regret that we observe that the exhibitors of spectacles in the British portion of the Exhibition have done nothing more than exhibit a collection of shop goods, and have regarded the improvement of the glasses themselves as a matter of little moment.'[36] An octant now in a public collection was evidently retailed rather than made by Braham, as its scale is marked as having been divided by the London manufacturers Spencer, Browning and Rust.[37] The business was taken over by another ocular specialist, M.W. Dunscombe in 1874, according to the street directories.

John King, as we have seen, began as foreman to Charles and Richard Beilby, and took over their premises on their retirement in 1821, but he was probably born in London, as was his son John, according to the 1861 Census. This was plainly a family firm, although the family appears not to have been as cohesive as some, in that members splintered into individual businesses, and some acrimonious correspondence survives between John King the elder and his son John, who had abandoned his wife and children, apparently for another woman, in 1831.[38] Thomas Davis King was a son of the younger John King, but left the business in 1857, and is mentioned in his father's Will twenty years later as a journalist living in Montreal, Canada. Their display at the Great Exhibition consisted of microscopes of which T.D. King was 'designer and manufacturer'; and the Jury thought that 'the workmanship ... is of the first order ... The Jury considered Mr King as well deserving Honourable Mention.'[39] Unusually, the Kings developed their own microscope model, based on a London design, and these were numbered: the lowest number recorded is 81, dating sometime between 1846 and 1850; the highest is numbered 223, and also inscribed with the date 1857.[40] Unfortunately, no information has surfaced to provide a price for these instruments, but

36. *Catalogue*... (1852), 439; *Reports*... (1852), 272-3.
37. Holbrook et al. (1992), 101.
38. Bristol Record Office, Accession N. 4966 (36).
39. *Catalogue*... (1852), 439; *Reports*... (1852), 266-7.
40. J.B. Dancer of Manchester and R. Field of Birmingham also numbered their microscopes:

this implies a rate of sale of 142 microscopes over a period of seven to eleven years.

Liverpool

It is illuminating to contrast Bristol's instrument activities with those of another port: Liverpool. In 1726, Daniel Defoe commented: ' 'tis probable it will in a little time be as big as the city of Dublin ... 'Tis already the next town to Bristol, and in a little time may probably exceed it, both in commerce, and in number of people'.[41] During the period of the Industrial Revolution, for a number of reasons, Liverpool overtook both Bristol and Dublin in size. A centre for the slave trade, for imports of cotton, tobacco and sugar, Liverpool was a dynamic, chaotic and growing mass of seething humanity. Unlike Bristol, whose street plan remained recognisably the same throughout this period, Liverpool's population grew enormously, reconstructing its docks and waterside as the port expanded: and as a result, instrument makers did not remain in the same premises nor indeed did their trade successions appear to be so smooth.

Although there was a handful of retail instrument makers in Liverpool in the first half of the eighteenth century - Robert Wild, Thomas Kendal, James Dykes, Henry Roberts and William Skegg - these individuals are very obscure, known only from the description of their occupation in parish registers.[42] By the time the first street directory was published in 1766 there were already two mathematical instrument firms listed, one proving very short-lived.[43] By the turn of the century, there were ten firms, and these numbers increased gradually over the next fifty years to 36 in the year of the Great Exhibition [see Table 2:8]. Initially some, such as John Grindrod and Thomas Howard, may well have been locals (judging by their names), but others, for example John Leverton, were trained in and had migrated from London. Advertisements appeared in the local

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for which see below and chapter 5. The King instrument 81 is discussed in Nuttall (1979), 49, and the instrument numbered 223 is in the City of Bristol Museum and Art Gallery: see Holbrook et al. (1992), 100.

41. Defoe (1971), 392. For a more recent overview of Liverpool, see Marriner (1982).

42. Listed by Fairclough (1975), pp.225, 405-408.

43. John Grindrod, mathematical instrument maker, appeared in directories for 1766 and 1767 only; John Leverton first appeared in 1766, succeeded by S. (Susannah) in 1787; she made her last appearance in the 1790 directory.

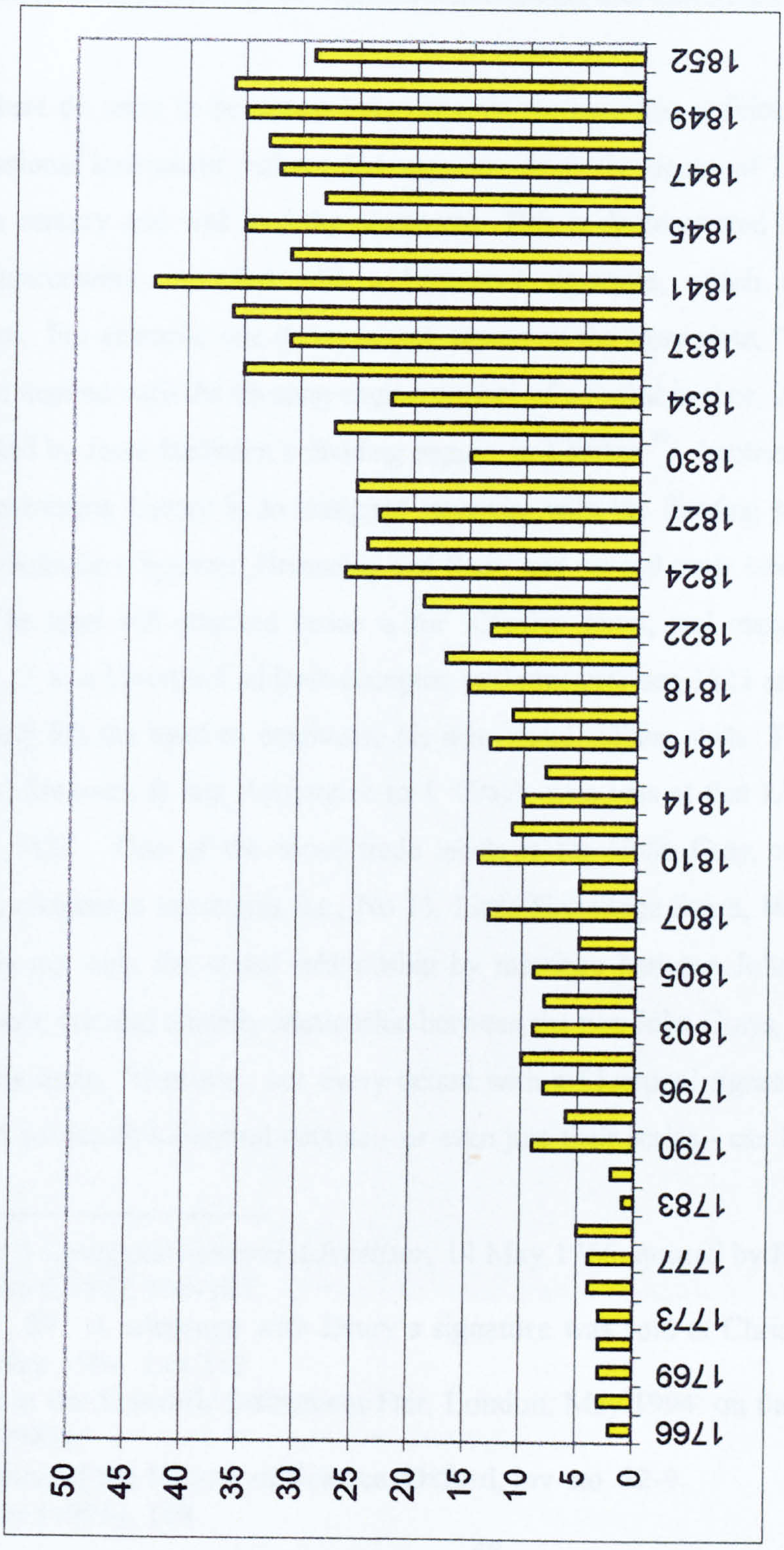

Table 2:8 Liverpool 1766-1853 : Numbers of instrument making firms from local directories

paper *Gore's Liverpool General Advertiser* in 1766 and 1767, in which Leverton claimed that he was 'from London':[44] Clifton's *Directory* confirms that his father was Lancelott Leverton, bricklayer of Waltham Abbey, Essex, that he was apprenticed to William Parsons of the Goldsmiths Company in 1749 and freed in 1761.[45] William Drury, active in Liverpool between 1769 and 1773, may have been an apprentice of the London ship chandler and instrument maker, John Urings.[46]

There do seem to be strong links between the specialist provincial trade in Liverpool and the navigational instrument makers and suppliers from the docks of London at the end of the eighteenth century and well into the nineteenth. This is demonstrated by a number of surviving nautical instruments, recorded with a Liverpool signature, which appear to have London connections. For example, one ebony octant, signed on the ivory plate, 'Thomas Holliwell' has the ivory scale marked with the dividing engine symbol of a fouled anchor, implying that it had had its scale divided by Jesse Ramsden's dividing engine, in London.[47] Another octant which appears to have an interesting history is an unsigned example, with the dividing mark on the scale for the London wholesalers Spencer, Browning and Rust, and several trade labels, now loose, within the case.[48] The label still attached inside is for 'Charles Jones, real manufacturer of sextants and quadrants ...' at a Liverpool address occupied by Jones between 1823 and 1827 [Fig. 2:9]. Jones clearly felt the need to emphasise his instrument-making skills. The label also reveals that 'C.J. [was] Step-son & late Apprentice to I. Gray', who was at that Liverpool address between 1814 and 1822. One of the loose trade labels is for 'John Gray, manufacturer of sextants, quadrants, compasses telescopes &c., No 13, Little Hermitage Street, Wapping, London'.[49] This must imply not only the stated relationship by marriage between John Gray of Liverpool and Charles Jones, but also a family relationship between the two John Grays, who may even have been one and the same. However, not every octant with a Liverpool signature has a dividing engine stamp, and so not all Liverpool octants - or even just their scales - can be assumed to have been

44. *Gore's Liverpool General Advertiser*, 14 May 1766, quoted by Fairclough (1975), 226.
45. Clifton (1995), 166-167.
46. *Ibid.*, 89. A telescope with Drury's signature was sold at Christie's South Kensington, 29 September 1994, Lot 212.
47. Seen at the Scientific Instrument Fair, London, May 1994: on the use of such marks, see Stimson (1985).
48. Museum of the History of Science, Oxford, inv. no. 32-9.
49. Clifton (1995), 118.

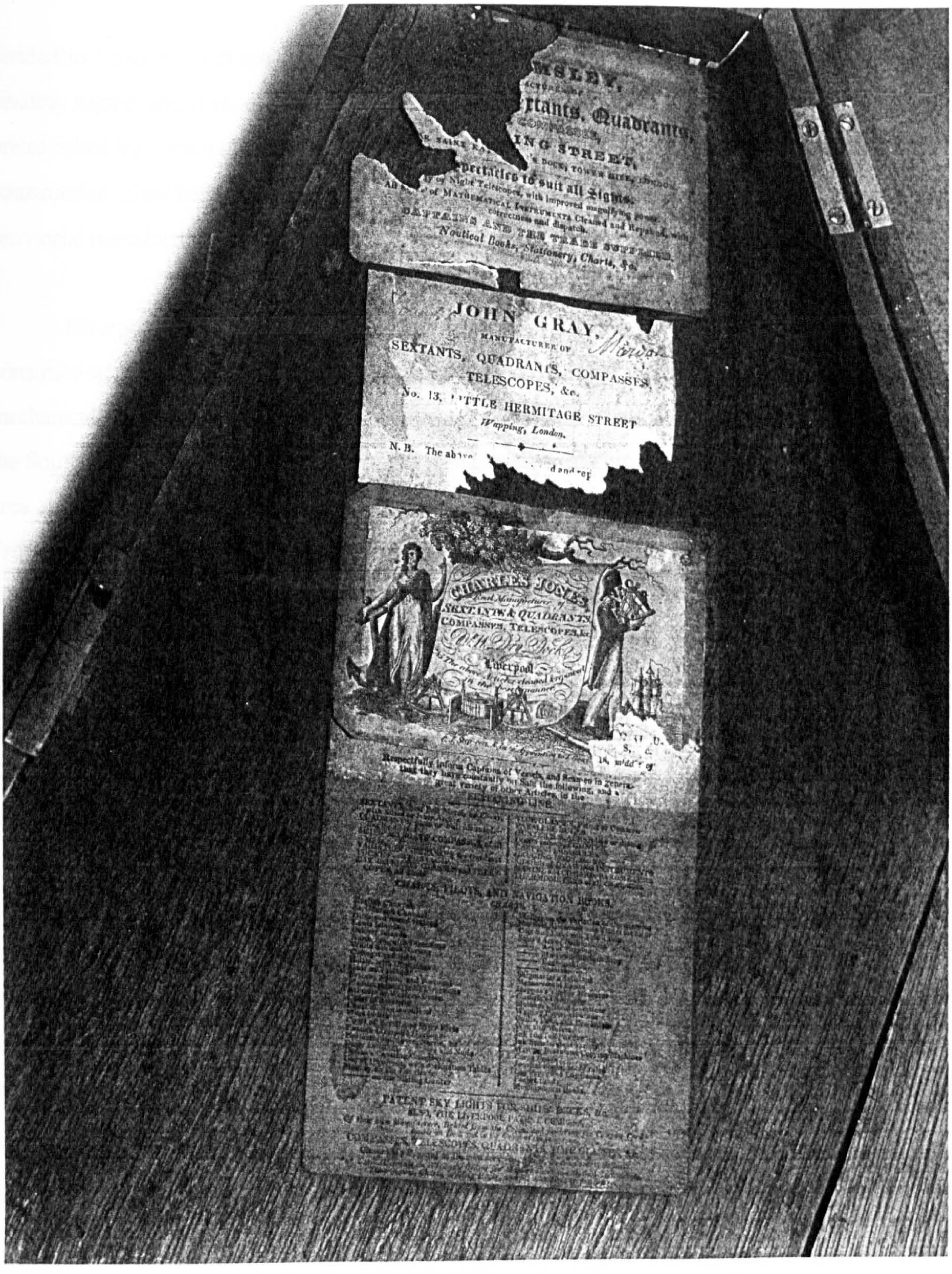

Fig. 2:9 Trade card for Charles Jones, Liverpool, 1823-1827.
Museum of the History of Science, Oxford.

divided in London. Yet the question remains: did any instrument maker in Liverpool possess a dividing engine, and if so, at what date was it obtained? At the least, this shows that the wholesale prices asked by volume manufacturers of specialist instrument types undercut smaller scale construction elsewhere and led to complex supply arrangements, in which both London and provincial manufacturers were undoubtedly active.

Liverpool is a geographically close neighbour of Prescot, the centre of watch-part construction and machine-tools for watchmaking: so nearby was a great pool of men with mechanical ability and skilful craftsmanship from which individuals no doubt sometimes moved to the flourishing port.[50] It is apparent that the rising number of chronometer makers in the Liverpool area – among them the Frodshams,[51] Gray & Keen, Edward Massey[52] - drew upon this expertise. From a relatively early stage, too, there was an apparent demand for domestic barometers initially tied in with mirror supply, and weatherglass makers with experience with glass working were able to survive. Amongst these were peripatetic Italians (of whom, more later), who made this part of the trade very much their own, starting with Antonio Beptsy, who married a local woman in 1771.[53] Less peripatetic were the later arrivals of the Casartellis (whose firm first appeared in 1821, and continued until the end of the century) and the Pastorellis, whose links with the London firm of the same name have yet to be established.[54]

By 1851, only three firms based in Liverpool - Chadburn Brothers (as part of their main Sheffield enterprise), Gray & Keen, and Abraham Abraham - were prepared to exhibit at the Great Exhibition. The description of the Chadburn display does not distinguish between its Liverpool and Sheffield elements, and included optical glass in various stages of preparation before being made 'ready for fitting into spectacles. The exhibitors grind 750 dozen per week, on the average'. Gray &

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50. Bailey and Barker (1969); Smith (1977).
51. Mercer (1981), 'Chapter VI: the Liverpool Frodshams', 56-61.
52. Treherne (1977).
53. Antonio Beptsy, instrument maker, married Elizabeth Merryjohn, 2 March 1771. Liverpool: St. Nicholas's Parish Registers: Marriages.
54. For the links between the Manchester and Liverpool Casartellis, see Wetton (1990-91), 63-66; for the Pastorellis, see Clifton (1995), 211. Although John Pastorelli first appears in the Liverpool directory for 1834, Joseph Pastorelli & Co. advertised quitting their business, selling (among other merchandise) 'weatherglasses and barometers' at 43 Atherton street some considerable period earlier: *Gore's General Advertiser*, 8 May 1800.

Keen, 'manufacturers and designers' of 'wheel barometers mounted according to various designs', while Abraham Abraham & Co, describing themselves as 'manufacturers' displayed a large and impressive triple magic lantern, and a 'compound microscope, exhibited for workmanship', none of which the Jury saw fit to comment upon.[55]

Precursors: York

Across the Pennines were to be found another two centres of instrument making, which provide contrasts with each other; and as neither are great ports, they in turn should illustrate different geographical characteristics than those shown by Bristol and Liverpool. 'York,' wrote Daniel Defoe,

> is a spacious city, it stands upon a great deal of ground, perhaps more than any city in England out of Middlesex, except Norwich; but then the buildings are not close and thronged as at Bristol, or as at Durham, nor is York so populous as either Bristol or Norwich. But as York is full of gentry and persons of distinction, so they live at large, and have houses proportioned to their quality; and this makes the city lie so far extended on both sides of the river.[56]

The see of one of England's two archbishops, centre of the northern medieval wool trade, and one of the richest and more settled communities, York had known instrument-making for some time:

> No city in England [Defoe wrote] is better furnished with provisions of every kind, nor any so cheap, in proportion to the goodness of things; the river being so navigable, and so near the sea, the merchants here trade directly to what part of the world they will...[57]

However, during the eighteenth century, York's importance as a port went into decline. Gloria Clifton's *Directory* mentions the group centred around the eminent early eighteenth-century clockmaker Henry Hindley, which included John Stancliffe and John Smeaton, both of whom migrated in due course to London, and subsequently became more involved in engineering.[58] All of them appear to have been involved in instrument manufacture at some stage in their careers, Stancliffe and Smeaton after they arrived in London. Hindley, who apparently had moved from Manchester to York because of religious persecution, made at least two refracting telescopes which have survived, and it has been suggested that he was supplied with glass of a suitable character by a

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55. *Catalogue....* (1852), 422, 436; *Reports* ... (1852), 301, 273.
56. Defoe (1971), 523.
57. *Ibid.*, 521.
58. Clifton (1995), 137; see also Setchell (1971), which formed the basis of Setchell (1973); Setchell (1970a) and (1970b); see also Law (1971).

local spectacle maker, Richard Eggleston, whose shop in Minster Yard was only a few yards from Hindley's workshop; both men were mentioned in the same advertisement (for an auction) in December 1734.[59]

Because of York's relative decline, the city had many fewer firms of instrument-makers in the late eighteenth century even than had Bristol: in fact, a more telling comparison can be seen by comparing York with Bath at this period. Both contained shops and amusements catering for the wealthy, and thus provided wares at the luxury end of the market rather than the tools of industrialisation or scientific endeavour - the exception being the case of William Herschel; for whom, see below. In York, however, 'RICHARD EGGLESTON, Spectacle-Maker from London ...' advertised his 'new Improved Dioptrical Telescope' in a local newspaper in October 1740.[60] He had served his apprenticeship with the London optician Richard Roak, but it is not clear why he chose to move to York.[61] In 1768, his son Nathaniel, who had served his apprenticeship with 'Mary Eggleston, optician' (presumably his widowed mother) also advertised himself as a spectacle maker in York, making and selling 'all Sorts of Spectacles, Telescopes, Microscopes ...'.[62]

In March 1774, his brother-in-law John Berry announced, shortly after Nathaniel Eggleston's death, that 'he continues to make and sell all sorts of reflecting and refracting Telescopes, single and compound Microscopes' and so on.[63] Berry himself died the following year, and his widow (born Elizabeth Eggleston) then remarried someone outside the trade.[64] Until this happened, the business had remained tightly within the family, with the involvement of at least two women. Now, one 'Matthias Wisker, glassgrinder and spectacle maker at the Golden Spectacles, Spurriergate, successor to the late Mr Berry' continued this trade succession, presumably by purchase.[65] Unlike some of the examples at Bristol, the business did not remain in the same premises, but appears to have moved around within York. Matthias (or Matthew) Wisker had

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59. *Yorkshire Courant*, 24 December 1734, quoted in Setchell (1971), 10.
60. *Yorkshire Courant*, 28 October 1740.
61. Clifton (1995), 93.
62. York City Archives: Register of Freemen, 1680-1986; *Yorkshire Courant*, 23 February 1768.
63. *Yorkshire Courant*, 22 March 1774.
64. *York Chronicle*, 4 August 1775 and 12 April 1776.
65. *Ibid.*, 7 November 1777.

served his apprenticeship with George Cowley, a York glass grinder and was made free in 1774; he was succeeded by his son John in August 1804, when the goods supplied took a more definite turn away from the scientific towards those of the general store; candles, spermaceti oil and lamps becoming the wares in preference to telescopes and microscopes, although spectacles were still on offer.[66] John's widow, Elizabeth, continued in business after his death at the age of 48 in 1822, with her son Matthias's assistance,[67] giving up in his favour in 1827.[68] Matthias Wisker retired in favour of his son, John Thomas Rigg Wisker in 1859 - another business which lasted well beyond the Great Exhibition, and by which time it claimed that it had been established in 1762.[69] This was a relatively common theme in advertisements, longevity implying reliability. In York, the Wiskers had no real competition, in the instrument line, until Thomas Cooke (1807-1868) founded his business in Stonegate in 1837.

Cooke's business broke the mould of the typical provincial enterprise described so far: the small family-run workshop, focusing on the supply of mainly retailed instruments to a fairly conservative local market, most of the income coming from repairs and retailing, offset by other ventures outside this narrow market when necessity demanded. By managing to produce a winning product (refracting telescopes), successfully finding and wooing local patrons (in particular those in the Yorkshire Philosophical Society),[70] Cooke was then able to expose his narrowly-concentrated skills to a wider audience - initially through the British Association for the Advancement of Science (which had first met in York in 1831), subsequently through patrons with wider influential networks embracing such figures as the seventh Astronomer Royal, G.B. Airy and the eminent astronomer Norman Lockyer (1836-1920), and through exposure of his products at the well-attended international trade exhibitions. Although no York instrument firm exhibited at the Great Exhibition in 1851, Cooke managed to put on a display at the Paris Exhibition of 1855, with some success.[71] As Anita McConnell has written:

66. York City Archives: Register of Freemen, 1680-1986; *Yorkshire Courant*, 20 August 1804.
67. *Yorkshire Gazette*, 9 and 16 March 1822.
68. *Ibid.*, 9 June 1827.
69. *Ibid.*, 11 June 1859; the firm first appeared in *Bailey's British Directory ... for the year 1784* in 4 vols. Vol III, first edition (London, 1784).
70. Brech and Matthew (1997).
71. *Catalogue* ... (1855), 23.

> Cooke's business did not suffer from being based in York rather than in London. Like his contemporary Thomas Grubb of Dublin, Cooke found that the astronomical market for large telescopes was so dispersed that any location with good transport links would serve as a base.[72]

By this time Thomas Cooke's business was able to take advantage of the railways. As one of Samuel Smiles's self-help heroes, slightly more is known about Cooke than most other provincial instrument makers.[73] Apparently inspired by the circumnavigational voyages of another Yorkshireman, Captain James Cook (1728-1779), Cooke (no relation) taught himself practical mathematics and navigation. The son of a shoemaker, he was determined to go to sea, but was persuaded against this course by his mother, and, instead became a village schoolteacher, pursuing practical optics in his spare time. He - legend has it - constructed a lens from the bottom of a glass tumbler, fabricating a rudimentary telescope which deeply impressed the curator of the Yorkshire Museum, John Phillips, who subsequently became a leading light in the British Association. His wife's uncle provided a loan of £100 for Cooke to set up in business, with his wife looking after the shop premises:

> Cooke set up his workshop in the rear and prepared to make, repair or retail instruments to order. One of his first tasks was to build his own screw-cutting machine... Thus equipped, he was ready to undertake his first substantial commission, an equatorial telescope of 4½ inches aperture, for William Gray. The Gray family had an established legal practice in the city of York, and their financial advice and support, again on the basis of family friendship, gave Cooke the practical assistance that he needed to get his business under way.[74]

Cooke's business flourished, and grew. His stock became more varied, and in 1849 he advertised a drainage level, of his own design, for use by farmers.[75] By 1843 he had moved to larger shop premises at 12 Coney Street, and according to McConnell, the 1851 Census 'shows him employing four men and an apprentice - one Lewis Angell, from Clerkenwell'.[76] In 1855, with Gray's financial support, Cooke purchased land at Bishopshill, within the York city boundary, where he erected his Buckingham Works. His orderbook, dating between 1856-68, a rare survival, gives a flavour of the range of items, and their prices that it was possible to supply from these new

72. McConnell (1992), 51.
73. *Ibid.*, 106, gives a bibliography; Smiles (1884), 336-348.
74. McConnell (1992), 50.
75. *Yorkshire Gazette*, 27 January 1849.
76. McConnell (1992), 51.

<£10	£10-£50	£50-£100	>£100	Total
308	191	40	77	616

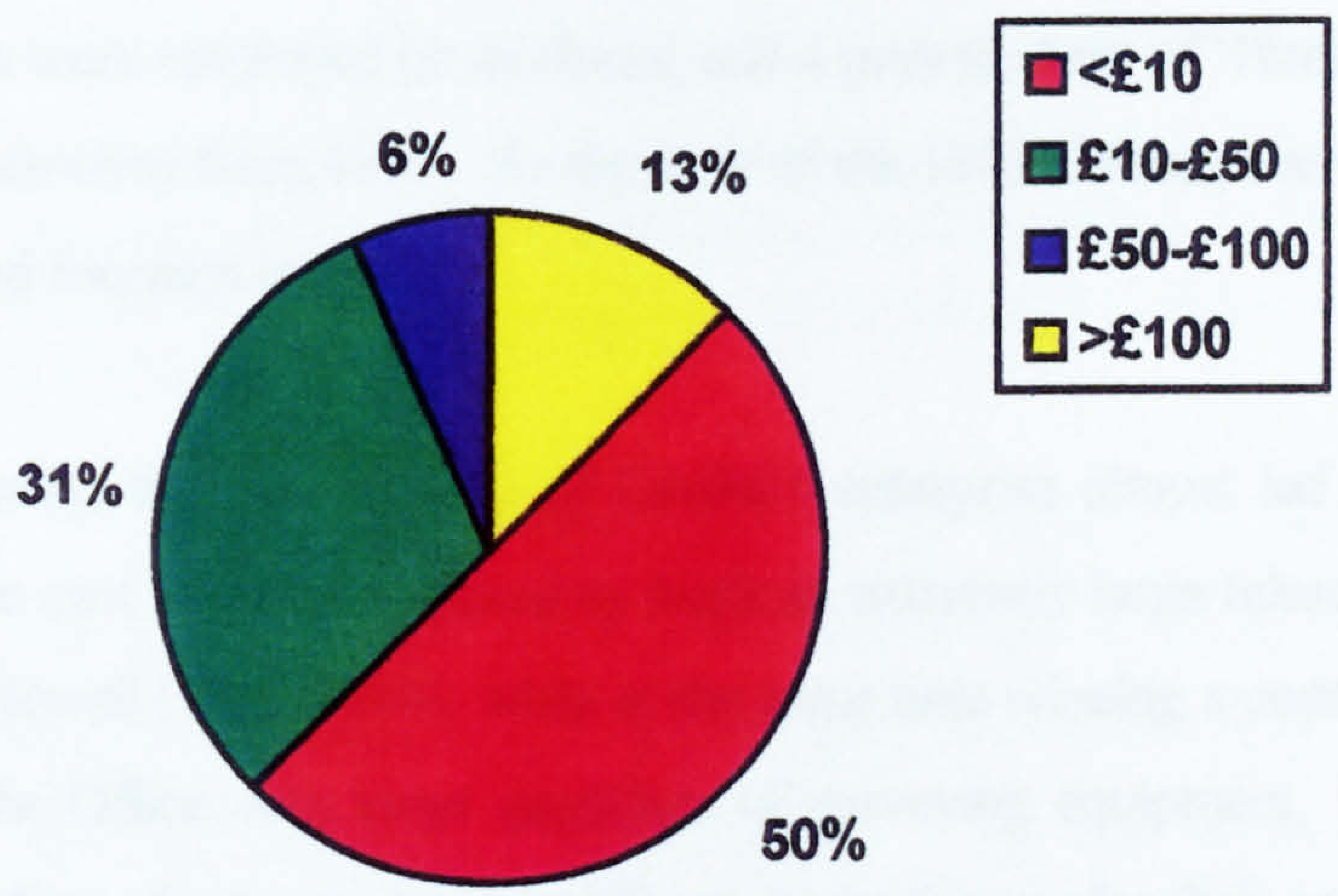

Fig. 2:10 Thomas Cooke's Orderbook 1856-68.
Vickers Archive, Borthwick Institute, York.
Much of the material is unpriced: orders estimated from Cooke [1863] and Cooke (1868). For a description of the orderbook and its problems and shortcomings, see McConnell (1993c).

purpose-built premises [Table 2:10]. Approximately half of the orders recorded from this period were for items under £10; yet a substantial fraction, mostly turret clocks, which would have to have been installed by skilled workmen, costing over £100 per order. As McConnell writes:

> This must have been one of the earliest scientific instrument manufactories; Cooke made most of his own machine tools and lens-grinding equipment, driven by steam power. There were workshops for brass, glass and wood, and a foundry where all but the largest castings were made.[77]

In fact, there had been an earlier factory at Sheffield, at the turn of the nineteenth century, but as we shall see, this was run along different lines. As noted earlier, David Landes defined a factory as having two critical criteria: 'concentration of production and maintenance of discipline'.[78] Clearly, Cooke's workmen were employed on this basis, and a printed sheet of 'Buckingham Works. Rules and Regulations' survives from 1865. At the time of the 1861 Census, the workforce consisted of twenty-six men and fourteen boys.

Unfortunately, the very success of Cooke's enterprise almost led to its destruction. He underestimated the cost and time required to work an extremely large telescope lens for a wealthy amateur, Robert Newall (1812-1889), while at the same time winning a contract for a new venture, supplying the India Office with large quantities of surveying equipment, which necessitated the designing and building of new precision machinery in the factory for their construction. Aged sixty-two, Cooke died in 1868: as McConnell recounts, Newall tried to force his heirs - his widow and two sons - into liquidation. Once again, wealthy family friends stepped in and rescued the firm.[79]

Sheffield

Contrast York's settled, regular existence with the explosion of activity, particularly of heavy industry, which occurred slightly further south at Sheffield. The reputation of Sheffield-made knives and edge tools goes back long before the Industrial Revolution. Hallamshire (an area including the parishes of Sheffield and Ecclesfield) was famous for the quality of its metalwares as long ago as the Middle Ages, but by the sixteenth century local iron was considered to be of inferior quality for the steel for tools requiring a sharp edge: iron was therefore imported for such

[77]. *Ibid.*
[78]. Landes (1969), 121.

steel manufactures, while local iron was used in nail making and goods without cutting edges, such as cooking pots.[80]

Sheffield had a great natural advantage over other provincial cutlery centres, namely, an abundance of local water power. At least ninety water mills were in operation in 1740, and two out of every three were used for the grinding of cutlery and edge tools. Another local fortunate geological feature was the coal-measure sandstones, which were ideal for the manufacture of grinding wheels - and these were of such quality that they were sold all over England from an early date.

When Daniel Defoe visited Sheffield in 1726 he wrote that:

> The town of Sheffield is very populous and large, the streets narrow, and the houses dark and black, occasioned by the continued smoke of the forges, which are always at work... The manufacture of hard ware, which has been so antient in this town is not only continued but much increased.[81]

Some time after 1750, the cutlers diversified into a huge range of products: those in the town centre made the high quality goods, while specific geographical areas were devoted to sickle makers, or nailmakers or scythemakers. In rural districts, metalwares were a part-time occupation, often combined with the farming of small-holdings. By the seventeenth century, further specialisations had developed - filemaking, buttonmaking and metal box construction. Despite Sheffield's landlocked position, there was no difficulty getting its sought-after goods to market: there was a weekly carrier service to London from at least 1637, but most manufactures went by inland waterways, which were being constantly improved. Although bespoke precision instruments required extra-careful package for transport - which added to their expense - the items being produced in Sheffield were not in this category.[82] The small workshops or forges were run by the

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[79]. McConnell (1992), 53-57.

[80]. Pollard (1959), 54-59 and David Hey, 'Introduction' to Barnes (1992), pp.9-12.

[81]. Defoe (1971), 482.

[82]. An instance of items being sent from London on long sea voyages is provided by the lading bill for new demonstration apparatus ordered from W. & S. Jones by Harvard University in 1797: 16 items costing £53.5s.6d, packing cases an extra 10s 6d: Harvard University College Papers IV HUA I.5.100* vol 4. Also an acrimonious exchange between the Colonial Office, the Transport Board and the instrument makers Watkins & Hill, where despite the 'strong packing case' costing £1.3s, an item was damaged in transit: PRO CO

so-called 'little mesters' (or masters), and well into the nineteenth century hand technology and craft skills dominated the Sheffield metal trades with its small units of construction, marked by the division of labour.

The first optical business in Sheffield, according to an apparently reliable local historian, was founded by

> Mr Samuel Froggatt ... although the exact year is uncertain. He was the inventor of the process of grinding the perspective glasses, concave or convex, though of course many improvements have been made since his day. He had his grinding wheel near the Twelve o'Clock public house, and there he carried on business many years. His trade was chiefly in common acromatic [sic] telescopes, microscopes, spectacles, reading glasses, &c. Mr Froggatt died in the year 1797.[83]

The first local directory was published in 1774, and it records two other names of instrument makers: John Handcock, a ring sun-dial and buckle-maker; and Joseph Wilson, an optician, mathematical instrument maker and spectacle maker. Proctor & Beilby, the largest of the late eighteenth-century Sheffield instrument manufacturers, appeared first in the directory of 1781: according to a contemporary account they ran a 'Little Mesters' system in their purpose-built premises in Market Street, in the centre of town.[84] This system, borrowed from the cutlery trades, allowed self-employed men to rent space within their factory under contract to carry out specific work. The 'little mester' would employ and pay his own workmen, providing them with both tools and equipment; materials were either bought from the factory proprietor, or elsewhere, and the finished items sold back to the factory proprietor: this allowed enormous flexibility in times of economic hardship, although few great fortunes were made.

The diversification of Sheffield-made goods can be seen in the advertisements of the Chadburn firm, whose close-knit family enterprise ensured that the business survived and expanded over a number of generations. The partnership of Chadburn & Wright was formed in 1818, and as an advertisement from 1825 shows, they manufactured optical goods as well as dealing in 'all kinds

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201/81/...3 April 1816.

[83]. Unsigned article [Robert Leader], 'A Chapter on Old Sheffield Trades', *Sheffield & Rotherham Independent*, 12 April 1873; and Leader (1875), pp94-7: much of this material was garnered through oral tradition from eye-witnesses and descendants.

[84]. [John Holland], 'Reminiscences of an Old Sheffield Workshop', *Sheffield Telegraph*, 23, 24, 26 and 27 December 1867; republished in Morrison-Low (1994b).

of hardware'.[85] William Chadburn, who had begun as an optician in 1816, was by 1828 advertising a greater versatility as an 'brass and iron founder, optician, cutler and general dealer';[86] and in turn the firm became Chadburn Brothers, who were Alfred and Francis Wright Chadburn from 1837, joined by Charles Henry in 1841.[87] Charles Henry Chadburn started up a branch in Liverpool in 1845, and by 1851 the firm was awarded an honourable mention for the items which they displayed in the Great Exhibition: '...everything exhibited by Messrs. Chadburn are remarkable for extreme cheapness, and in this respect they deserve Honourable Mention.'[88] They were granted Prince Albert's Royal Warrant, and continued well beyond 1851. The other Sheffield firm to exhibit at the Great Exhibition, was that of Samuel Sharp, who displayed a set of ten lenses for a simple microscope of differing powers, but the Jury did not comment on the quality of these.[89]

The numbers of such businesses in Sheffield appear to be initially few, two or so from 1775 until 1800; but as John Holland's account makes clear, Proctor & Beilby acted as a 'manufactory' in the sense that completed parts of instruments were brought into their premises for assembly and passing on to the point of sale by the firm: unlike Thomas Cooke's later Buckingham Works, the men were not 'employed' by Proctor & Beilby. They were contracted to do piece work, although there was considerable division of labour. That this was indeed a large factory can be corroborated by a surviving instrument trade catalogue or pattern book dating from 1815, which shows the printed wholesale prices against the manuscript piecework costs.[90] The manufacturing work, casting the brass or glass components, which was skilled work, appears to have been done exclusively by men. Various parts of the work - the boring of wooden telescope tubes, and the grinding of optical glass components - were done in water-powered mills on the Rivers Don and Rivelin: Proctors was also the first Sheffield firm to acquire a steam engine, used in the grinding of

85. *A new general and commercial Directory of Sheffield and its vicinity ... Compiled by R Gell.* (Manchester, 1825).
86. *Sheffield Directory and Guide* ... (Sheffield, 1828).
87. Chesworth (1994), 14-15.
88. *Catalogue*... (1852), 436; *Reports*... (1852), 273.
89. *Catalogue*... (1852), 442; *Reports*... (1852), 267.
90. Sheffield City Libraries, Special Collections no. 33237: Bradbury Record 293.

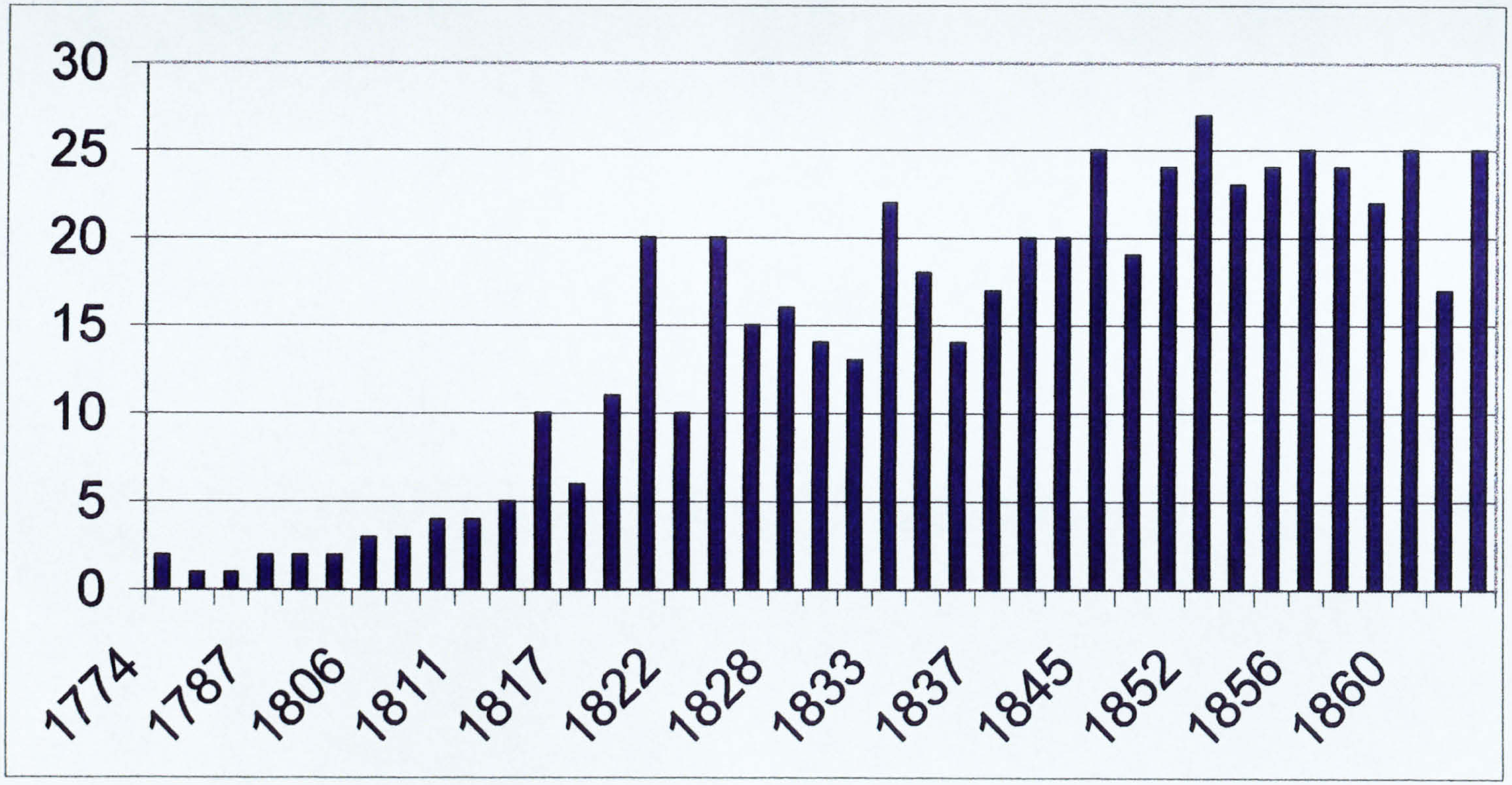

Table 2:11 Sheffield 1774-1860 : Numbers of instrument making firms from local directories

optical glass.[91] Holland's account also describes the methods used by the firm to tie the workforce to their particular business through what Holland describes as 'stuffing', elsewhere called 'trucking'. He deplores the drunkenness, the lack of godliness and education. He also stresses the rural aspects of life, keeping employees aware of the seasons, in a way similar to the rural metal-workers or hand-loom weavers, whose work on their small-holdings appears to have been a seasonal, but vital part of their earning capacity.

Family enterprise was clearly behind what Holland characterised elsewhere as the 'largest optical manufactory in the world',[92] the Sheffield venture of Proctor & Beilby, begun by the brothers Charles and Luke Proctor, who initially made 'lancets' or fleams, devices used as surgical or veterinary blades, subsequently moving into items of brass.[93] Luke left the business, but Charles, a widower when John Holland knew him, was committed to the business:

> His family, consisting of himself, his three sons - Luke, George, and William, - his daughter Deborah, and last, but not least in those days, his sister, "Miss Nancy," a sharp, little, consequential woman, who did a great part of the familiar book keeping of the concern, including especially the entering of the men's work and wages. Of the children, Luke died young; George went to Birmingham, where he married and died; William, of whom more hereafter...; Deborah married Thomas, a son of the original Beilby...[94]

Unfortunately, in the second generation, the spirit of entrepreneurship failed, and William Proctor first went bankrupt, and subsequently out of business.

By 1815 there were about eight instrument businesses in Sheffield, rising to eighteen in

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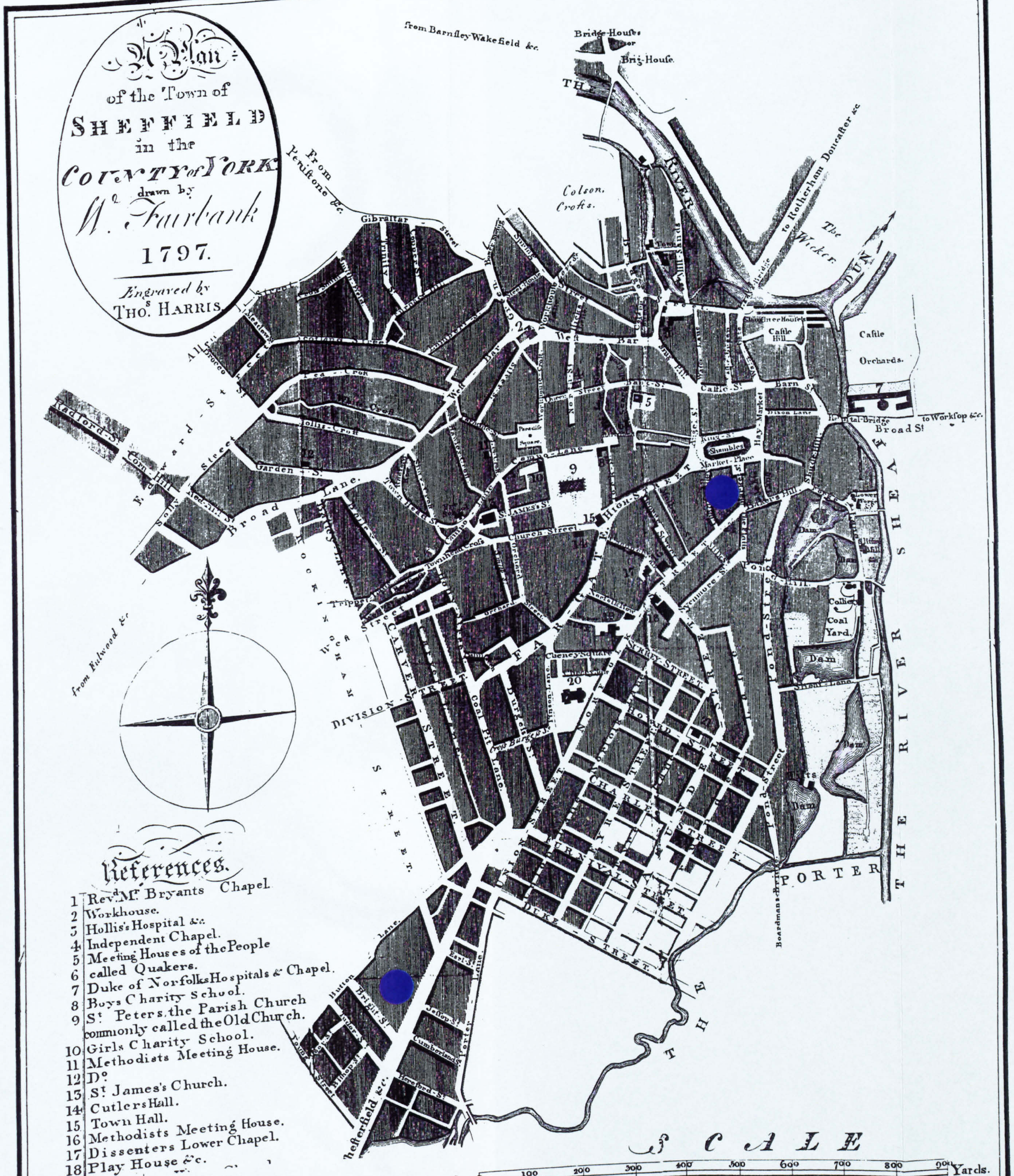
[91]. The involvement of Proctor & Beilby in two watermills is noted in Crossley et al. (1989), 40 and 65. One, on the Loxley at Wisewood, was leased by G. Proctor from 1813 to 1816; the other, on the Rivelin at Rivelin Bridge Wheel, was leased to Charles Proctor and Thomas Beilby for 63 years. By 1814, glass-grinding troughs there were let to a lens-maker by the name of Chadburn. Proctor & Beilby erected the first steam-engine in Sheffield, in 1786: see Leader (1875), 97. This is confirmed by a letter from Proctor & Beilby enquiring about application of the steam engine to rotary motion, dated 22 November 1776 in Birmingham Reference Library, Archives Department: Letter to Boulton & Fothergill, steam engine manufacturers, B&W: Box 26/1/2.

[92]. Holland (1834), 261.

[93]. Examples noted are in the Wellcome Museum, Science Museum, London, inventory number A626565; and a four-bladed fleam offered for sale by Tesseract, Catalogue 21, item 57, Summer 1988.

[94]. Quoted in Morrison-Low (1994b).



A Plan of the Town of SHEFFIELD in the COUNTY of YORK drawn by Wm. Fairbank 1797.
Engraved by Thos. HARRIS.
from Barnsley Wakefield &c.
Bridge-Houses
Brig-House
THE RIVER
Colson Crofts.
From Peniftone &c.
to Rotherham Doncaster &c.
The Wicker
DUN
Castle Hill
Castle Orchards.
to Worksop &c.
Broad St.
Gibraltar Street
Castle St.
Barn St.
Hay-Market
Market-Place
Shambles
King St.
Dixon Lane
Garden St.
Broad Lane
Radford St.
Church Street
St. James's St.
Paradise Square
Coal Yard
Dam
Pond Street
Surrey Street
Norfolk Street
Charles Street
Union Street
Duke Street
Division Street
Carver Street
Coal Pit Lane
Rockingham Street
Tripper St.
Burgess St.
Cheney Square
Brigit St.
Jessop St.
Cumberland St.
Hereford St.
Chesterfield &c.
Button Lane
Porter Lane
East St.
Boardmans Bridge
THE RIVER SHEAF
THE PORTER
from Ecclesall &c.
SCALE
100 200 300 400 500 600 700 800 900 Yards.
References.
1 Revd. Mr. Bryants Chapel
2 Workhouse.
3 Hollis's Hospital &c.
4 Independent Chapel.
5 Meeting Houses of the People called Quakers.
6 Duke of Norfolks Hospitals & Chapel.
7 Boys Charity School.
8 St. Peters, the Parish Church commonly called the Old Church.
9 Girls Charity School.
10 Methodists Meeting House.
11 Do.
12 St. James's Church.
13 Cutlers Hall.
14 Town Hall.
15 Methodists Meeting House.
16 Dissenters Lower Chapel.
17 Play House &c.

Fig. 2:13 Map of Sheffield for 1832, showing locations of firms for 1832.

1820, with a slight diminution in numbers over the next fifteen years or so, but rising to twenty in 1840 and twenty-six in 1850. It is clear from the descriptions at the end of this period that Chadburns ran a number of powered premises: for example, the 'Steam wheel, Johnson street'; and the 'Shilo Wheel, 44 Stanley street' of 1841, and their subsequent 'Nursery Wheel', named after the rural days when the land was a market garden, or 'nursery'.

Manchester

The third major pre-industrial English population centre after London was Norwich; but Norwich's instrument-making base was negligible. As a city in the centre of a large agricultural hinterland, the local demands for instrumentation were not large: surveying instruments would have been owned by the surveyors themselves, and only towards the mid to late-nineteenth century were retailers of barometers to be found there, usually combining this with selling jewellery or spectacles. Barometers, as Nicholas Goodison has shown, appealed to a largely domestic market, and perhaps should more properly be considered as furniture rather than as a professional mathematical tool; yet they appealed to the luxury end of the market and judging by the rate of survivals, were a popular purchase with the growing wealth of the consumer.[95] In particular, with the growth of amateur interest in meteorology, makers and retailers were able to sell barometers and thermometers in increasing numbers to farmers and horticulturalists: it is possible that their fashion-conscious wives influenced this.

On the opposite side of the country, where the unprecedented growth of Manchester into an industrial city produced entirely different circumstances, there was an unexpectedly high number of instrument makers offering barometers for sale: among the earliest instruments known to have been retailed there were barometers signed by the mid-eighteenth century clockmakers, John Berry

[95]. Goodison (1969); Goodison (1977); for Norwich firms, Clifton (1995) notes the following: Henry Banyon, optician, 1847; John Dixey, optician (previously worked with G. & C. Dixey of London), 1834-41; Thomas Hawkes, mathematical instrument maker, 1750-83; William Thomas Hunter, rule maker, 1830; James Jones, optician, 1847; Michael and Abraham Keyzor, opticians, 1847-54; Francis Molton, optician and barometer-maker, 1822-30; Myers & Wiseman, opticians, 1830; Thomas Page, barometer seller, 1750-84; Baptista Pedralio, barometer seller, 1790-1820; George Rossi, barometer seller, 1822-30; Samuel Sly, optician etc., 1830; ? Trombetta, barometer seller, c.1800-20.

and Peter Clare.[96] Two of the first three instrument makers recorded in the local 1784 directory, John Gally and Baptist Ronchetti, were 'weather-glass makers'. Jenny Wetton explains that many of these were Italians who had made similar instruments in the Lake Como and Lake Maggiore areas, but were forced by local taxation and population growth to emigrate. Even so, 'barometer makers' reached a maximum of thirteen in the directory for 1843, but this line 'may never have been very profitable and those who could do so supplemented their trade with other business.'[97]

Judging by their names, most of the instrument makers who started up in Manchester towards the end of the eighteenth century were foreigners, and much of Wetton's further research has verified this: many were indeed immigrant Italians, but there were also a number of Jewish opticians. This is not to say that Italian or Jewish instrument makers were not to be found in other provincial centres, but that there seemed to be a higher proportion in Manchester than elsewhere. Unlike many of the other centres discussed, it does not appear that many London-trained people came to Manchester, thinking it a likely new market for their skills: exceptions were Stephen Norris Cooper, a rule maker in Holborn between 1809 and 1811,[98] who appeared in the 1817 Manchester directory (after his final appearance in 1843, the business was continued beyond 1851 by Sarah Cooper, presumably his widow); and possibly the Thomas Gregory, optician, who appeared in the 1834 directory only, who may have been the same Thomas Gregory, optician, who was previously listed between 1824 and 1834 in London.[99]

More noticeable is the movement of businesses between Manchester and nearby Liverpool, perhaps the most famous example being that of J.B. Dancer (1812-1878), whose grandfather Michael was based in London between 1766 and his death in 1817. One of his apprentices had been Benjamin Jasper Wood, who appears to have moved to Liverpool and started an instrument business in 1810. Dancer's son, Josiah, upon inheriting his father's business in 1817, moved from London to Liverpool, with his son, John Benjamin. J.B. Dancer took over his father's business after his death in 1835, and in 1841 went into partnership with another long-established Liverpool optician, Abraham Abraham. Dancer moved to Manchester, and started a branch in Cross Street;

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96. Goodison (1977), 302 and 312.
97. Wetton (1990-91), 37-38.
98. Clifton (1995), 65.
99. *Ibid.*, 119.

after his partnership with Abraham ended after only four years, Dancer remained in Manchester, working there on his own account.[100] As did Thomas King of Bristol, Dancer numbered his microscopes, for which he was particularly noted; however, these are more difficult than King's to date convincingly, and thus a rate of production is unclear.[101] Dancer supplied customised apparatus to the Mancunian scientists J.P. Joule and John Dalton; he was a considerable experimenter himself, and developed a process for making microscopic photographs (the ancestor of the microfilm). He also patented a stereoscopic camera in 1856. 'By 1871, he was employing eight men and about four apprentices,' Wetton recounts. 'His workshop was powered by steam and was equipped with machinery for the manufacture of instruments.'[102]

Other businesses which made the move between Liverpool and Manchester include that of Thomas Underhill, recorded as a mathematical instrument maker and rule maker in the Liverpool directories between 1824 and 1827, reappearing in the Manchester directories as a 'mathematical rule maker' in 1828, and continuing in business there until 1881.[103] William Chadwick, an optician based in Liverpool between 1827 and 1830 may be the same person as William Henry Chadwick, a barometer maker who first made an appearance in the 1836 Manchester directory. The Casartellis of Liverpool, already related to the Ronchettis of Manchester, took over the latter business in 1852 when Joshua Ronchetti retired to Italy; the brothers Antonio and Gaspar Introvino ran a business in Manchester from 1816 to 1852, but Antonio also had a shop in Liverpool's Duke Street between 1821 and 1825.

No instrument making or retailing activity was recorded in the Manchester directories until 1794, and then the number of businesses remained at three or four until 1820, when there was a

100. *Ibid.*, 75-76; Wetton (1990-91), 59-63.

101. The lowest recorded example, numbered 26, passed through the antiques trade in about 1990; number 38, in a private collection is dated after 1855; number 317, has a date of 1861: Manchester Museum of Science and Industry, inv. no. 1970.12.4, with a design registered in 1861 marked on the binocular tube, which may be a later addition to the instrument; the uppermost number of 407 has no clear date (Christies South Kensington, 26 Sept 1991 and 2 April 1992); while that numbered 385 has been dated from a trade catalogue, itself dated at c.1855, and costing £18-0-0 new (now in the National Museums of Scotland, inv. no. NMS.T.1979.73: see Nuttall (1979), 49).

102. Wetton (1990-91), 63.

103. Clifton (1995), 284-5.

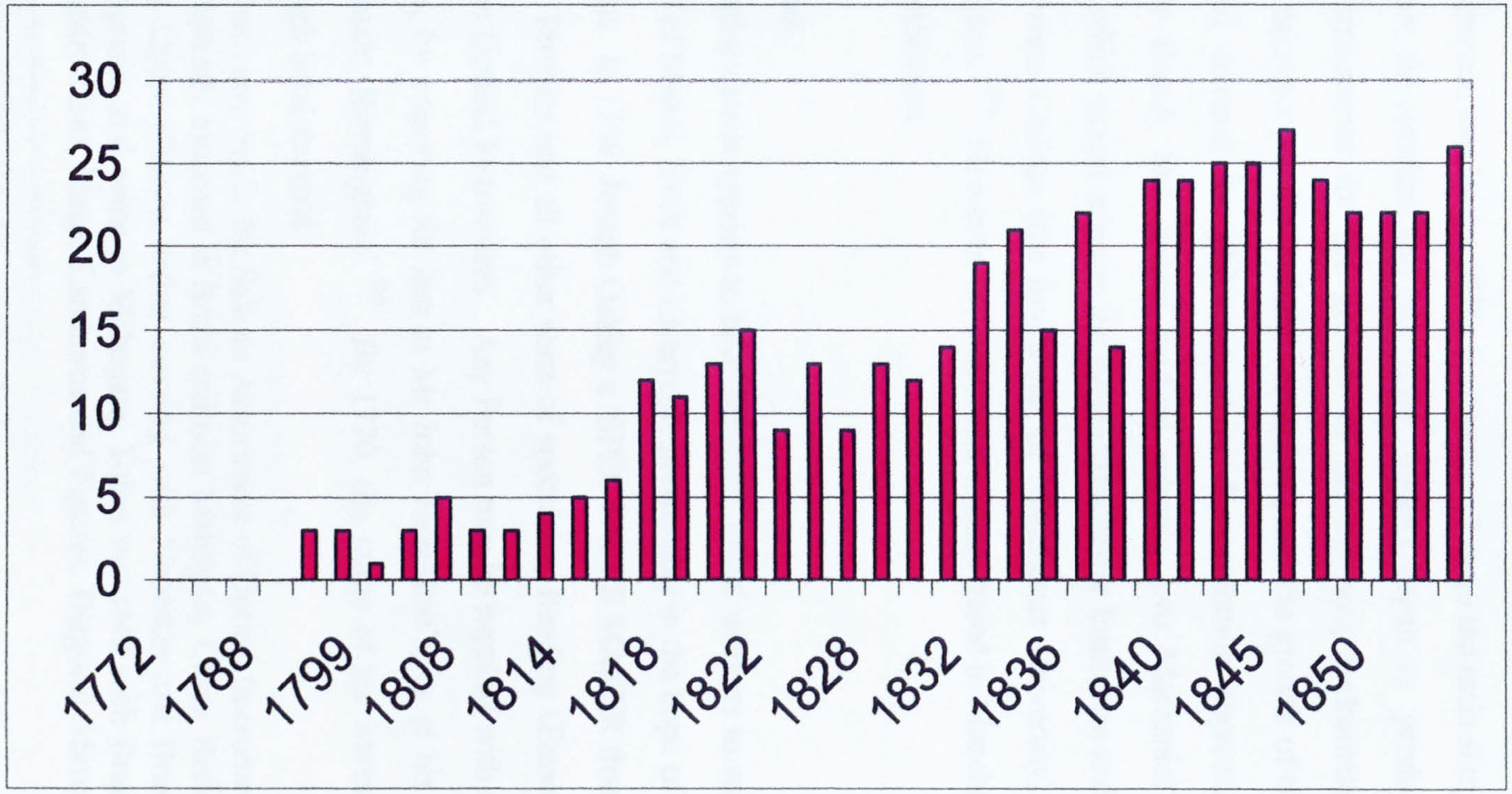

Table 2:14 Manchester 1772-1852 : Numbers of instrument making firms from local directories

sudden rise to fourteen [see Table 2:14]; by 1835 there were twenty firms and the numbers continued to rise until 1845, dropping slightly to twenty two in 1850. Jenny Wetton characterises these as initially 'barometer makers', who had to include other lines of business (such as the traditional 'carving and gilding' - that is, providing picture frames and looking-glasses - or venturing into the fine art and print trade, the most successful example being that of Thomas Agnew, one-time apprentice to the firm of Vittore Zanetti of Manchester); and 'opticians', who were first itinerant, and by the 1820s in premises close to the main shopping areas. Subsequently, as demand grew, the opticians and barometer makers began to produce 'scientific instruments': surveying instruments for the growth of the railways; hydrometers for brewers, dyers and excisemen; microscopes for 'rational recreation', and the growth of the educational market meant an increased demand for philosophical or demonstration apparatus. As Wetton points out, 'Manchester already had several medical schools, two Mechanics' Institutes, and two other institutions which taught science: the Royal Manchester Institution and the Royal Victoria Gallery. In 1851, Owens College (the forerunner of Manchester University) opened offering courses in science subjects.'[104] However, no instrument makers based in Manchester exhibited their wares at the Great Exhibition.

Birmingham

The Birmingham trade appears to have attracted optical workers to migrate there from London, as in the cases of Bristol, York and Liverpool, presumably in the hope of finding and opening up new local markets. In 1758, Joseph Oakley a 'SPECTACLE MAKER from LONDON' advertised that he 'Makes Temples and all other sorts of spectacles, Reading Glasses, Telescopes, Microscopes, and all other Optical Instruments... Any Person may be supplied with any Apparatus for the above Instruments, by enquiring for him at Mr John Hazeldine's, or at his Workshop near the Dog in Mount-Pleasant, Birmingham'.[105] By 1770, the range of his wares had expanded, presumably partly through local demand:

> he hath now ready for Sale an Assortment of Optical Instruments ... Reflecting Telescopes, compleatly mounted in Brass and neat Mahogany Cases, Reflecting Telescopes, Prospects and Opera Glasses, either covered with Nourskin and Brass, or Black in imitation of Shagreen, and some in Mahogany Tubes mounted with Brass, Microscopes of Different Constructions, Magic Lanthorns and Figures, Diagonal Mirrours [sic], Concaves, Glasses

104. Wetton (1990-91), 43.
105. *Aris's Gazette*, 3 July 1758.

for Short Sight, Convex Glasses of every different Size and Focus &c.[106]

However, it is apparent from the remainder of the advertisement, that Oakley's bread-and- butter business came from producing spectacles for Birmingham's ageing population:

> He will do his utmost Endeavours to suit those who please to favour him with their Custom for Spectacles &c. not only with the best of their Kind, but such as see peculiarly adapted to their particular Sight, and may depend on having such as will give the Necessary help, and not in the least prejudicial, which is the sure Consequence of an injudicious Choice.[107]

He cannot have been alone in having to find another aspect of work to make a living wage. In fact, this appears to have been the characteristic of the Birmingham trade during the period under discussion: those engaged in instrument production - or possibly parts of instruments - also produced other metal goods to which they could switch [Table 2:15]. For instance, one of the longest-surviving businesses, that of Richard Bakewell and his successor Isaac Trow, which continued for over sixty-one years, was described in the 1791 street directory as a 'mathematical instrument, dog-collar and watch key maker';[108] the advertisement which announced this demonstrated this versatility:

> RICHARD BAKEWELL, late Partner with Messrs Inshaw and Hinksman, respectfully informs Merchants, Factors and the Public in general, that he carries on the Mathematical Instruments, Brass Compasses, and Brass Dog-collar Businesses, on his own Account, at his Manufactory in Loveday-street, at the bottom of St. Mary's-Row, Birmingham; where all Orders will be executed with the greatest Punctuality upon the lowest Terms, and every Favour gratefully acknowledged by
>
> Their humble Servant
>
> R. BAKEWELL.[109]

His trade successor, Isaac Trow, was as versatile forty and more years later, being described as 'manufacturer of mathematical instruments, surveyors' measuring tapes, dog collars, mariners' and miners' compasses' in 1831.[110] In a city renowned for its brass metal manufactures, it is not surprising to find descriptions such as 'manufacturer of plated and brass telescopes, fancy hearth brushes, toasting forks, plated and brass tubes for umbrellas &c. plated and brass tubes of every description, umbrella and parasol frames complete &c.' or 'compass and pincer maker', or 'military

106. *Ibid.*, 28 May 1770.
107. *Ibid.*
108. Charles Pye, *The Birmingham Directory for the Year 1791* (Birmingham, n.d.[1791]).
109. *Aris's Gazette*, 19 April 1790.
110. [Wrightson's], *The Directory of Birmingham*... (Birmingham, 1833).

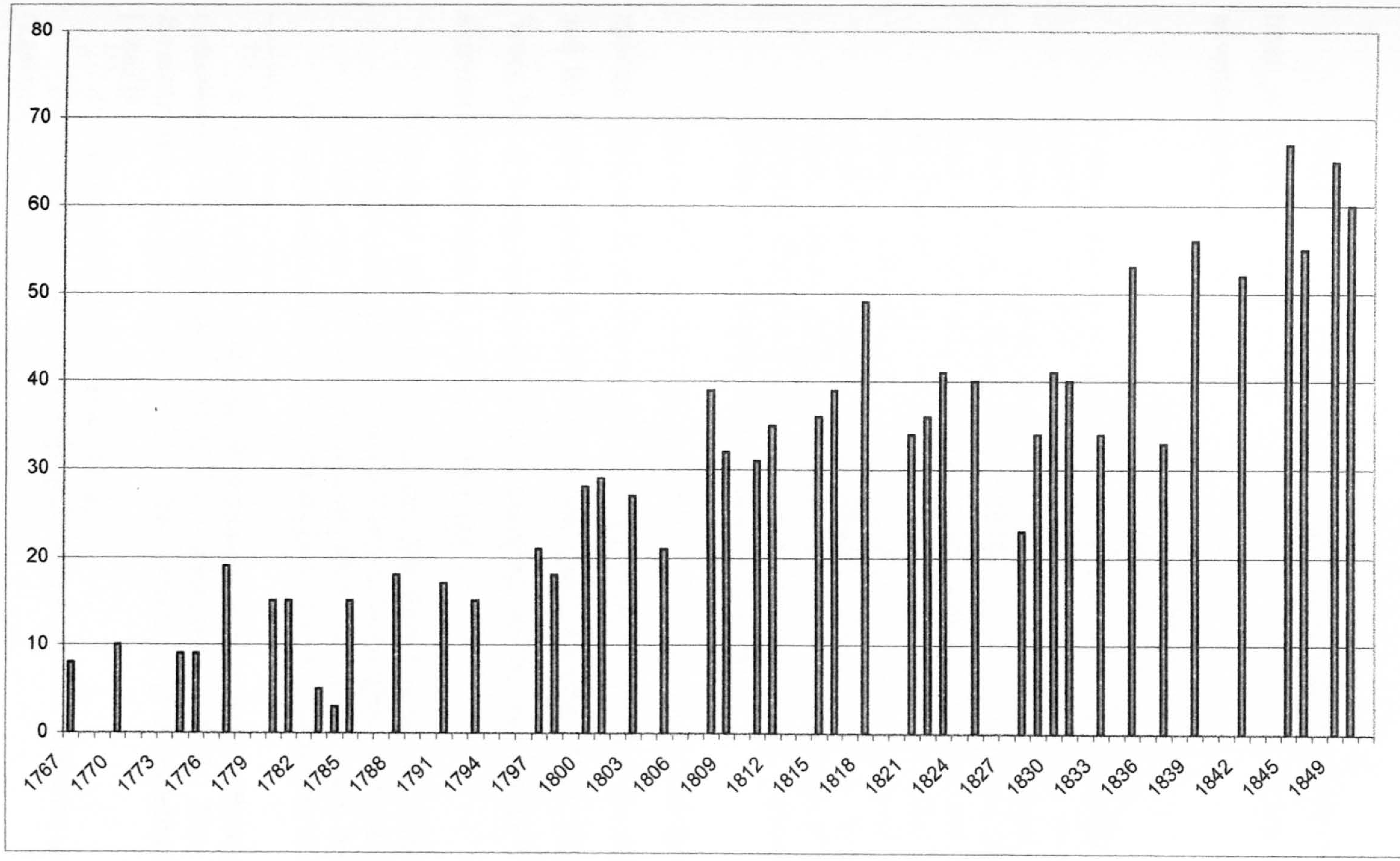

Table 2:15 Birmingham 1767-1850 : Numbers of instrument making firms from local directories.

feather and barometer maker', or 'gilt toy, mathematical instrument maker and bell founder', and the more macabre 'coffin furniture and measuring tape manufacturers'.[111] It is apparent, that over time, various manufacturers would slip in and out of instrument making as the markets increased or dwindled. Individual businesses (if they survived) could switch their goods to suit the economic climate.

A large proportion of businesses were devoted to producing box and ivory rules. This trade was initially based in and around Wolverhampton, as can be seen from the following advertisement from 1761:

> New Improved SLIDING RULES
> WHICH, for their Utility and Accuracy,
> are much superior to any other Joint Rule whatever; by which may easily be measured Superficies or Solids of all Denominations, by an entire new Method; made by the Improver, Christopher Jacob, in Bilstone-street, Wolverhampton, Staffordshire, or may be had at his Shop on Snow Hill, Birmingham; likewise makes all other Sorts of Sliding Rules, and all sorts of Rules for Gauging, with Rules of all Sorts, and for the Use of all Trades; Also Parallel Rules, T. Squares and Bevels, with Drawing Boards for Architecture, Bricklayer's Bevels and Squares, Shipwright's Drawing Bows, Sectors, with or without French Joints; either in Brass, Wood, or Ivory, or Silver; Scales of all Sorts, such as Gunter's Scales, Navigation Scales, Plotting Scales, Setting-off Scales, Feather-Edg'd for Surveying, Stationer's Lined Rulers, Station Staves, and Protractors of all sorts; all made after the newest Improvements, and neatest Manner.[112]

Even as early as 1761, this specialised trade was moving into Birmingham. From there, it appears that rules of all sorts went to London, some for finishing, for retail to the London market and for export; indeed, by 1845 one of the longer-surviving firms, F.B. Cox, was described as 'ivory, box & foreign rule manufacturer, wholesale and for exportation'.[113] An account written by a rulemaker, John Rabone, in 1865, stated that:

> At the latter part of the past century only three or four rule masters, each employing a few apprentices and men, were to be found in Birmingham, and one at Harborne adjacent; but now the trade has almost deserted Wolverhampton, which numbers only four or five persons employed in it, while Birmingham affords employment to as many hundreds.

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111. *Wrightson's New Triennial Directory of Birmingham...* (Birmingham, 1818); [Pigot's] *Commercial Directory for 1818-19-20...* (Manchester, 1818); *New Triennial Directory of Birmingham...* (Birmingham, 1812); *The Directory of Birmingham;...* (Birmingham, n.d. [1847]).

112. *Aris's Gazette*, 23 November 1761.

113. [Kelly's] *Post Office Directory of Birmingham, Warwickshire and part of Staffordshire* (London, n.d., [1845]).

> With the exception of three or four makers scattered throughout the country the trade is now entirely confined to Birmingham and London. Many of the rules sold as London-made are produced in Birmingham, and many are framed in Birmingham and sold to the London makers, who mark or finish them themselves.[114]

As in Sheffield, a number of instrument makers were connected with pubs or with food supply as a secondary part to their business: for example, Samuel Ault, 'victualler and compass maker', who by 1788 had become solely a 'victualler'; William Hodges, whose business in 1801 as a 'victualler, compass and pincher maker' by 1805 had moved into the metalware end of the business; and Joseph Lunt both ran 'The Golden Cup' inn and was a 'box [wood] and ivory rule maker' between 1842 and 1852.[115] Another characteristic which was similar to the Sheffield trade was that the workshops were small, with considerable division of labour even by 1760, so that output was relatively high in terms of labour productivity. As Eric Hopkins has written:

> The essential point is that the great economic achievements of the successive decades were based not on massive technological breakthroughs, as in the cotton industry, but on existing modes of production, and principally on the small workshop with its hand machinery. Only in the 1830s did steam power begin to be used on any significant scale, and only then were larger work units becoming more common and more prominent. There was thus a gradual and undramatic change to more modern means of production, in a town which was already industrialized by 1760. By 1840 the larger workplace and the traditional small workshop existed side by side, but with the latter predominating numerically.[116]

At the Great Exhibition, the firms of Robert Field & Son and J. Parkes & Son both exhibited instruments; in the case of Field, this was microscopes and photographic lenses, whereas Parkes displayed mathematical drawing instruments, compasses, and slide rules. The Jury thought Field's microscopes 'not as such as demand especial notice', and merely noted Parkes' compasses.[117] More will be said about their wares in chapter 5. The other major Birmingham exhibit in this Class came from Chance Brothers & Co., manufacturers of glass, who displayed a dioptric apparatus for lighthouse illumination, but won in Class XXIV, 'Glass', a Council Medal for

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114. J. Rabone, jun., 'Measuring Rules' in Timmins (1866), 629.

115. Charles Pye, *The Birmingham Directory for the Year 1788* (Birmingham, [1788]); Chapman's *Birmingham Directory* ... (Birmingham, 1801); *Pigot and Co.'s ... Directory of Birmingham and its Environs* ... (Birmingham and London, n.d. [1842]); *Slater's...Royal National Commercial Directory* ... (Manchester and London, 1852).

116. Hopkins (1989), xii.

117. *Catalogue...* (1852), 435, 467*; *Reports...* (1852), 267, 281.

Fig. 2:16 Map of Birmingham for 1750, showing locations of firms for 1767.

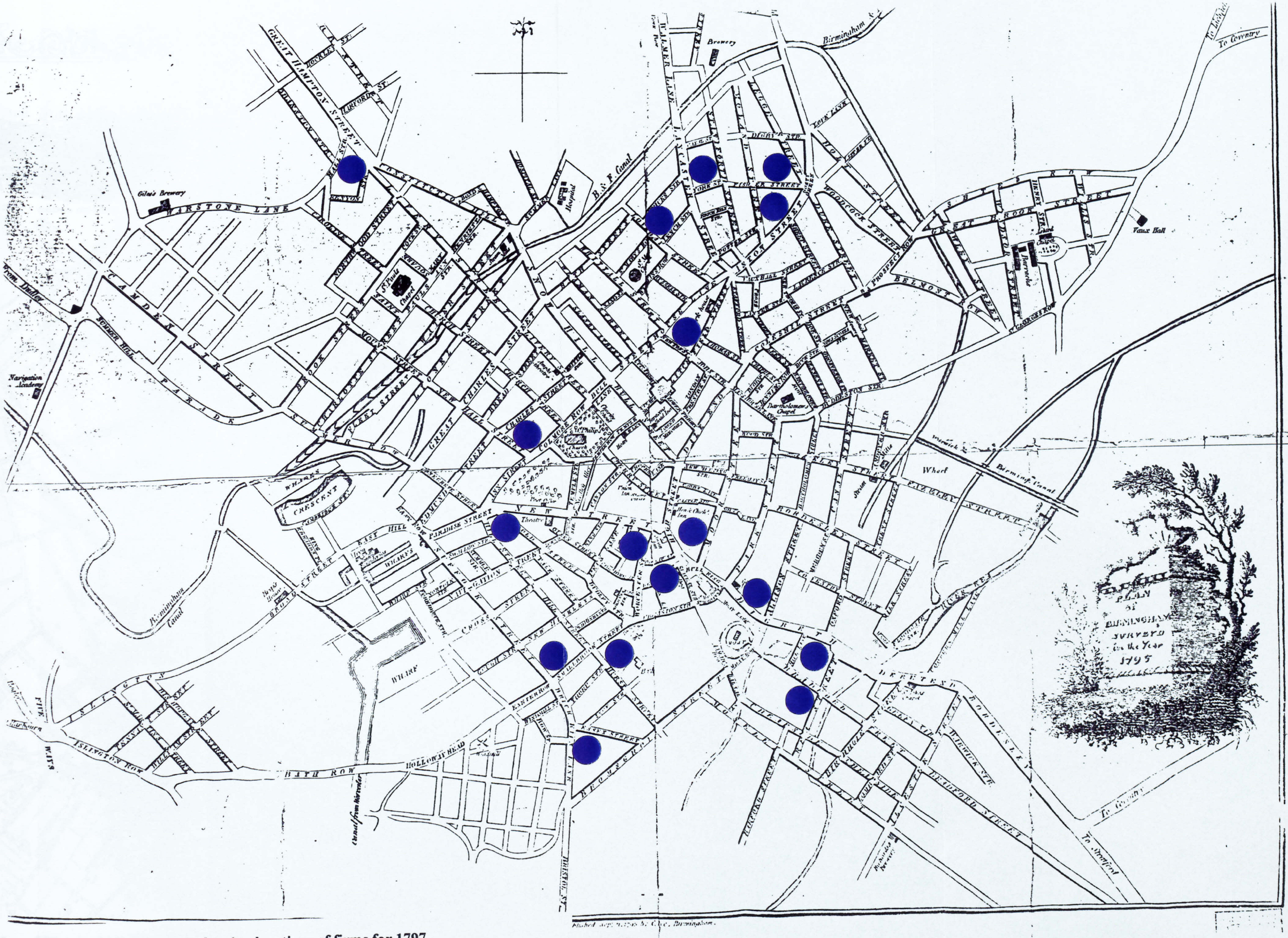
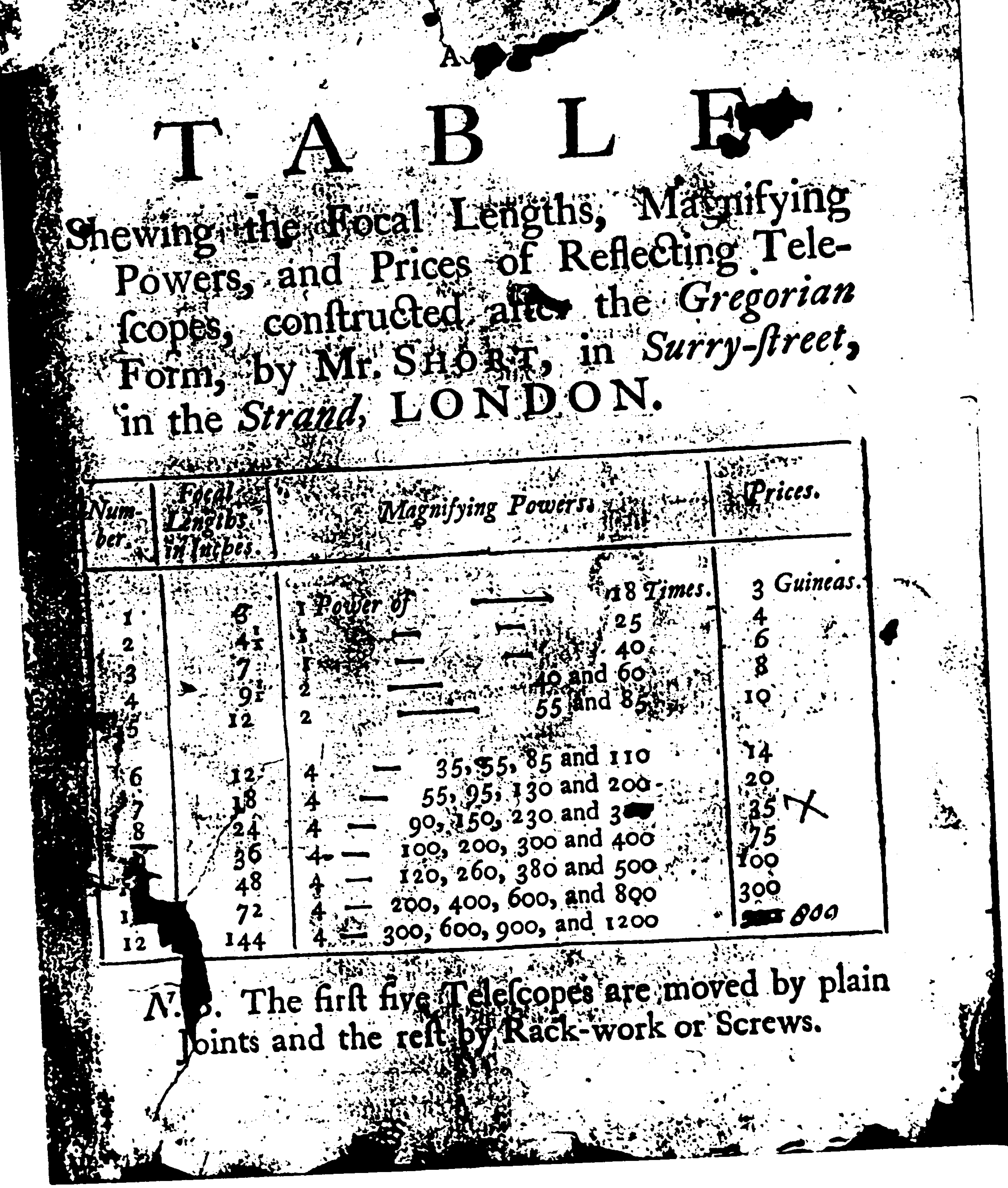


Fig. 2:17 Map of Birmingham for 1795, showing locations of firms for 1797.



A

TABLE

Shewing the Focal Lengths, Magnifying Powers, and Prices of Reflecting Telescopes, constructed after the *Gregorian* Form, by Mr. SHORT, in *Surry-street*, in the *Strand*, LONDON.

Number.	*Focal Lengths in Inches.*	*Magnifying Powers.*	*Prices.*
1	6	1 Power of —— 18 *Times.*	3 *Guineas.*
2	4½	1 — — 25	4
3	7	1 — — 40	6
4	9½	2 —— 40 and 60	8
5	12	2 —— 55 and 85	10
6	12	4 — 35, 55, 85 and 110	14
7	18	4 — 55, 95, 130 and 200	20
8	24	4 — 90, 150, 230 and 3[illegible]	35
[illegible]	36	4 — 100, 200, 300 and 400	75
[illegible]	48	4 — 120, 260, 380 and 500	100
1[illegible]	72	4 — 200, 400, 600, and 800	300
12	144	4 — 300, 600, 900, and 1200	800

N. B. The first five Telescopes are moved by plain Joints and the rest by Rack-work or Screws.

Fig. 3:2 Undated price list for James Short's telescopes. Private collection.

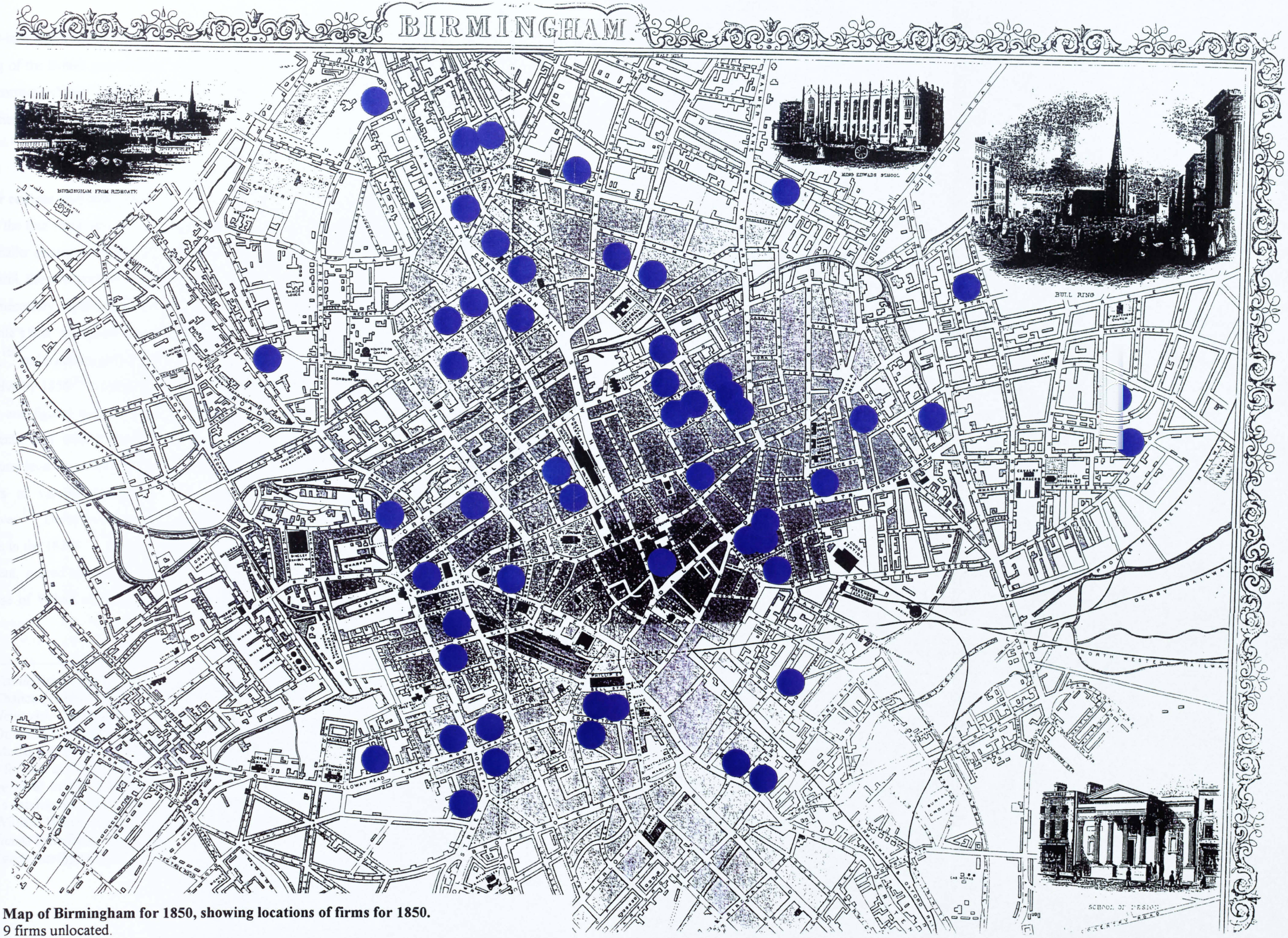


Fig. 2:18 Map of Birmingham for 1850, showing locations of firms for 1850.
9 firms unlocated.

their 29-inch diameter disc of flint glass.[118] This however, failed to find a buyer, despite some lobbying of the British government. It was again displayed at the Paris Exhibition in 1855, along with a correspondingly large disc of crown glass. Mortifyingly, both were acquired by the French government.[119]

Smaller centres and individuals

Besides the four main new centres of provincial instrument production outlined above, there were other smaller clusters of instrument production, which developed during this period. As with York and Bristol, the new ports of Newcastle-upon-Tyne and Hull attracted ships' chandlers who could supply necessary equipment and repair navigation instruments in response to a local market. Newcastle's first 'mathematical instrument maker', William Bowie, advertised in a local newspaper in 1795,[120] and numbers grew to six or so by the mid-1830s. These had increased to eight by 1840, and twelve by 1850:[121] as with Manchester, there was a mixture of 'opticians', Italian barometer-makers, and figures such as John Cail, who supplied a whole range of nautical and surveying instruments, and who is known to have bought in examples of Thomas Cooke of York's agricultural level for resale, engraved with his own name.[122] By 1837 Hull had eight instrument suppliers of varying descriptions, but most of these had other occupations to describe themselves.[123] Derby became the eventual home of the peripatetic firm of Davis, which had begun in Leeds in the 1820s.[124] Once settled, its wares moved from the general to specialising in mining equipment, geared towards a local market: more will be said about this firm and the similar enterprise of Wilton of St. Day, Cornwall, in chapter 6, although it is worth mentioning that

118. *Catalogue...* (1852), 477*; *Reports...* (1852), 529-530.
119. Chance (1919), 176-7.
120. *Newcastle Chronicle*, 31 January 1795: Clifton (1995), 16.
121. Directories for Newcastle-upon-Tyne, passim.
122. McConnell (1993c), 440; an example made by Cooke but with a trade card for Cail was offered for sale at Christie's South Kensington 4 June 1987, lot 256: Cooke first advertised his drainage level in the *Yorkshire Gazette*, 27 January 1849, and it appeared unchanged in Cooke's catalogues between 1862-91.
123. William White, *History, Gazetteer and Directory of the West-Riding of Yorkshire ... in two volumes* (Sheffield, 1837 and 1838).
124. *Leeds Intelligencer*, 1 January, 7 May, 21 May, 10 December 1821; 29 July 1822.

William Wilton exhibited magnetic dip and intensity instruments at the Great Exhibition.[125]

In the fashionable spa town of Bath, Ribright & Smith set up a shop which appears to have lasted only a year: Thomas Ribright, a London retailer, was obliged by his father's death in 1783 to return to London and run the business there.[126] Benjamin Smith continued in business on his own account until 1809, and there were a handful of retailers over the years who catered for the seasonal visitors and their expensive whims. Perhaps the most notable individual provincial firms of the entire period were the telescope-producing businesses - which reached international markets - of Thomas Cooke of York, and the earlier example of William Herschel, based first in Bath and subsequently in Slough (a third would be Thomas Grubb of Dublin, but that business was located firmly outside 'provincial England').[127] Anthony Turner has made the point that

> Herschel owed much to Bath. Outside London, the facilities for intellectual exchange were limited, though not completely lacking. The cultural life of the English provinces was buoyant and interesting; but for Herschel, a German outsider, the opportunities were fewer and the isolation from which he suffered in his years in the North was very real. Only in a large town or city could he hope to find men interested in a similar width of philosophical or practical problems as he was himself, and perhaps only in Bath did the conditions exist in which he could amass sufficient wealth as a musician to support a long and expensive series of practical investigations.[128]

William Herschel did most of his work on metal telescope speculae in isolation, and spent his time in endless experiments. In 1795, he wrote 'I made not less than 200, 7-feet; 150, 10-feet; and about 80, 20-feet mirrors'[129]: in all, Turner estimates that Herschel sold about one hundred of the 7-feet telescopes which he made: 'although of exceptional quality and widely spread throughout

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125. *Catalogue...* (1852), 452-3; *Reports...* (1852), 254, 281.

126. Clifton (1995), 231. The Will of George Ribright, who died March/July 1783, of the parish of St. Mary Cole, Poultry, London, stated that all stock in trade, shop fittings, counters, glass cases and the like, both in London and Bath, except working tools, was to be sold. No partnership ever existed between George and his son Thomas, although they traded as George Ribright & Son: if the son wished to set up for himself, he should have first refusal of the shop fittings and stock, but must pay for them or give security. Part of the estate was to be invested in an annuity for George's widow, the remainder to be shared between Thomas and other children. The working tools were bequeathed to Thomas. Public Record Office, PROB 11/1106 f.232r.

127. Burnett and Morrison-Low (1989), 89-117; Glass (1997).

128. Turner (1977), 115-6.

129. Quoted in *ibid.*, 76.

Europe, few of his telescopes seem to have been regularly used by practising astronomers.'[130] His reception by the King, George III, in 1782, and the successful comparison of his telescope with others, together with his international reputation as a practising astronomer - most famous, perhaps, for his discovery of the planet Uranus in March 1781 - eventually led to the award of an annual salary of £200, enabling Herschel to give up music, but obliging him to move close to the court to fulfil his obligation of giving the royal family astronomical entertainment as and when they requested.[131]

Conclusions

The characterisation of each major centre of instrument production during the Industrial Revolution outside London has been outlined above, as it appeared from the fieldwork. Some general findings agree with those uncovered in regional studies made by economic historians, helping to support this overall framework.[132] Although there seems to have been little in the form of direct royal, State or aristocratic patronage in promoting the industry to move into provincial centres, other preconditions for setting up in business as an instrument maker outside London may well have some validity. From the mid-eighteenth century, London provided a pool of skilled workers from which enterprising individuals could make their way to a number of growing and prosperous provincial centres of population, closer to sources of raw materials in the reasonable hope of setting up a successful business, initially with small local markets and tapping into pre-existing labour pools. A supporting infrastructure of transport, marketing and banking allowed them to reach beyond the region to customers further afield, and even back into the main London market. However, there was change over time, with some of the location factors relevant in 1760 no longer important by 1851. The evidence from local newspaper advertisements shows that in a number of instances the pattern followed was that a London-trained instrument maker would set up in business, and if successful, could maintain a trade succession for several generations, either through family connections - often the link was through women: either by marriage or a widow running the business while a son grew to maturity - or through a trade link through a foreman or former apprentice, when there were no male heirs to inherit a going concern. As Daunton has written, 'most industrial concerns were still family businesses which raised their capital from ploughed-back

130. *Ibid.*, 77.
131. *Ibid.*, 106.

profits or local contracts through a network of kin and co-religionists', and although there has so far been little direct evidence of this in this trade, presumably this is how the mechanism worked.[133] Immigrants with various skills in metalwork, woodwork and glass manipulation, appear to have been attracted to the anonymity of the new industrial centres, matched with growing opportunities for expanding markets and prosperity, once the conditions in their place of origin had prompted them to leave behind their native land.

Between 1760 and 1850, there were several locations outside London which did start to produce instruments in significant numbers: in England, the main centres were Birmingham, Bristol, Liverpool, Manchester and Sheffield. Although the production figures are unknown, they were large enough for the manufacturers to label themselves as 'mathematical instrument maker' or some such permutation, in the local street directories; and many of them remained in business for longer than a year or two. This is not because there were substantial local markets for instruments in the English provinces, although in the cases of the ports of Bristol and Liverpool, this may well have been a contributory factor. This period saw the growth of a number of ports which acted as gateways for their own industrial hinterlands, among them, Hull, Newcastle and Liverpool.[134] Sheffield, home for centuries to the cutlery trade, already had an infrastructure of independent metal workshops, where skills closely allied to those necessary to the manufacture of instruments could be found. It also had regular methods to transport the items to the London market - carriers, canals, subsequently the railways.[135] Similarly, Birmingham was the centre for the manufacture of brass goods, and had even fewer restrictions - for instance, there was no guild structure - and metal workers there could make instrument parts as easily as they made dog collars. 'Beginning as a small master,' says an 1866 account, 'often working in his own house, with his wife and children to help him, the Birmingham workman has become a master, his trade has extended, his buildings have increased.'[136] It seems more than likely that most of these anonymous instruments were

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132. Hudson (1992), 101-132; Daunton (1995), 279-83; Berg (1993).
133. Daunton (1995), 280.
134. Corfield (1982), 39-41.
135. Barnes (1992), 11.
136. Timmins (1866), 223.

channelled into the London market for finishing or their point-of-sale; in fact, to have a Sheffield or Birmingham address engraved on (for instance) a telescope in the early part of this period would have proved a distinct disincentive for the purchaser.

The local street directories, despite their problems of lack of continuity and probable inaccuracies, have provided a basic outline upon which further results can be built. Following the model devised by Millburn, some details of individual businesses have been provided here for the first time, such as the size of the trade and longevity of particular businesses. However, financial preconditions – such as how individuals found the capital to set up in business initially, whether the overheads were less than in London, or wage rates of employees undercut those of the capital – are still unknown. Neither do we have a very clear picture about what was made and what was retailed. We can state with some confidence, though, that although numerically tiny in comparison with the contemporary on trade, it can be seen that in some instances at least, provincial instrument makers were going to give their metropolitan cousins a run for their money in the future.

Chapter 3: The London Trade and its National and International Contexts

Introduction

The instrument-making activity outside London described in the preceding chapter was on a much smaller scale than that which occurred in the capital, and to some extent it has been masked by the apparent pre-eminence of London at this time. It has long been accepted by instrument historians as a given, that, during the eighteenth century, London was the world centre for this trade. For example, Gerard Turner has observed that 'during this period, the London scientific instrument trade achieved an international reputation';[1] J.A. Bennett has written that 'by the late 18th century, London makers had achieved a position of international pre-eminence in the mathematical instrument trade';[2] and Willem Hackmann, synthesising the earlier authority of E.G.R. Taylor, wrote:

> London emerged as the premier market for scientific instruments in the mid-eighteenth century ... [when] the ... trade consisted of an intricate network of specialist makers and retailers. Workshops congregated in the Clerkenwell region, jostling with makers of clocks, watches and engines, and other craftsmen in wood and metals.[3]

Yet no instrument historian has yet outlined just how and why, in economic terms this position was attained. In fact, London's pre-eminence was based on its ability to produce 'precision' instrumentation, as opposed to the more general 'scientific' material; but this more general material helped to underpin the trade and thus assisted in the important work taking place by a handful of pioneers on the edge of technical frontiers. These individuals were often of provincial origin, and moved to London in order to reach national and international markets. However, instrument makers who had been trained in London but who migrated to the provinces appear to have served their apprenticeships with masters in the more general 'scientific' instrument trade, and this is supported by the wares they advertised in the provincial press.

This chapter will attempt to characterise how London gained its pre-eminent position, especially in relation to Paris, and give an example of how an attempt to infiltrate a 'precision'

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1. Turner (1979), 173.
2. Bennett (1985), 13.
3. Hackmann (1985), 53-54.

workshop failed, demonstrating that these skills were not easily transferred, either abroad, or by implication, to the English provinces. The incidental detail in this case, however, reveals workshop practice in both the precision and the more general scientific trade, at the end of the eighteenth century, not found elsewhere. As a contrast to the discontinuity of provincial production, with makers providing parts or intermittently moving into closely-allied trades as demand dropped, or existing on income from repairs, the long-lasting career of a London workshop not producing precision instruments - that of the brothers W.& S. Jones - which spans much of the period covered by this thesis, is examined.

Bespoke instruments before about 1750

Although instrument-making had its origins on the continent of Europe, by the mid-eighteenth century London had become the world centre for the precision instrument trade. This has been characterised by Anthony Turner:

> Although special items were still made specially to order, master instrument-makers themselves now routinely invented, developed and improved the standard instruments which made up their stock-in-trade. Although in financial terms instrument-making was still of only minor importance in the national economy, its values in terms of skills and services was far greater, especially with the great trading nations of France and England with large fleets of merchant ships to be navigated... The changes that had taken place in the structure of the scientific instrument-making trade by the middle of the eighteenth century were the result of changes in attitude towards instruments themselves; the invention of new instruments; a considerable increase in demand; and a greater continuity of workshops and makers.[4]

London makers of precision instruments were able to lead successful careers through having their work promoted by the Royal Society and published in its prestigious *Philosophical Transactions*, a journal which reached an international audience. In particular, the astronomical observatories supplied by the London instrument maker George Graham and his associates, Jonathan Sisson and John Bird, helped to bring the 'Big Science' of its day to Europe with a suite of standard instruments - mural quadrant, transit instrument, zenith sector and astronomical regulator clock - for the first time. [See Table 3:1] This suite of extremely expensive bespoke instruments, in terms of capital investment, was purchased after Edmond Halley, second

[4]. Turner (1987), 173.

Greenwich					
Primary instruments			£	s	d
8 foot iron quadrant	1725	Graham/Sisson	322	10	4
8 foot brass quadrant	1750	Bird	500	0	0
(payment included publishing methods of construction and division)					
6 foot mural circle	1810	Troughton/Dollond	816	14	6
6 foot mural circle	1821	Thomas Jones/?Tully	411	3	2 1/2
6 foot mural circle	1822	Thomas Jones/?Tully	[?]		
5 foot transit	1721	Graham	61	10	0
8 foot transit	1750	Bird	73	16	6
10 foot transit	1816	Troughton	315	0	0
12 1/2 foot zenith sector	1727	Graham	[?]		
2 1/2 foot Zenith sector	1735	Graham	35	0	0
2 x 5 foot equatorial sectors	1773	Sisson/Dollond	642	0	0
Smaller instruments					
20 foot refractor	1748	Bird	7	10	0
6 foot Newtonian reflector	1748	Short	100	0	0
46" focus replacement lens	1772	Dollond	63	0	0
62" focus replacement lens	1797	Dollond	70	0	0
10 foot refractor	1797	Dollond	157	10	0
7 foot reflector	1783	Herschel	105	9	6
10 foot reflector	1813	Herschel	350	0	0
Clocks					
'Plain week clock'	1726	Graham	5	0	0
2 x month clocks	1726	Graham	24	0	0
1st fitted with gridiron pendulum	1743	Graham	15	13	0
2nd fitted with gridiron pendulum	1744	Graham	10	0	0
Month clock	1750	Graham	39	0	0
'Special escapement' clock	1809	Hardy	210	0	0
Oxford					
2 x mural quadrants, transit instrument, zenith sector and equatorial sector ordered from Bird in 1771: estimate, including optics from Dollond at:					
			1260	0	0
Total paid by 1777, for 5 instruments			1392	16	0

Fig. 3:1 Costs for setting up equipment at the Royal Observatory, Greenwich, and at the Radcliffe Observatory, Oxford, in the eighteenth century (figures from Howse (1975), and Gunther (1920-67), vol. 2, 311, 319-25, 336, 394-6).

Astronomer Royal, eventually received a government grant in 1724 to re-equip the largely-empty Royal Observatory in Greenwich, which had been established by Charles II in 1675 specifically to solve the problem of finding longitude at sea. Although reluctantly provided by the State, this is a clear indication of government motivation to invest in expensive plant in order to ensure in the long-term the safety of both its Royal Navy and merchant fleets: improved celestial cartography ensured better navigation in the longer term. It also had longer-term significance for the growth of trade and imperial ambitions. Nor was this the only way in which state interest manifested itself: a series of maritime disasters, culminating in the loss of a squadron of naval ships under the command of Sir Cloudesley Shovel, wrecked on the Scilly Isles in 1707 with the loss of 800 men, led to a Parliamentary committee of enquiry.[5] This in turn resulted in the setting up of the Board of Longitude by act of Parliament, offering a prize of £20,000 to the discoverer of a method which could determine a ship's longitude to within half a degree.[6]

With the provision of a number of breakthroughs in technology in the construction and subsequent use of the suite of instruments at Greenwich, their success - publicised through publication and by word of mouth by foreign visitors - led to further orders: a similar suite of instruments was ordered for the Radcliffe Observatory, Oxford, from Graham's successor John Bird in 1771, and subsequently others came from all over Europe. The next generation of London-based precision instrument makers, Edward Troughton, Jesse Ramsden, the Dollonds (who were optical specialists) and to a lesser extent, Thomas Jones, were able to continue this line, ensuring that where large astronomical instruments were needed, it was the London makers who sprang to the mind of would-be purchasers as being those most likely to fulfil the contract: and as these instruments represented a large amount of investment for the purchasers - usually foreign governments - completion as well as quality was important.[7]

Information about the availability and success of these instruments was diffused through the scientific community through its literature, in the form of journals and textbooks which, again, reached an international audience. The size of this scientific community and its composition is

[5]. Stimson (1996), 80-81.
[6]. 12 Anne, c.15 (1714): An Act for Providing a Publick Reward for such Person or Persons as shall Discover the Longitude at Sea. This has been dealt with most recently by Andrewes (1996).

difficult to gauge, but it was probably initially very small. In Britain, in the early eighteenth century, Fellows of the Royal Society - amongst whom were numbered these most distinguished instrument makers - were seen as at the forefront of this 'scientific community' (this term is of course an anachronism), and the Royal Society's publication of the *Philosophical Transactions* was central to reaching its members. This would include published correspondence between Fellows on an extremely broad range of subjects; and the journal would have been exchanged abroad with those of similar societies, national observatories and foreign correspondents. Close contacts, despite political differences, were maintained with, for example, the French Academie des Sciences; for instance, comparisons between the national weighing systems - enshrined by each state in long-standing legislation - of France and England were undertaken as early as the 1730s through the co-operation of their national scientific societies.[8] However, it is probable that any 'scientific community' in the early eighteenth century was centred around either a capital city, a national observatory or a university town (all of which would have had libraries); whereas a century later, there was a considerably stronger scientific community particularly in the English provinces, thanks to the growth of literacy and a general increase in a desire for knowledge amongst the expanding leisured classes.[9]

The late seventeenth century had seen the creation of cabinets of instruments for wealthy patrons across Europe, but these had only ever been a numerically small part of the market, important for the development of skills and extension of knowledge within the slowly-evolving trade. For example, in Amsterdam, the Musschenbroek workshop provided mathematical and philosophical apparatus to a limited market in the Netherlands and to parts of Germany.[10] It was, however, the provision of large good-quality telescopes to wealthy clients which paved the way for English pre-eminence in the European market.[11] These, promoted by influential patrons, particularly the national societies of England and France, were to win this position for the London

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7. Bennett (1992); Gunther (1920-67), II, 311, 319-25, 336, 394-6; Howse (1975).

8. Sorrenson (1993) gives an overview of the importance of the Royal Society to the instrument makers George Graham, Peter and John Dollond, and Jesse Ramsden and, reciprocally, of the instrument makers to the Royal Society; the comparison between French and English weights is discussed by A.D.C. Simpson and R.D. Connor, 'The Mass of the English Troy Pound in the Eighteenth Century', *Annals of Science*, forthcoming.

9. Stewart (1992); Golinski (1992); Inkster and Morrell (1983).

10. De Clercq (1997); for an overview, see Daumas (1972), 136-148.

élite makers.

Breaking into the European market

The first London maker to break into the European market was George Hearne (fl.1725-41), whose reflecting telescopes were sold across Europe from Poland to Lisbon. He learned his skills in a direct line from James Gregory's optician, Richard Reeve, through the towering figure of Isaac Newton, to the Hadley brothers, John, George and Henry. The Hadley brothers' technical information found its way into the standard natural philosophy text book of its day, Robert Smith's *Compleat System of Opticks* (1738), which capitalised on the success of Newton's *Opticks*, and like Newton's *Opticks*, named and recommended specific instrument makers. Smith also spelled out the fact that technical difficulties had inhibited production for some time:

> The main drift of all our tryals [by Bradley, Hadley and Smith] hath been if possible to reduce the method of making these instruments [i.e. reflecting telescopes] to some degree of certainty and ease; to the intent that the difficulty in making them, and the danger in miscarrying, might no longer discourage any workman from attempting the same for publick sale; which no body but Mr *Hauksbee* in *Crane Court* hath ever ventured upon. He has made a good one of about 3½ foot, and is now about one of 6 foot and another of 12 foot, and deserves very well to be encouraged, being the first person who hath attempted it without the assistance of a fortune, which could well bear the disappointment. About the beginning of the last winter being pretty well satisfied as to most of the circumstances in this performance, and being desirous that these instruments might become cheap and of publick sale, we acquainted Mr *Scarlet* near St *Anne*'s Church, and Mr *Hearne* a Mathematical Instrument-maker in *Dogwel Court, White Friers*, with the whole process of the operation as we had practised the same; and they have since succeeded in making these instruments. However as they are not yet become so common, so cheap and so universally made and used, as one would wish an instrument of this nature to be, we have been encouraged to give this following account, for the general information of all persons who would make the same for their own use or for sale.[12]

The production of good-quality large telescopes was initially hampered by technological frontiers, rather than economics. Anthony Turner has commented that 'Even in the eighteenth century the apparatus of astronomy, although still relatively simple, was expensive.'[13] This was because it was time-consuming and difficult to construct. The section of Smith's work entitled the 'Mechanical Treatise' explains in great detail how to make a number of different optical

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11. This has been investigated by Simpson (1981), chapter 4.
12. Smith (1738), II, 302-3.
13. Turner (1977), 53.

instruments, including telescopes and microscopes, and the tools necessary to construct them, drawn from earlier authorities such as Christiaan Huygens (1629-95) and Samuel Molyneux (1689-1728). Smith's book was part of the vindication of the optical theories of England's great scientist, Sir Isaac Newton (1642-1727).[14]

The most prolific manufacturer of telescopes during the eighteenth century was Edinburgh-born James Short (1710-1768), who constructed a numbered sequence of over 1300 instruments, most of which were of medium size and aimed at the new consumer market of wealthy gentlemen who could afford to dabble in astronomy as a pastime [Table 3:2].[15] D.J. Bryden estimated that '[telescope] models with focal lengths of 18 inches and below accounted for 90% of this output. The larger and more expensive models were probably made for specific customers, whereas the smaller telescopes could have been purchased off the shelf'.[16] Gerard Turner was able to produce a graph showing the serial number against the date, and using the figures given in Table 3:2, estimated an approximate annual sales income at about £620. He went on to suggest that Short did not make any of the brasswork associated with his instruments, but focused exclusively upon the manufacture of the reflecting optics:

> Assuming Short's working life was thirty-five years, his total income from sales was at least £21,700. This figure is an underestimate ... Short's outgoings must, unfortunately, be a matter of guesswork. A good-sized house in central London could have been leased for around £50 a year. *A General Description of All Trades* [London, 1747, p.138] records that the cost of setting up a private workshop is £50 for tools, and a mathematical instrument maker is said to earn a guinea a week ... [Short] would have bought wholesale, and without mirrors, perhaps at 60 per cent of retail price, so making the cost to him of the telescopes he sold 30 per cent of their retail price. According to these rough estimates, expenses to be taken away from the gross income are: £6,500 for materials (stands), thirty-five years' rental £1750, the same for living expenses (Short had no dependants), for tools £50; a total of some £10,000, which leaves in round figures a profit of £12,000, almost certainly an underestimate... It is not inconceivable that he left an estate worth over £20,000, made chiefly out of polishing speculum metal.[17]

It has been established more recently that Short did indeed buy in the brasswork for his

14. Simpson (1981).
15. Bryden (1968); Turner (1969b); 'James Short', in Clarke et al. (1989), 1-10.
16. Bryden (1968), 23.
17. Turner (1969b), 100-102.

telescopes from a London supplier, and was involved in negotiations for this as early as 1736.[18] Short worked alone, and by keeping the volume of work within his own control, he did not have to share the secrets of his skill with others: his instruments were expensive, but such was his reputation that he was able to command twice the price of contemporaries. After his death, his tools were acquired by a Swedish instrument maker, Carl Appelquist, but the tools alone could not reproduce Short's superlative telescopes: Appelquist did not have Short's 'knowhow'.[19] Although Short left no description of his mirror-making methods, the Plymouth physician John Mudge FRS (1721-93), an amateur astronomer and telescope maker, visited Short's London workshop and, in 1777, after Short's death, he presented before the Royal Society a detailed investigation into the methods of making speculum metal for reflecting telescopes, and discussed some of the skills which he thought must have been employed by Short. These included particular recipes for specula casting, in order to allow subsequent grinding; polishing directly on pitch, which would leave no minute scratches on the surface; a final parabolic figure to the spherical mirror produced with a spiral motion; and finally, matching and rotating the two mirrors so that their aberrations most nearly cancelled each other.[20] Yet English-made telescope speculae did not again reach Short's standards, as we have seen, until William Herschel (1738-1822), based in Bath, had worked them out for himself, through a heroic series of trials, undertaken in isolation from other workers.[21]

James Short was unusual amongst his contemporaries: his workforce consisted only of himself, and since he bought in all his brasswork, he was able to concentrate on the optics of a single instrument, the reflecting telescope, improving it so that he could sell it for twice as much as his contemporaries. He was also unusual in numbering his instruments in such a way that some assessment of his profit-margin has been estimated: this has not been possible for later, numbered, provincial, instruments, such as those by Dancer, King or Field. However, Short was not alone in adding to London's prestige as the instrument-making centre of large astronomical instrumentation during the latter part of the eighteenth century, as J.A. Bennett has observed:

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[18]. Clarke et al. (1989), 3.
[19]. Bryden (1968), 31.
[20]. Mudge (1777); discussed by Simpson (1981), 314-326.
[21]. Turner (1977), 53-109.

> Any survey of the observatory instruments in use on the Continent towards the end of the eighteenth century will soon come upon the names of such English makers as Bird, Sisson, Dollond and Ramsden ... There is no doubt that London makers dominated the trade in mathematical instruments in the second half of the century. This is clear from the historical record, but was also well understood at the time. If we look for examples of large fixed instruments at observatories in France, Italy and Germany, we know of mural quadrants by Sisson in Paris, Bologna, Pisa and Berlin; by Bird in Paris (two examples), Göttingen, Mannheim and Berlin; and by Ramsden in Milan and Padua. There were transit instruments by Sisson in Bologna and Florence; by Ramsden in Paris, Mannheim, Gotha, Leipzig and Palermo. There was a zenith sector by Sisson in Florence, and equatorial sectors by Sisson in Milan and Naples, and by Dollond in Kassel. There were altazimuth circles by Sisson in Naples and by Ramsden in Palermo. This list is not exhaustive, but can easily be extended by looking further afield...[22]

That even French scientists were prepared to turn to London makers can be demonstrated by the price list included in the 1771 second edition of Jerome Lalande's *Astronomie* [Table 3:3], which lists items by Dollond, Ramsden, Bird and the more expensive and larger items given on Short's price list, with the comment 'Il faut une permission pour les faire entrer dans le Royaume'.[23]

Why did instrument makers in France not dominate this embryonic global - European and north American, at any rate - market? Economic historians interested in 'the key problem of growth' have asked a more broadly-focused question, in order to see 'what factors were peculiar to England and might therefore have determined what is a unique phenomenon, the English Industrial Revolution of the eighteenth century.'[24] A.E. Musson, paraphrasing François Crouzet, summed this up:

> ... despite French leadership in many branches of industrial science, the British were able to adopt French advances fairly quickly, as well as making many of their own, and forged ahead in industrial development. Practical scientific knowledge seems to have been more widely and deeply diffused in Britain than in France. Britain also had substantial economic advantages in natural resources (especially coal) and wider overseas trade and empire, as well as institutional advantages such as freedom from tolls and fewer government restrictions, together with social advantages such as a more developed and enterprising middle class and greater social mobility.[25]

[22]. Bennett (1987), 88.
[23]. Lalande's third edition of 1791 had a variation on this list: see Howse (1989).
[24]. Crouzet (1967), 139.
[25]. Musson (1975), 82.

PRIX DES INSTRUMENS D'ASTRONOMIE en 1771.

Lunettes.

UNE LUNETTE de six pieds avec un tuyau de tôle ou de fer battu, fait de quatre pièces qui se montent à vis, chez M. Georges, Opticien de Mrs de l'Acad. des Sciences, quai de Conty, coûte quatre louis ou .... 96 livres.

Les successeurs de M. Passemant au Louvre, M. Pâris à l'Estrapade, & M. Gonichon, rue des Postes, font aussi de très-bonnes lunettes de toutes les longueurs.

Pour une lunette de 15 pieds (2284) il faut un objectif de 15 pieds de foyer qui coûte un écu le pied, c'est-à-dire, 45 liv. un tuyau de fer blanc de 15 liv. (un tuyau de bois ne coûte que 10 liv.); un oculaire de 6 liv. Total, soixante six livres .....66 liv.

Les lunettes achromatiques (2298), qui sont destinées à mettre dans la poche, toutes montées coûtent deux guinées & demi, à Londres, ou 60 liv. de France, mais elles ont plusieurs oculaires. Les objectifs achromatiques de 3 pieds, 3 guinées; les objectifs de 9 pieds, 8 guinées; ceux de 12 pieds, 10 guinées; ceux de 18 pieds, 15 guinées. On en trouve chez M. Dollond dans le Strand, & chez M. Ramsden. Il y a de nouvelles lunettes achromatiques de 3½ pieds qui ont 3½ pouces d'ouverture (2307) & qui coûtent 26 louis à Londres, environ un louis de port; mais il faut une permission pour les faire entrer dans le Royaume.

Quart-de-cercle.

Un quart-de-cercle mural de 8 pieds Anglois de rayon, fait à Londres par M. Bird; tels que sont ceux de Gréenwich, celui de Pétersbourg, & celui de M. le Monnier à Paris....... 8000 liv.

Quart-de-cercle de 18 pouces de rayon, avec deux divisions de Vernier; une lunette fixe, une mobile, & un micromètre extérieur, chez M. Bird,.......................... 1200 liv.

Quart-de cercle mural d'un pied, 25 guinées, ou 600 liv. & les autres à proportion du rayon, pourvu qu'ils ne soient pas fort grands.

Un quart-de-cercle mural de 6 pieds de rayon, tel que celui de l'Observatoire de Paris, & celui de Milan chez M. Canivet, Ingénieur du Roi & de MM. de l'Académie Royale des Sciences pour les Instrumens d'Astronomie................ 5000 liv.

Sextant.

Un sextant (*Fig.* 207) de 6 pieds de rayon, à deux lunettes,.................................... 3000 liv.

Tome I. g

Un sextant pareil de 4 pieds de rayon,.......... 2000 liv.

Un sextant de 3 pieds,...................... 1500 liv.

Un petit sextant d'un pied, pour prendre seulement les hauteurs correspondantes,......................... 600 liv.

Un quart-de-cercle de 2 pieds ½ (*Fig.* 149), avec une alidade pour mesurer des angles sur le terrein, & un double genou, (*Fig.* 153).. 2400 liv.

Autres Instrumens.

Lunette parallat. en bois avec son axe (*Fig.* 176).... 240 liv.

Un micromètre, tel que celui que j'ai décrit (2358)..300 liv.

Un micromètre simple de la grandeur de celui qui est décrit (2366),.................................. 160 liv.

Micromètre simple, plus petit, suffisant pour une lunette de 7 à 8 pieds,................................ 150 liv.

Lunette méridienne, ou instrument des passages (2387) avec ses supports & son niveau,...................... 600 liv.

Le niveau de 2 pieds seul, avec un tube calibré (2398). 144 liv.

Octant de réflexion de 18 pouces de rayon, en bois, pour observer en Mer les hauteurs & les distances (2458) avec une lunette,.. 120 liv.

Le même en cuivre,........................ 150 liv.

Le même de 2 pieds de rayon, fait avec un soin particulier par Ramsden à Londres,............................ 300 liv.

Télescopes.

LES TÉLESCOPES de Short à Londres, qui ont un pied de foyer, mesure d'Angleterre, ou 11 pouces ¼, mesure de France, coûtoient 14 guinées, c'est-à-dire, 14 louis d'or, ou 336 liv. & grossissoient jusqu'à 110 fois; on verra les prix des autres grandeurs dans la Table ci-jointe avec les amplifications. Je suppose que les artistes qui lui ont succedé, ne s'éloigneront pas des prix qu'il avoit fixés; mais je doute qu'ils voulussent entreprendre le télescope de 144 pouces de foyer (ou 11¾ pieds de Paris), que Short lui-même n'a jamais exécuté qu'une fois.

Pouces Anglois.	Guinées.	Amplifications.
12	14	110
18	20	200
24	35	300
36	75	400
48	100	500
72	300	800
144	800	1200

Les télescopes François se comptent ordinairement, non pas sur le foyer de leur grand miroir, mais sur leur longueur totale, y compris le petit miroir & les oculaires. Nous allons rapporter les prix de M. Passemant d'après le catalogue qu'il en avoit donné au Public, peu de temps avant sa mort, & qui seront entretenus par ses successeurs.

Les télescopes de 16 pouces qui équivalent à des lunettes de

Fig. 3:3 Lalande's price list for astronomical instruments, 1771.
Royal Observatory, Edinburgh.

These last reasons have been developed by Anthony Turner in a series of essays on the French instrument trade at this period, in the most recent of which he writes as a footnote, citing the work of Maurice Daumas:

> Daumas's exceptional and pioneering study remains the authoritative work on French instrument-making. If it is cited only on this one occasion, it is because I have deliberately sought to re-examine the evidence (and to find some new) independently of Daumas's perspective. That in the end we arrive at somewhat similar conclusions is reassuring.[26]

Turner begins his work on the Parisian instrument maker Etienne Lenoir (1744-1832) by discussing the 1771 price list published by Lalande, which by its inclusion of London-made precision instruments demonstrates for him that 'by the end of the third quarter of the 18th century, French (which is to say Paris) instrument-makers could no longer compete with their English counterparts in the production of large-scale, precision, observing instruments'.[27] This was because, as Turner describes, Parisian workshop size was closely controlled by the inflexible Paris guild structure, and was thus dependent on a very small, local, luxury clientele: that of the royal court, a few nobles and colleges. Unlike the London trade which was able to support investment in large-scale, technically-innovative precision instruments, or large-scale production of essential, and thus lucrative, instruments such as octants or sextants, 'no Paris manufacturer had a sufficiently large everyday retail trade to enable him to carry out development, innovation and improvement on his own behalf.'[28] Despite attempts to reform this system by the astronomers Lalande and J.D. Cassini, it was the radical social change effected by the 1789 Revolution which ended the inextricable straitjacket in which the Paris trade had found itself.

Turner maintains that from the early 1790s the state saw instrument-making as 'essential to French national security', and thus one to be encouraged. 'The exigencies of war, the reform of the weights and measures, the introduction of metrication, the installation of Chappe's telegraph system, all produced an immediate governmental need for the skills of not just one or two instrument-makers but of many.'[29] However, these were numerically few, and not particularly skilful. This led to further governmental encouragement in the form of training and education, and a

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26. Turner (1998), 84, citing Daumas (1972), first published in 1953.
27. Turner (1989), 3.
28. *Ibid.*, 8.
29. *Ibid.*, 17.

programme of frequent national exhibitions with prizes. Turner shows how the vast governmental order for new weights and measures led to the development of new tools and machines within the workshop, while one instrument business, the brothers Jecker, pioneered 'the introduction of large-scale mechanised production into Paris instrument-making' along the lines of that already used in the London workshop of Jesse Ramsden, with whom François-Antoine Jecker had worked for five years.[30] The Jecker business was to survive for some forty years.

The London trade in the mid-eighteenth century

By the mid-eighteenth century, this business, dominated by firms based in London, would have been a traditionally-organised craft. How did instrument-making compare with other industries in about 1760? It was quantitatively tiny in size - the figures produced by Project SIMON suggest that in 1751 there were 161 makers in charge of their own businesses in London, compared with a total of 232 in the entire British Isles.[31] More recent figures, produced in Table 3:4, show the number of businesses at five year intervals from 1760, compared with those uncovered in the provincial centres in the course of work for this thesis.[32] Numbers of the London instrument community over this period show that it was always the largest centre nationally for this trade, although there were two periods where numbers declined: during the 1790s, and in the second decade of the nineteenth century. Apprenticeship was strictly governed (although there was not an exclusive London guild which covered the trade, and theoretically restriction applied only within the City of London and not in neighbouring Westminster), so that the transfer of skills was through a seven-year training and initiation into trade secrets. Yet, in comparison with the Paris guild-structure, the craft was protected but not suffocated. The markets were largest where the population was greatest and wealthiest, that is, in London. As Gloria Clifton has shown, the external economies created outside the trade in eighteenth-century London gave individual firms a number of advantages by their proximity to each other, where 'clusters of small firms could form a critical mass, creating a pool of skilled labour, exchange of ideas, and support services, which allow

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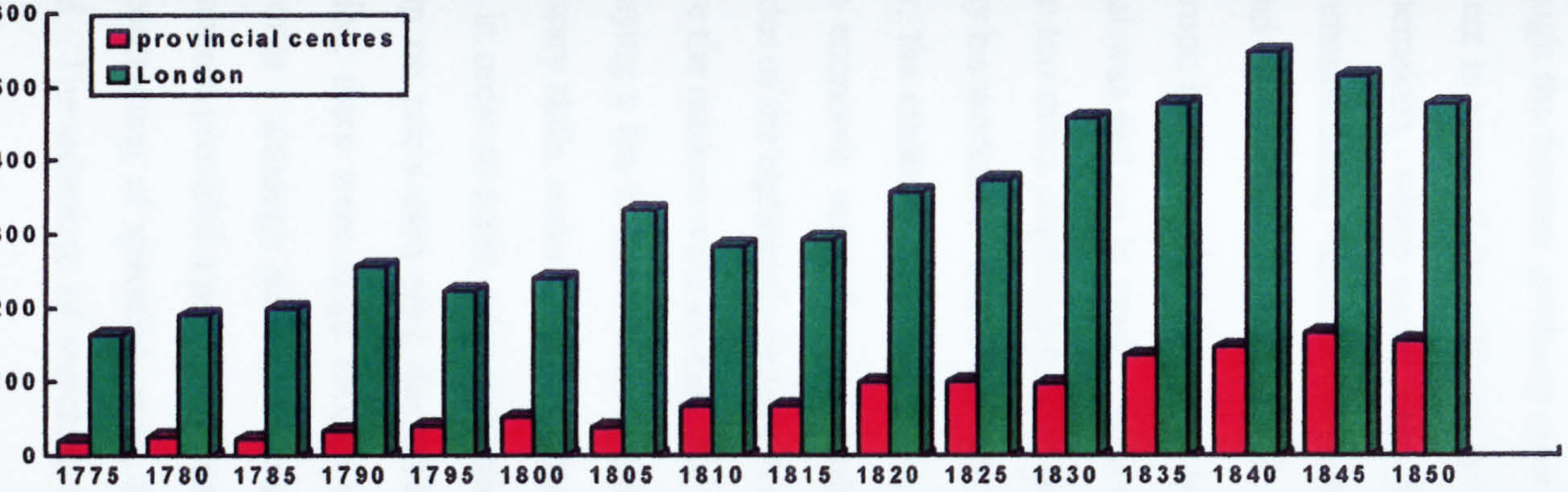
30. *Ibid.*, 20.
31. Clifton (1995).
32. Statistics supplied from the database of British scientific instrument makers maintained by Dr Gloria Clifton at the National Maritime Museum and Old Royal Observatory Greenwich, London SE10 9NF.



Year	1775	1780	1785	1790	1795	1800	1805	1810	1815	1820	1825	1830	1835	1840	1845	1850	1855	1860
Bristol	5	5	4	4	6	7	1	9	6	9	9	10	7	9	10	10	13	7
York	-	0	1	1	1	2	0	1	1	1	3	3	4	2	2	2	2	2
Birmingham	9	15	15	18	21	28	21	36	36	41	40	41	53	53	67	60	-	-
Liverpool	4	4	2	9	7	10	9	14	11	16	24	15	35	39	35	35		
Manchester	0	0	0	0	3	3	4	3	5	14	9	14	20	24	27	22		
Sheffield	2	2	1	2	2	2	3	4	8	18	15	14	16	20	25	26	24	25
Total	**20**	**26**	**23**	**34**	**40**	**52**	**38**	**67**	**67**	**99**	**100**	**97**	**135**	**147**	**166**	**155**		
London	**164**	**191**	**200**	**256**	**224**	**240**	**333**	**284**	**293**	**357**	**373**	**457**	**478**	**548**	**515**	**477**		

Table 3.4 Numbers of London instruments makers compared with six provincial centres in table 2:4 1775-1850
London figures supplied from the database of British scientific instrument makers maintained by Gloria Clifton at the National Maritime Museum, Greenwich

the whole industry to advance.'[33]

The markets were also at their most diverse in London, ranging from dilettantes paying for the newest technical toy to impress their contemporaries, to clients at the Royal Society wanting to realise ideas in brass, through to burgeoning custom from mariners, surveyors and teachers; and although the finished products could be any of a growing variety, there were few of the pitfalls inherent in some of the other luxury trades - such as a whimsical change in fashion, as befell the bucklemakers - which would mean that overnight goods became unsaleable. This is not to say that instrument-making was a secure business: bankruptcy, like the other Grim Reaper, was always just around the corner. Between 1774 and 1786, five London-based instrument businesses went bankrupt; however, of these, three businesses apparently recovered and continued.[34] If too much capital was tied up in stock - as in the example of Jeremiah Sisson, who, according to Lalande, began too many projects but completed none, and found himself having to pawn his tools in order to pay his workmen - and if this was compounded with the length of time taken to complete a large order, the creditors would be at the door.[35] Despite such pitfalls, however, it would have made more economic sense for any aspiring instrument maker setting up in business in the middle decades of the eighteenth century, to be located in London rather than in the provinces, as that was where the markets were located, and where the foreign visitors would come. Entry to the trade was by paying a fee to become an apprentice, followed by a seven years' apprenticeship to gain the necessary skills, under a master. Then, it was necessary to obtain freedom of the company and the City, in order to trade, take apprentices and employ journeymen. Finding the necessary capital to set up on one's own after this probably depended critically upon family networks; however, in London, there were large enough workshops to absorb skilled hands, and the sub-contracting networks - although difficult to trace - were clearly run along well-established lines. 'Trained apprentices provided a pool of skilled labour, and the enormous range of individual crafts facilitated subcontracting of specialist work, the transfer of skills, and the exchange of ideas,' Clifton has noted. 'The existence of merchant bankers, packers, shippers, insurance companies and agents

33. Clifton (1994), 68, quoting M. Porter, *The Competitive Advantage of Nations* (London, 1990), 434, 735-6.

34. Anon. (1789), discussed in Morrison-Low (1994a).

35. Quoted in Morrison-Low (1994a).

provided the services needed for those who wished to conduct business beyond London.'[36]

An oblique indication of the nature of his in-house and sub-contracted support is provided in a comment first published in 1746, by the prominent London instrument maker George Adams the Elder, of any particular commission:

> I always inspect and direct the several Pieces myself, see them all combined in my own House, and finish the most curious Parts thereof with my own Hands.[37]

In his day, Adams was one of the most prestigious figures in the instrument trade, who held the appointment of Mathematical Instrument Maker to the Royal Ordnance between 1748 and 1753, and later held Royal Appointments to the Prince of Wales and to George III.[38] His statement implies that his business was underpinned by a complex trade structure - hidden to historians, yet probably taken for granted by contemporaries - of outworkers and subcontractors, channelling specialist instrument parts to be assembled for sale in Adams' Fleet Street premises. Just how complex this structure was at this date can be gleaned only from foreign attempts to acquire these skills through espionage.

Other European countries - and their governments - were eager to find out what went on inside individual first-rate workshops. As David Jeremy has pointed out, there was legislation in place to prohibit the export of machinery from before the 1760s, and 'no skilled artisan or manufacturer was legally free to leave Britain or Ireland and enter any foreign country outside the Crown's dominions for the purpose of carrying on his trade.' Although this legislation, up to 1824, was 'comprehensive' concerning textile machinery, that covering metal-working tools (including so-called 'clock-making' tools) was not.[39] Occasionally, friendly foreign powers would - with greater or lesser success - place men in some of the top-ranking London workshops for a considerable fee. At other times, the manufacturer would refuse to take them on. In conjunction with Catherine the Great's policy of enticing skilled workers from England to Russia, a series of commercial treaties between the two countries during the eighteenth century allowed some

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36. Clifton (1994), 68.
37. Adams (1746), 224.
38. Clifton (1995), 2.
39. Jeremy (1977), 2. He lists the following acts: 5 Geo. 1, c.27 (1718); 25 Geo. 3, c.67 (1785) and 26 Geo. 3, c.89 (1786), covering the metal trades.

exemption from the general restrictions on technological exchange. Thus, the Russian instrument maker Nikolai Chizhov worked with George Adams the Elder for eight months during 1759,[40] but towards the end of the century, when Vasilii Sveshnikov and Osip Shishorin came to London, they had to bribe workers to disclose the secrets their masters refused to show them.[41] Reciprocally, a number of British-born, London-trained instrument makers were inveigled to go abroad, taking their trade with them: John Bradley worked in Moscow between 1710 and 1716, then went to St. Petersburg, where he died in 1743; Francis Morgan emigrated to St. Petersburg in 1772 and died there in 1803; Samuel Whitford went to St. Petersburg in 1771, but returned to London and took over Morgan's business. Benjamin Scott emigrated in 1747, and Robert Hynam in about 1775, both to St. Petersburg; they were contracted not just to make instruments but also to train young Russian craftsmen in their skills.[42] Anita McConnell mentions foreign workers of other nationalities who were allowed to work with Jesse Ramsden, considered to be the pre-eminent London instrument manufacturer of his generation: François Jecker, discussed above, a member of the Parisian family of instrument makers worked with Ramsden for five years between 1789 and 1794, Georg Dreschler of Hamburg also spent a similar length of time, and Jasper J. Marquez and Jose Maria Pedroso - presumably Spaniards - each paid 150 guineas for the privilege of being taken on in the Ramsden workshop in 1798.[43] How little of Ramsden's secrets could be gleaned from such a position is revealed by the frustrated comments of the Dane, Jesper Bidstrup, to his patron, Thomas Bugge.

How foreigners saw the London trade

Foreigners from all over Europe came to visit London - and later the English Midlands and subsequently Scotland - and were often allowed, thanks to their contacts, to see around all manner of industrial sites. However, those who came to gather information rather than as innocent sight-seers, were usually obliged to make their descriptions and sketch their illustrations of what they had seen, presumably some hours after the event, rather than at the time. Jeremy has observed that 'we have ... little idea of the extent to which technology transfer occurred through correspondence'.[44]

[40]. Boss (1972), 204-5; Cross (1979), 35.
[41]. Woolrich (1988), 36.
[42]. Cross (1980), 185-9; Chenakal (1972).
[43]. McConnell (1994b), 46.
[44]. Jeremy (1977), 16.

As an example of one country's attempt to bring its knowledge up-to-date, that of Denmark would appear superficially to be an unlikely place to have (or even desire) a flourishing trade in indigenously-manufactured scientific instruments, but by the late eighteenth century there was evidently a perceived need for this. Denmark was and remains predominantly rural, its native geology lacking both coal and iron, and its population small. Denmark had, of course, produced earlier scientists of European stature, principally the astronomers Tycho Brahe (1546-1601) and Ole Rømer (1644-1710).[45] Thomas Bugge (1740-1815), had studied theology and mathematics at the University of Copenhagen, had worked as an assistant at the Royal Observatory at Copenhagen and subsequently was appointed chief land surveyor of the kingdom of Denmark. He made two visits abroad to see foreign observatories and examine instrument-making concerns, the first of these in 1777 shortly after his appointment as professor of astronomy and mathematics at the University for Copenhagen and Danish Astronomer Royal.[46]

The journal recording Bugge's 1777 journey was made as a personal aide-memoire, and was not published during his lifetime; he appears to have jotted his impressions and sketches later the same day. He visited the Netherlands and England, and was naturally most interested in astronomical material at this point in his career. Evidently his position had equipped him with suitable introductions to eminent scientific circles: on 2nd October 1777 he was introduced to the Royal Society Club and invited to dine with the president, Sir John Pringle, the following night.[47] In turn, this would have furnished him with introductions to where science was practised: in the observatories, and in the instrument workshops. He first visited mathematical instrument shops in and around the Strand, including that of Addison Smith: 'He is a very polite man. At his shop I bought a ruler with English, French, Dutch and Antwerp standards for 3 sh[illings].'[48] Subsequently, Bugge visited a Mr Russell who lived nearby, who 'showed me a small scale by [John] Bird ... I compared an inch rule, bought at Smith's, and found that 24 inches were $^{1}/_{10}$th too

45. For Tycho, see most recently Thoren (1990); for Danish astronomy, including Rømer and Tycho, see Thykier (1990).

46. Crosland (1969), in his Introduction, gives the background to Bugge's life and times. A transcript of Bugge's diary of his 1777 visit to the Netherlands and England has been translated and edited by Karl Møller Pedersen of Aarhus University, 1997, and is here referred to as Bugge (1777).

47. *Ibid.*, 191.

48. *Ibid.*, 129.

short.[49]

Already Bugge was discovering that retailed instruments were not necessarily of the quality of bespoke items. Bugge went on to describe his 'very beautiful transit instrument by Bird ... I also saw one of Graham's astronomical clocks with a Gridiron pendulum; it had a peculiar device for correcting the pendulum if the brass and steel rods did not have the correct ratio, if the pendulum changed with warm and cold.'[50] Again, this is sketched in detail and carefully described. George Graham's gridiron pendulum was an improvement of that of John Harrison, announced in 1728, and by the 1770s was seen as a fundamental part of observatory equipment for accurate timekeeping: it was not, however, new.

Bugge visited other precision clockmakers, notably the chronometer maker John Arnold, who showed him his chronometer improvements using helical instead of spiral springs, his balance movement, and his heat-compensated pendulum for astronomical clocks.[51] He also visited Alexander Cumming, and saw an example of his famous barometer clock on his shop premises.[52] Cumming had a small observatory at the top of his house, with two instruments used for calibrating his clocks made by Jesse Ramsden, which Bugge examined closely and subsequently described and sketched.[53] Bugge went to see Ramsden 'who at once showed me an 8-foot mural quadrant which was in preparation.' There then ensued some technical conversation, with the heading underlined: 'Ramsden's ideas about some new instruments.'[54] However, he clearly learned nothing of any crucial importance on this brief visit.

Foreign visitors interested in astronomy and precision instruments always made a point of seeing Ramsden, considered by contemporaries to be at the pinnacle of the trade. After commenting on the general state of the instrument trade, the Frenchman Faujas de Saint Fond stated in 1784 that its practitioners:

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49. *Ibid.*, 191-3. John Russell (1745-1806) was a portrait painter, but also known for his maps and globes of the Moon: Ryan (1966).
50. *Ibid.*, 199.
51. *Ibid.*, 157-161; 171-177.
52. Goodison (1977), 315.
53. Bugge (1777), 163-171.

> are, in general, men of great information; and spare neither time nor expense to carry their workmanship to a high degree of perfection. A more careful education than is elsewhere is obtainable; the demands of the navy, and the great number of persons whose wealth enables them to appreciate and to pay well for the best-constructed instruments, are causes which have concurred to form artists of high reputation, and who have served as instructors to others...
> I found the skilful and modest Ramsden occupied in making an instrument simple in appearance, but which demanded much care and many combinations to make it perfect...
> I had much pleasure in conversing with Ramsden. I went to see him several times; and I purchased several instruments at his shop. He possesses all the modesty and simplicity of manners of a man of great talents.[55]

The accessibility of Ramsden, together with his 'modesty and simplicity of manners' impressed foreign scientists, and Bugge, a few years before De Saint Fond, had found him happy to discuss theory and for a few brief hours politely show the visitor instruments under construction. However, this was not to be the case with foreigners who wished to learn his trade and export it back to their native land, as Bugge was subsequently to find.

Bugge listed the books and instruments he bought in London. In total, he paid £34 6s 6d for books, but bought only one - Ramsden's *Description of an Engine for Dividing Mathematical Instruments* (1777) - which was new.[56] Although books would have been available through exchange at the Royal Danish Academy of Sciences and Letters, and at the Royal Danish Observatory, Bugge built up his own large personal library: this, containing some seven thousand volumes, and his collection of mathematical instruments were destroyed in the bombardment of Copenhagen by the British fleet in September 1807.[57]

For his instruments he paid considerably more: a total of £88 4s. Apart from the substandard rule purchased from Smith, he bought an eight-guinea compound microscope from Dollond in the St. Paul's Churchyard; then 'I visited the other Mr Dollond who lives in the Hay Market. I bought the new parallel ruler invented by him. None of the Dollond brothers seems to have any theoretical knowledge.'[58] This comment can only be seen as damning, and is

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54. *Ibid.*, 185.
55. De Saint Fond (1907), 91-93.
56. Bugge (1777), 199-205.
57. Crosland (1969), 17.
58. Bugge (1777), 155. These would appear to be the sons of John Dollond the elder: John (1733-

corroborated by an earlier comment by the French astronomer Bernoulli,[59] but the firm and its outstanding reputation, particularly with optical instruments, had been established by the father of the two brothers, with the solution of the problem of chromatic aberration and the patenting of the achromatic lens in 1758. Most of the rest of Bugge's purchases were made to order at Nairne & Blunt's in Cornhill, where on 20 September Bugge had been treated to a demonstration of 'several experiments with the electrical machine', and subsequently ordered an electrical machine and an airpump.[60] Then he visited the observatories at Oxford, Greenwich and Cambridge, marvelling at the instrumentation and sketching them beside the notes in his journal. By early November he was back in the capital where: 'On my last day in London I saw the instruments which Mr Nairne and Blunt had made for me, and I found them all very pleasing'.[61] These appear to have been good-quality, standard demonstration instruments of the time, presumably to be used in his university teaching.

Bugge returned to Denmark in late 1777, where it seems that only one instrument maker was then at work: this was a Swedish immigrant, Johannes Ahl (1729-1795), who had fled his native land in 1762 to escape personal debt, and was welcomed by the astronomy faculty at the University of Copenhagen. Ahl had learnt his craft through apprenticeship under the pre-eminent eighteenth-century Swedish instrument maker, Daniel Ekström (1711-1755).[62] Part of Ekström's own education, with his government's patronage and encouragement, had been a year spent in England, working in George Graham's workshop during 1739-40; he had also visited Greenwich Observatory, and listened to J.T. Desaguliers lecturing at the Royal Society.[63] Through Bugge's patronage, Ahl supplied major instruments to the Royal Observatory at Copenhagen, and to the national survey carried out by Bugge under the Royal Danish Academy; other clients, such as army engineers involved in the construction of the Ejder Canal, and the Admiralty which required its navy supplied with navigation instruments, had to be supplied by Parisian and London products.[64]

1804) and Peter (1731-1820). The brothers were in partnership between 1766 and 1804, with Peter running the shop in St. Paul's Churchyard and John that in the Haymarket: see Clifton (1995), 87.

59. Quoted by Daumas (1972), 239.
60. Bugge (1777), 141.
61. *Ibid.*, 345.
62. Andersen (1995), 12.
63. Amelin (1994).
64. Ahl and Bidstrup are discussed by Christensen (1993).

Bugge determined to establish an indigenous instrument trade, and he encouraged one of Ahl's apprentices named Jesper Bidstrup (1763-1802) to take up a university grant as well as a supplementary royal grant, and travel to London with letters of recommendation, one addressed to Sir Joseph Banks, president of the Royal Society. This explained that Bidstrup had already had some instruction from Johann Ahl, that he came with a government stipend of £100 a year, as 'he has a mind to begin with the beginning and to work as a common workman.' Bugge suggested Ramsden as a possible master, diffidently anticipating that he 'will perhaps not trouble himself with the case of a foreigner', discarded the bankrupt Jeremiah Sisson, and hoped that a good word from the powerful Banks would persuade 'Mr Nairne and Blunt [who] will not disdain to bring a youth of knowledge and ability to perfection in his favourite art'.[65]

Bugge also wrote a letter of recommendation to the renowned maker of reflecting telescopes, William Herschel (whose work as a provincial maker is discussed in chapter 2), summarising his letter to Banks, and after some well-placed flattery concerning Herschel's skills in both astronomy and telescope construction, requested that 'you will give Mr Bidstrup leave to look on your other instruments and your other fine inventions...'[66]

However, this hopeful approach was not to succeed. As Bidstrup subsequently wrote to Bugge, he was unable to find work with any of the first rank workshops, and in particular, not with Jesse Ramsden, but he was able to report back to Bugge in March 1789 that he had found a position with a 'Mr White':

> ... with whom I work. He is an honest man and has most readily passed on to me all his own learning, and even introduced me to artists, whose acquaintance I have turned to good account and hope moreover to retain in the future, just as I am also pleased with the decision I took and adhered to, for I am now fully convinced that it was not Nairne & Blunt, Adams or Dollond or their peers from whom I would have learnt anything, as their most prestigious instruments are manufactured all around the city, and what men they employ in their houses are either simply put to repairing instruments, or for executing some [...?], on the other hand I should not omit to ask for these men's opinions for I dare say it is not from lack of knowledge that they deal with instruments like that, but because it is to

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65. British Library Add Mss. 8097 ff 14-15, Bugge to Banks, 9 July 1787.
66. Royal Astronomical Society, Herschel letters, W1/13.B.171, Thomas Bugge to William Herschel, 6 July 1787.

their advantage to do so.[67]

'Mr White' was probably Joseph White, identified from insurance records, who had been working off Gray's Inn Lane as a subcontractor until 1786, and subsequently at Hatton Street.[68] It would appear from Bidstrup's description that little of ground-breaking technical importance was constructed on most London shop premises, although he went on to say:

> Ramsden is the only one to have the most important instruments manufactured in his house, he has often got 40 to 50 workers each of them manufacturing various parts of an instrument, some are plane filing, others turning on the lathe, making screws and so forth. Those few who create or sometimes even manufacture an instrument, doing nothing else, must already be well known as a good and experienced craftsman. Had I even entered his workshop as a hired man, this being the only way, yet it would have been of little advantage to me, for they would of course have set me to plane, file, turn on the lathe, and so on, just like everyone else, and being a hired man, I would have had to do what was ordered of me, by which I would have been deprived of increasing my knowledge of other parts of the art, not because Ramsden could not give the best instruction, but because no mortal would make him do that.[69]

This description of a London 'factory', where an entire instrument appears to be constructed on the premises - instead of going to specialist makers to the trade all around London - demonstrates at least one example of the specialist division of labour in this trade. McConnell sees this as unusual in the instrument trade at this date, commenting that Ramsden, a known associate of Matthew Boulton, may have been influenced by the division of labour practised at the Soho Works.[70] Yet, Bidstrup also made clear that Ramsden and others at the top of the trade were masters of all the skills necessary to produce a completed instrument. They were also, evidently, keen to keep strangers out of the workshop, and managed to do so by keeping a strict division of labour. Bidstrup emphasised the trade secrecy:

> For the most part the artists here are particularly reticent, keeping these secrets among their acquaintances, and the smaller masters keep the secrets of their own people who in turn keep many tricks of work secret from each other, and it is seldom that anyone can be found who is willing to show anything to another man.
>
> So this art perhaps more than any other is richer in intrigues than people imagine, and if you want to search for insight and artifice in it, then you must take your time undeterred by the

67. This correspondence is in Royal Library, Copenhagen: Ny Kongelig Samling 287 ii 4, translated by Claus Thykier and Anita McConnell. Bidstrup to Bugge, 6 March 1789.

68. Clifton (1995), 30 and 296.

69. Royal Library, Copenhagen: NKS, Bidstrup to Bugge, 6 March 1789.

70. McConnell (1994), 46.

first difficulties, and not trying to save money as this often clears away secrecy if you want to attain the object of your desires, and hardly anyone unless he has tried can imagine the difficulties with which this is encumbered.

So I have spent the greater part of my time on the art and becoming familiar with the artists, particularly the journeymen, which I soon learned was most useful to me; and as often as I could find time from practical exercises I have frequented the Library of the British Museum, and with Professor Torkelin visited the societies...[71]

Bidstrup was finding the whole venture expensive and insecure, hoping that the end results -setting up in Denmark and running a monopoly - would pay off, pleading that it took time to obtain the 'knowhow' of the trade. After eighteen months he wrote:

England is beyond question the only place where I can progress to be the best in my trade ... I should be reluctant to leave England, having just gained the confidence of some of the artists, something which is difficult and takes time to achieve. I was nearly 8 months in London before I came to know any artist to my advantage ... my wish is to acquire as much learning as I can, to the benefit of my native country, in compensation for the expense to which it has been put that I might be admitted to the company of artists here ...'[72]

After a year in London, Bidstrup constructed a sextant, which he forwarded to Bugge, so that it might be shown to various powerful Danish patrons, 'for I think that it would recommend me somewhat, especially as there is no-one in Copenhagen manufacturing similar instruments.'[73] He continued:

Instruments here are no longer divided by hand, unless their radius is 2 feet or more, but everything is done on machines of which there are about 3, namely: Ramsden's, Stancliffe's and Troughton's, this last being here considered to be the best, and my sextant was divided on this machine. Their owners will not permit anyone to see these machines, for fear that others should have any similar, by which they would lose their share of the advantage they have by dividing.

However, there is no witchcraft at all in the establishment of machines like these, which you may clearly see from Ramsden's description, besides I know an artist who has been a foreman with Ramsden and had there the opportunity of acquainting himself with the arrangement of his [machines]. The screw is the principal part, which to begin with you need a machine to cut, I know an artist here has offered another £50 sterling for a pair of screws (for you must have 2, one for cutting grooves in the wheel, and another for the proper screw), but he would not sell them for that...[74]

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71. Royal Library Copenhagen, NKS: Bidstrup to Bugge, 6 March 1789.

72. *Idem.*

73. *Idem.*

74. *Idem.*

Spies were clearly everywhere, and Bidstrup was keen to gain all the knowledge that he could, from whatever source.

Correspondence between Bidstrup and Bugge was infrequent, partly because Bidstrup kept hoping for an improvement in his finances: with living expenses, 'the acquisition of knowledge', and being obliged 'to provide myself with my own consumable implements like files and tools etc. which become worn and break, which brought me no small expense...', he was permanently living on the edge of debt.[75] Yet Bidstrup remained sanguine about his future: 'There are many useful things which I might acquire during my stay and acquaintances here in London which on my return would greatly contribute to my speedily becoming useful to my native country, such as patterns for casting the different instruments manufactured here ... when leaving England I should be the owner of a complete set of patterns, tools and machines necessary for an artist contemplating making himself useful in his art, but for this indeed money is required which I have not got...'[76]

Bidstrup left White in August 1789 for another workshop, run by a Mr Higgins, who was a subcontractor for both Nairne & Blunt, and George Adams, and had formerly been apprenticed to Ramsden.[77] In order to transfer from White to Higgins, Bidstrup had to buy himself out, as 'several tools being common to Mr White and myself', but this meant he now had 'a rather good, though incomplete collection of tools ... on the other hand, my time is more restricted and I can hardly manufacture anything for myself, for I must spend at least 10 hours a day in the workshop, the common rule being 12 hours...[78]

At this stage, Bidstrup intended to send back the first of the instruments he had made himself to Denmark for sale, through Bugge, the following spring. He felt he remained ignorant of only two remaining areas of London instrument manufacture, which would cost money to obtain as he would have to bribe the specialist workmen. These were:

> Dr Herschel's way of giving metal mirrors a true parabolic figure, and [John] Bird's practical way of graduating, both are kept very secret and are, as it were, quite separated

[75]. Royal Library Copenhagen, NKS, Bidstrup to Bugge, 29 December 1789.
[76]. *Idem.*
[77]. Higgins has not been identified.
[78]. Royal Library Copenhagen, NKS, Bidstrup to Bugge, 29 December 1789.

> from the remaining sections of the art, since the artists of these are occupied with nothing else, still I might be informed about it, if only I had got money to offer, since I know 2 men, after Herschel and [Edward] Troughton considered the best in London in these trades; even though I know the theory of both, and by intercourse with these people have elicited a lot, besides knowing and having been practising the Engl. way of grinding glass and that usual with metal mirrors, yet it would be preferable if I could learn and see these performed. I could soon pick up both, having already a fairly good knowledge thereof, and the knack of the art presumably lying in its practice, but alas! I do not know where to obtain or save [money] for this purpose, probably therefore I must do without, and be content with applying the theory and experience I already have in the best way.[79]

This paragraph demonstrates most clearly that despite Bird's 1767 publication of his method of hand division, this skill still had to be practically taught, and mastered by experience: the 'knowhow' for precision instruments could only be learned by doing.

A year later, Bidstrup again contacted his patron to say that he had finally left Higgins's workshop: 'finally I have become familiar with the Engl. working method in all parts of the art, only grinding mirrors with a parabolic shape I have not dared to commence because of the accompanying not inconsiderable expense...'[80] Bidstrup was by now in such debt that he asked for more money, otherwise he would be obliged to sell the equipment he was hoping to bring back with him to Denmark:

> Since the beginning of last year ... I have over time amassed a not inconsiderable assortment of models, tools and machines which are all specific to the art and which are for the most part not available in Denmark. These and others, up to a complete set, it would be useful for me to send home before leaving England, by which I should save much time and expense, for should I be unable to begin to procure these things until I returned, it would be some time before I could be active, since conveying them here would involve time and expense. Obviously I should need support until I could improve my acquired knowledge, for it stands to reason that even the handiest artist cannot accomplish anything without the requisite models, tools, etc.[81]

By 1793, Bidstrup had set up in business just off Leicester Square, and a copy survives of his *Catalogue of Optical, Mathematical & Philosophical Instruments...*, running to eight pages.[82] Judging by the difficulty he had had in selling those few instruments which he had made already,

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79. *Idem.*
80. Royal Library Copenhagen, NKS, Bidstrup to Bugge, 31 December 1790.
81. *Ibid.*
82. In the Bodleian Library, Oxford; Anderson et al., (1990), 12.

those listed must have been instruments which he could buy in for resale rather than those he would have made and had in stock. Christensen has recounted how Bidstrup's entire endeavour then went horribly wrong: despite his country's continuing but stinted financial support (partly engendered by suspicion of his motives), Bidstrup was unable to acquire quickly enough what he considered a viable array of basic tools to set up a Danish instrument enterprise. These were: a dividing engine, a tube-drawing machine with steel cylinders, and a glass-grinding machine with steel cups. Although he finally managed to do this, and to smuggle them successfully out of the country and to safety in Copenhagen in 1798, after years of debt and worry, he became seriously ill. Bidstrup was hugely in debt to the Danish government, which meantime built him workshops, just as his patron Thomas Bugge left for Paris: Jesper Bidstrup died in 1802, without having begun the enterprise to which he had devoted his life. His workshops, tools and all belongings were claimed as state property, and taken over by his more fortunate compatriot Jeppe Smith, who thus acquired ready-made and up-to-date equipment, and was able to produce instruments, but for the Danish domestic market only, up to his death in 1821, after which the firm was continued to 1855 by his nephew. Any hard-won first-hand 'knowhow' was lost.[83]

In this instance, technology transfer through industrial espionage for the instrument industry was not particularly successful, partly through the resistance of the London trade to part with its secrets, and partly because of the nature of those secrets. Denmark's indigenous instrument industry over the next century helped serve a local market only, but quantities of apparatus continued to be imported. Inkster has pointed out that it was 'not... the transfer of scientific knowledge, or of machines and skills [which] determined the industrialization of receiver nations in the eighteenth century ... the mere possession of a technology or set of technologies is not a sufficient explanation of the industrialisation process.'[84] It was no trivial task to transfer the secrets of the precision instrument trade out of London: an observation as applicable for provincial England as it was for foreign competitors. Yet the manuscripts which describe the attempts of Bugge and Bidstrup, all highlight aspects of an industry, which, as described in chapter 1, has left little record of its day-to-day workings, and as such are invaluable detailed information, unobtainable elsewhere.

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[83]. Christensen (1993), 225-6; for Jeppe Smith, see Andersen (1994).
[84]. Inkster (1991), 59.

Other glimpses into the day-to-day running of a London instrument-maker's workshop at this period are difficult to find. One illustration - an exceptional portrait of the eminent optician John Cuff, in his working clothes in his workshop, by Johan Zoffany, dated 1772 - quite literally gives an idea of just how small and cramped the workspace of an instrument maker might be.[85] It also demonstrates how very different the working styles of the distinct types of instrument maker could be: here the optical worker Cuff constructs lenses, which are small and precious, and are therefore carefully contained, and he assembles instruments individually, matching the optical components. This is very similar to the watchmakers' practise, but necessarily very different from that of the precision instrument makers, especially Ramsden.

A rare manuscript survival is the daily accounts of John Smeaton's workshop between September 1751 and February 1752, and these demonstrate the variety of work within such a business, which was more broadly-based than that of Cuff, and its hierarchy - Smeaton employed three, subsequently four workmen, each doing differently-skilled, and therefore differently-paid work, during a six-day week.[86] Smeaton had come from Yorkshire to London, where he studied law before turning to instrument-making, and from that to civil engineering.[87] At this period, the origins of the most skilful of the London instrument-makers was provincial: examining the eight names chosen by J.A. Bennett as the élite makers of the 'heroic' period of London instrument making - the mid- to late-eighteenth century - Jonathan Sisson came from Lincolnshire, George Graham and Edward Troughton from Cumberland, John Bird from Durham, Jesse Ramsden from Yorkshire, James Short from Edinburgh, Edward Nairne from Kent, and only the Dollonds appear to have been Londoners, and they were of comparatively recent Huguenot origin. The links - through apprenticeship, through business and in some cases, through family - between these individuals once they reached London, were close, and Bennett has made the point that these makers had similar career patterns, centred around the patronage of three institutions - the Royal

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85. This portrait is in the Royal Collection, and has been reproduced in Porter et al., (1985), 27; Morton and Wess (1993), 98. Discussed in Millar (1969), 152; Webster (1976), 55-6.

86. Institute of Civil Engineers: Mss. Smeaton, Private Letter Book for 1764: see Skempton (1981), 239.

87. For Smeaton, see Skempton (1981). Smeaton worked as an instrument maker between 1748 and 1752.

Observatory, the Board of Longitude and the Royal Society.[88]

The mid-nineteenth century London instrument-making trade

Finding contemporary descriptions of the instrument trade is always difficult: and for the mid-nineteenth century London trade this is particularly so, because the status of the maker had changed considerably. No longer did foreigners come to marvel at the craftsman's workshop. This was convincingly argued by J.A. Bennett: 'a revised relationship between scientist and instrument maker became more common, in which leading scientists became intimately involved in instrumentation - George Airy and William Thomson [Lord Kelvin] are important examples - and makers were reduced to contributing their technical skills alone.'[89] His discussion of the changes in the structure of the broader scientific community, shows that its effects were being felt in the trade more generally than at the individual interface between scholar and craftsman: the industrialisation of society had left the instrument trade behind, as there was a general neglect of the science education necessary to keep it in touch with new requirements. This is reflected in the brave words in the Introduction to Class X in the *Illustrated Catalogue of the Exhibition of all Nations* ... (London, 1852):

> Regarding this Class as representing the culminating point of mechanical skill, it forms an appropriate conclusion to those devoted to machinery generally. Delicacy and precision of workmanship are absolutely requisite in the industry occupied in producing philosophical apparatus. It will be found, on inspection, that the genius of this country, so remarkably developed in mechanics applied to commercial purposes, is not less successful in its application to the higher pursuits of experimental and practical philosophy.[90]

These remarks belied the outcome of the Exhibition, which, as Bennett has commented, showed unexpectedly that for the host country 'a careful look at the awards of Council Medals at least - remembering that these were intended primarily to reward originality - would have suggested that the lead in developing the traditional areas of manufactured scientific instruments might be slipping away from Britain.'[91] In a careful examination of the outcome of Class X, Bennett has shown that Britain put on a proportionally large display, and thus apparently won most of the prizes: 16 out of the 31 Council medals. However, seven of these were in the newly developed

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[88]. Bennett (1985), and Porter (1985).
[89]. Bennett (1985), 25.
[90]. *Catalogue*... (1852), 405.
[91]. Bennett (1983), 4.

areas of telegraphy and photography, outside the traditional areas of instrument-making, and of the remaining nine medals, 'four were for rather special pieces of apparatus, or "inventions".'[92] In fact, the remaining five Council medals were awarded in 'traditional' areas, and all but one to makers based in London, the exception being Chance Brothers of Birmingham, for the large disc of optical glass discussed earlier. John Newman won his medal for an air pump and a tide gauge; that of Ludwig Oertling, a recent immigrant from Berlin, was for his balances; Andrew Ross and Smith & Beck won theirs for their microscopes.[93]

Looking again at the London exhibitors, it is clear that individual firms had become more specialised than their counterparts in the mid-eighteenth century. There were distinct 'microscope makers', such as Andrew Pritchard, Andrew Ross and Smith & Beck; but in the area where London had previously excelled, it was clear that the Germans now produced better precision astronomical instrumentation, and the Americans were more innovative in their design: both nations won Council Medals. The most successful competition was coming from abroad, but the provincial instrument makers were clearly seeing their way by this time to bypassing the London market on their own account. After the stimulus of the Great Exhibition, makers outside London were prepared to produce catalogues of their products, advertise to a broader market, and, in the case of at least one Sheffield manufacturer, engage agents in London and New York.[94]

As Bennett commented, 'the idea that the exhibition in Class X could of itself do much to increase the scientific and technical expertise in manufacturing industry was short lived'. However, it awoke a complacent government to the real state of affairs, by demonstrating, not just in Class X, 'the fast-growing capabilities of Britain's European rivals and the suggestion that their success was due to the provision of scientific and technical education that Britain lacked.'[95] Although superficially a triumph for British industry, the Great Exhibition provided confirmation for the 'decline of science'; nonetheless, the spur for educational reform necessary for the country to

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[92]. *Ibid.*, 3.
[93]. *Reports...* (1852), 262, 258, 266; Bennett (1983), 4.
[94]. J.P. Cutts, Sutton & Son of Division Street, Sheffield, advertised an agency at Hatton Garden, London in the 1852 local directory, and one in Pearl Street, New York in 1854. The role of agents will be discussed further in chapter 5.
[95]. *Ibid.*, 11.

maintain its lead acquired by being the first industrial nation was not to be set in train until the 1870s.

W. & S. Jones as a 'representative' London instrument making firm

There was one substantial London firm of instrument makers which survived for much of the period of the Industrial Revolution: this was the business begun in 1759 by John Jones (1737-1808) and subsequently run by his sons, the brothers William (1762-1831) and Samuel Jones (1770-1859). Between about 1780 and 1855, they published many different lists of the goods which could be obtained from them, and, as one would expect, the compilation of these varied over time [Table 3:5].[96] W. & S. Jones were by no means the first instrument suppliers to publicise their wares in this way - John Prujean's *Catalogue of Instruments* dates from 1701,[97] and the example of the arch-publicist Benjamin Martin provided the Jones brothers with contemporary inspiration[98] - but the range and scope of their catalogues provides detailed evidence of how the firm attempted to reach a broad spectrum of customers. The first 'big break' for the Jones business came in 1782, as a result of Benjamin Martin's bankruptcy, death and the subsequent sale of his business. A second, perhaps even more important boost came in 1795/96 as a result of the death of the younger George Adams, and the subsequent sales of his effects by his wife Hannah. No specific evidence has been found by John Millburn to indicate that the Jones brothers purchased any instruments at either the Martin or Adams sales; but, at the very least, their business must have benefited from the reduced competition after the closure of two of the largest and apparently most successful contemporary London instrument suppliers.[99]

The Jones brothers were able to secure the copyright of the influential scientific and mathematical textbooks written by George Adams: from 1797 onwards each of these popular Adams works had catalogues and price lists of instruments supplied by W.& S. Jones bound in the back of every volume. As a form of advertising, this appears to have had considerable success, since the Joneses sold the instruments that Adams described, and 'puffs' for Adams' books even

96. Anderson et al. (1990), 43-44, gives a brief preliminary listing, which is problematic and incomplete.
97. *Ibid.*, i, 65; discussed further by Bryden (1993).
98. Millburn (1986b) compares three of Martin's listings: 1757, 1765 and c.1780.
99. Millburn (1976), 178-80; Millburn (1986b), 75.

	Date	phil.	math.	opt.	Instruments of Recreation	Philosophical Chemistry	ast.	total
[John]	1784	27	17	46		-	-	90
1	[1793]	112	56	86	29	-	-	283
2	[1794]	133	60	100	30	19	-	342
3	[1795]	109	64	107	25	15	25	345
4	[1797]	109	65	107	25	17	26	349
5	[1797]	110	64	107	22	15	33	351
6	[1797]	110	64	107	22	15	33	351
7	[1800]	112	63	103	22	15	33	348
8	[1801]	116	63	103	20	16	34	352
9	1804	117	61	103	20	16	34	351
10	1805	117	61	103	20	16	34	351
11	1810	117	61	103	19	16	34	350
12	1811	117	61	103	19	16	33	349
13	1814	141	82	117	--	32	38	410
14	1814	141	82	117	--	32	40	412
15	Nov.1817	145	83	120	--	33	42	423
16	Jan .1818	145	83	120	--	33	42	423
17	Oct. 1825	145	84	118	--	33	43	423
18	Aug. 1827	150	86	121	--	33	43	433
19	1830	150	84	123	--	34	44	435
20	1835	151	84	123	--	34	44	436
21	1836	150	85	124	--	34	44	437
22	1838	150	84	124	--	34	44	436
23	1843	220	92	130	--	48	42	532
24	1850	223	101	133	--	48	42	547
25	1855	221	99	131	--	48	41	540

Table 3:5 Analysis of contents of W.& S. Jones trade catalogues, c.1780-1855, showing breakdown of content by subject, according to their category.

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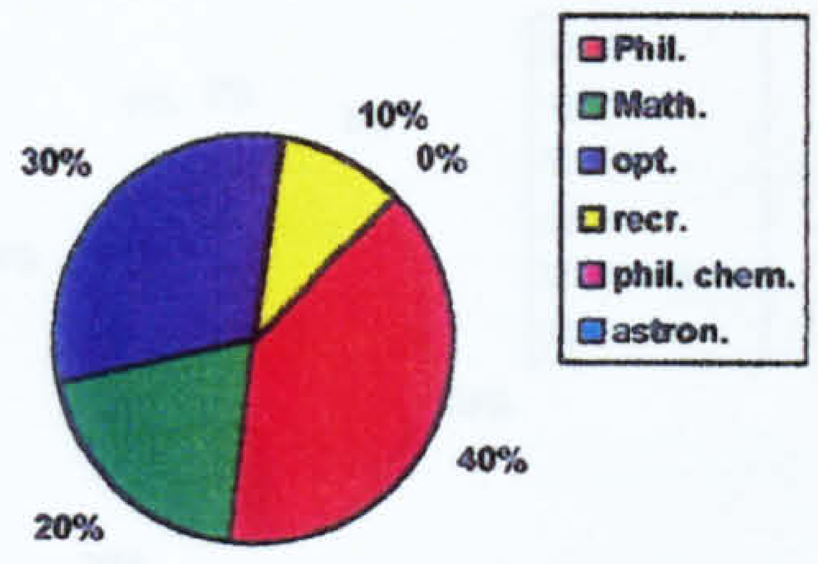

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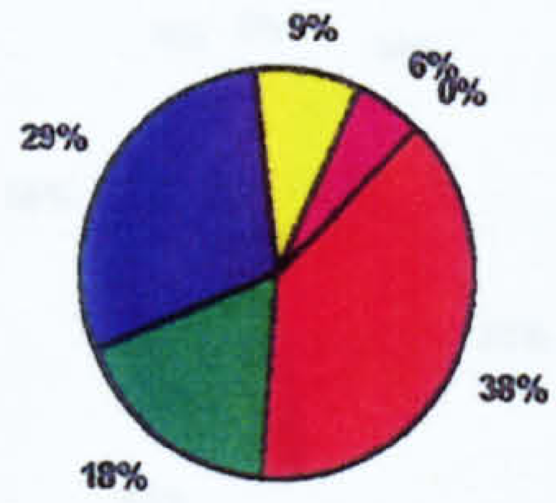

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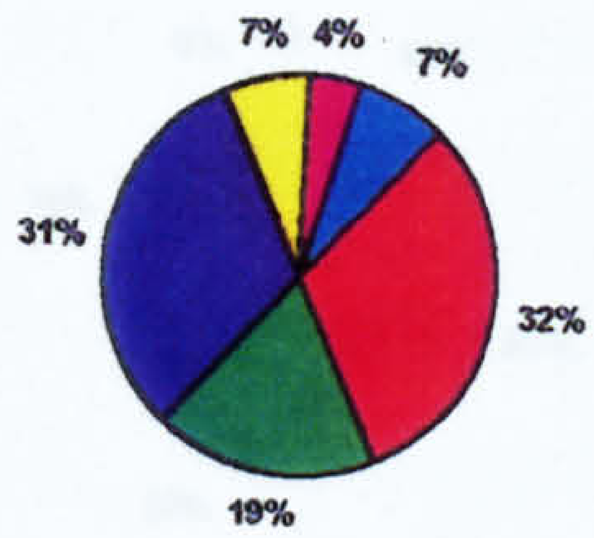

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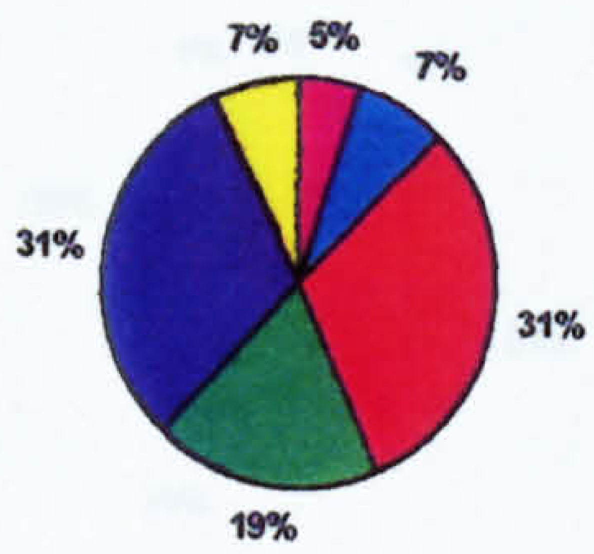

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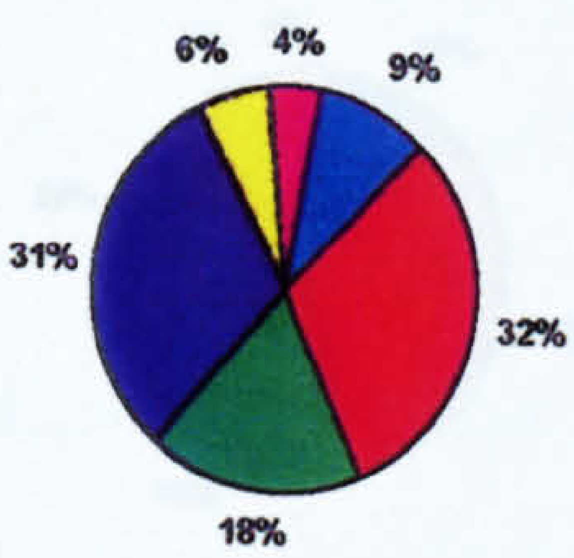

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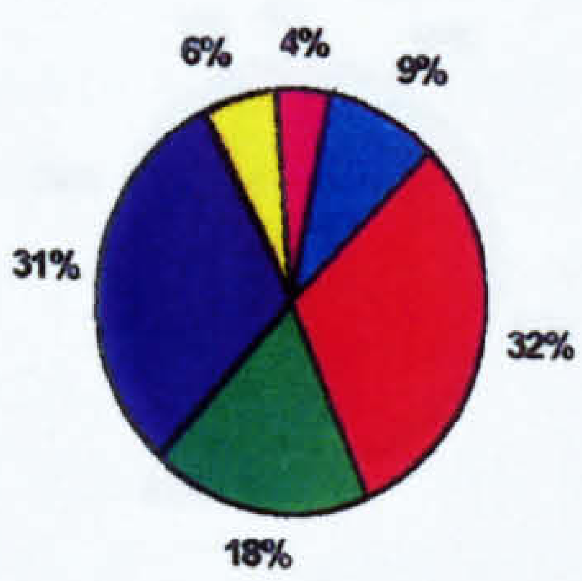

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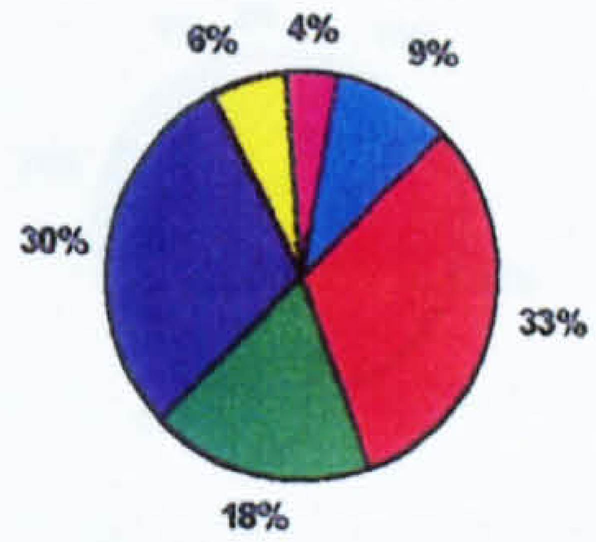

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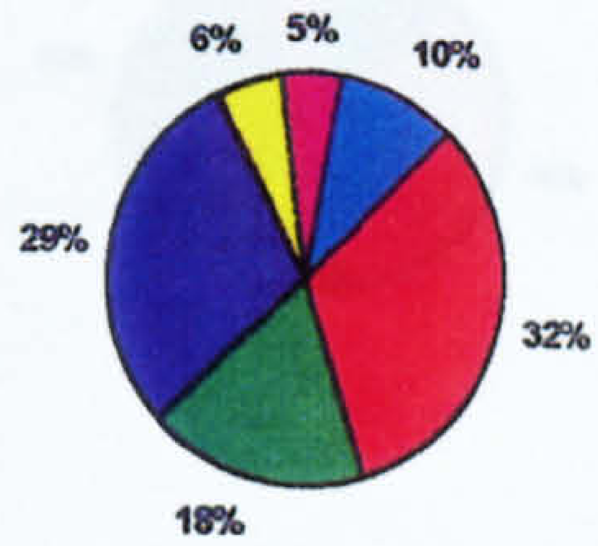

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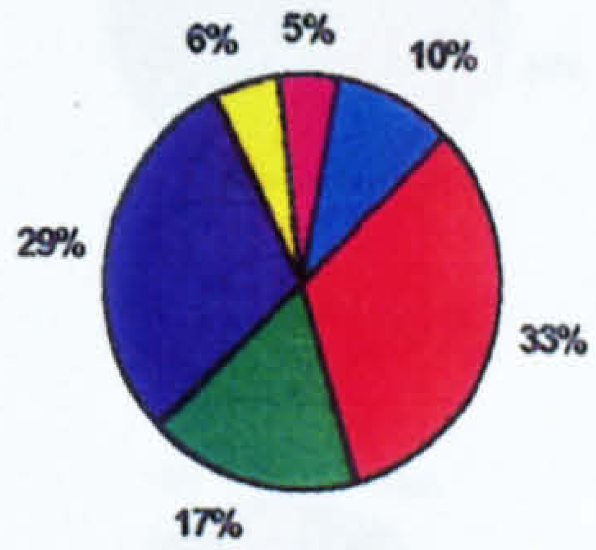

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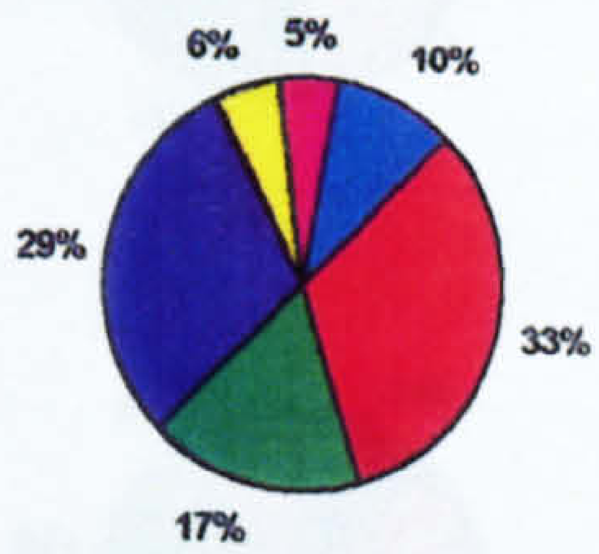

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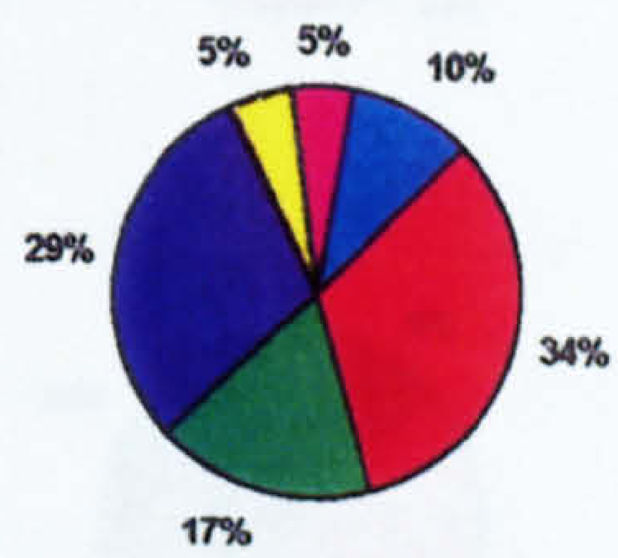

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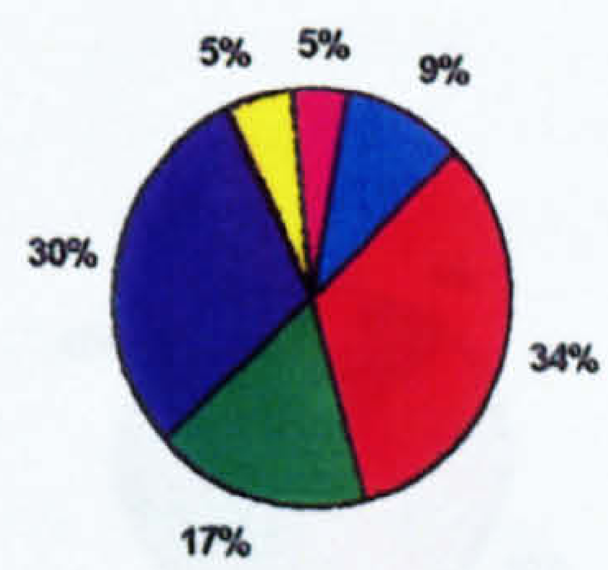
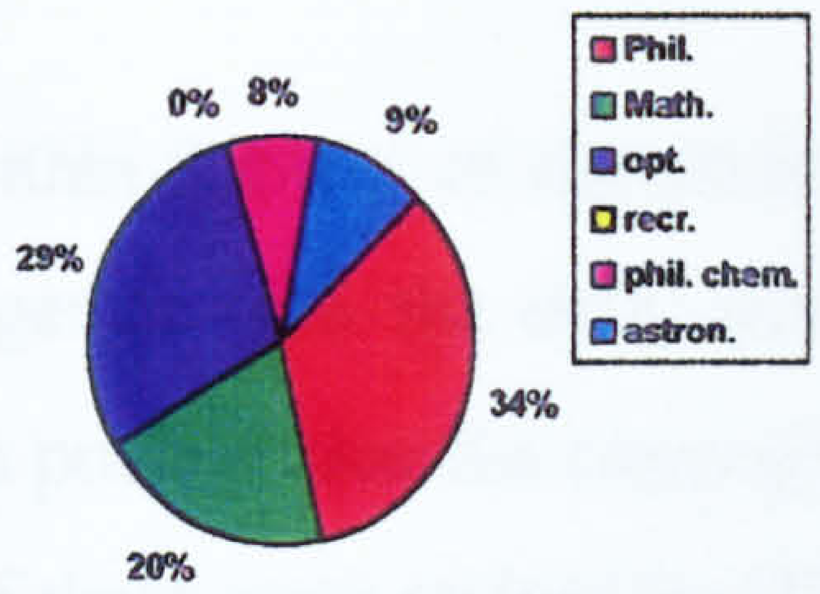


Phil. Math. opt. recr. phil. chem. astron.

13.



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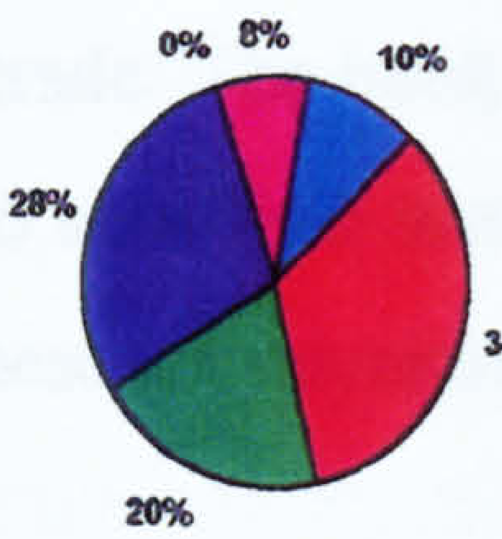

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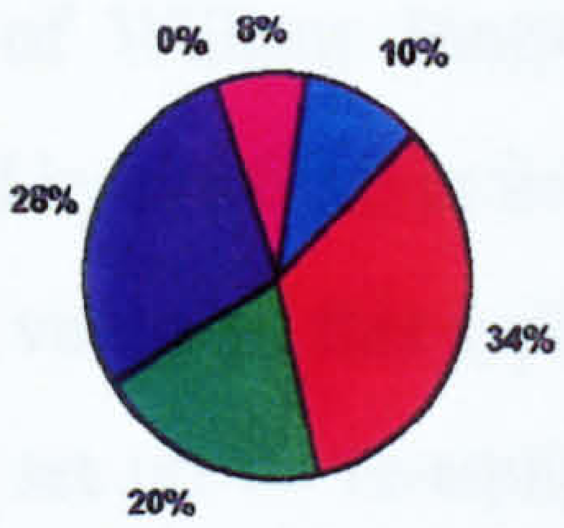

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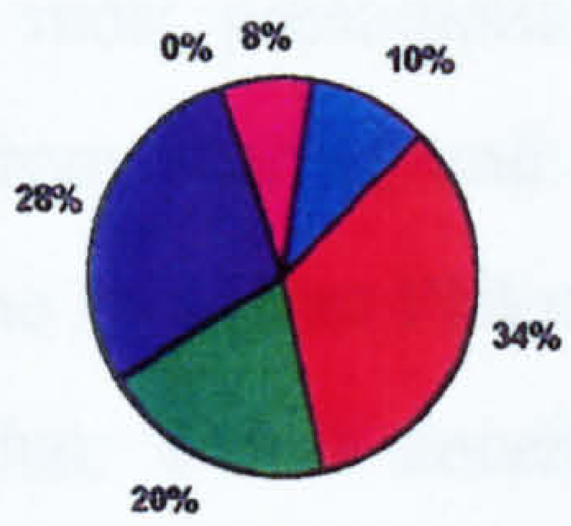

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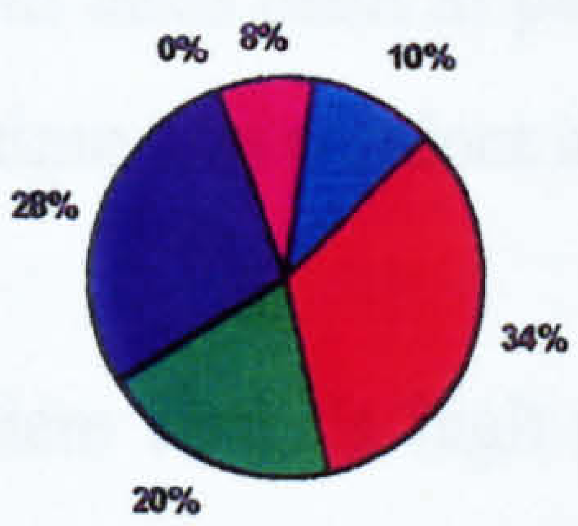

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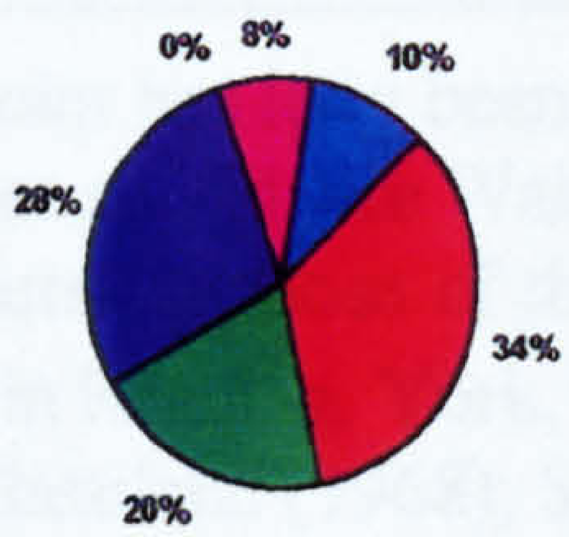

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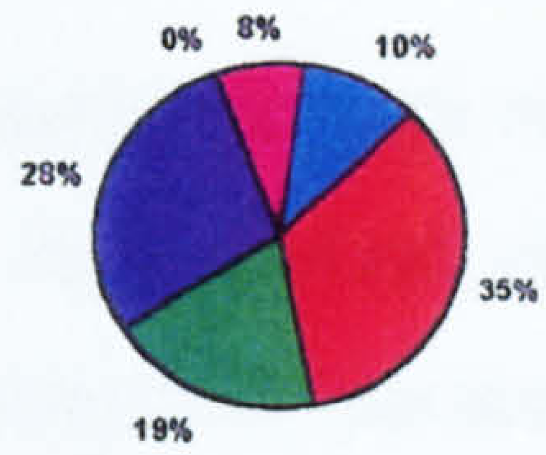

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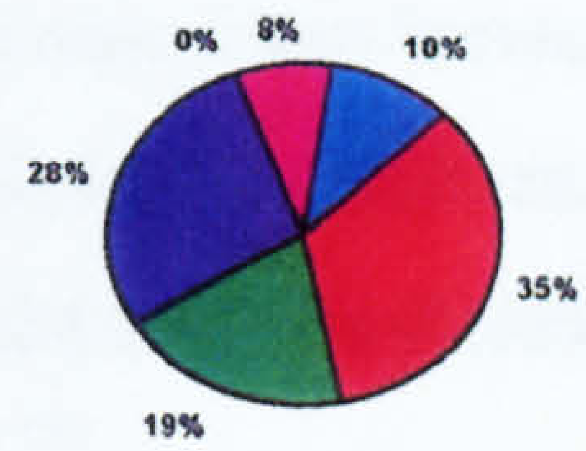

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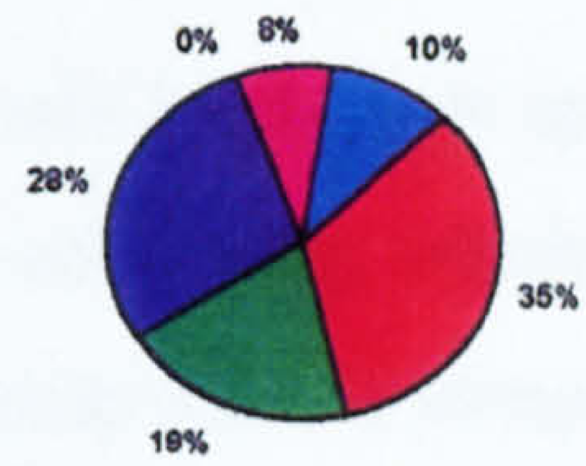

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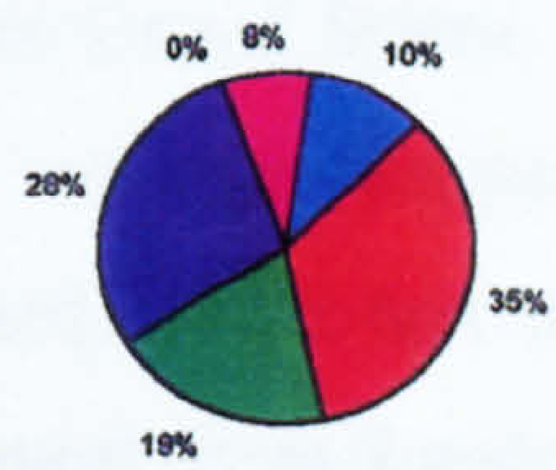

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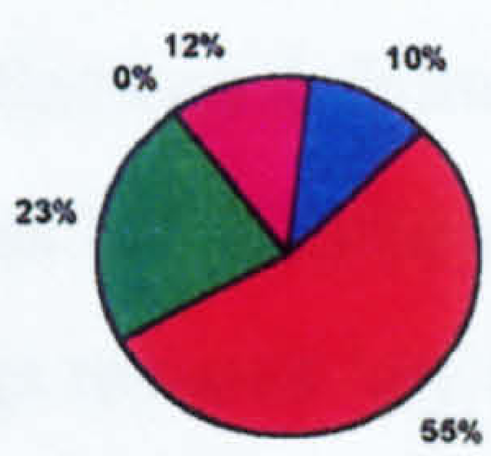

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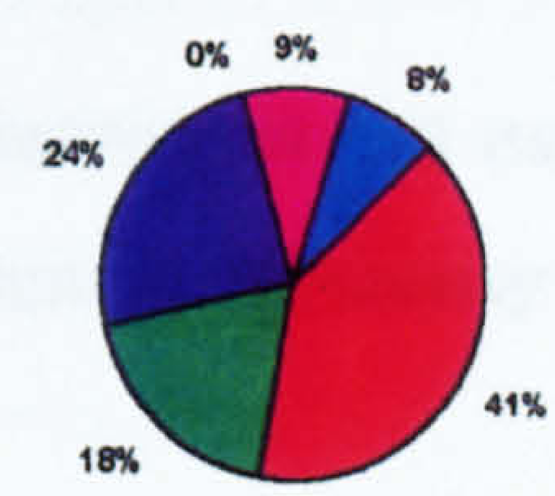

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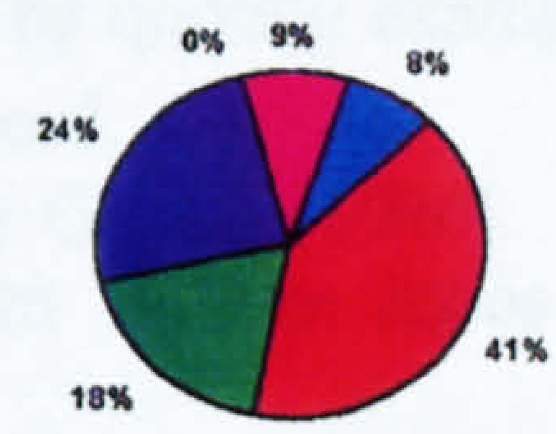


appeared within the text of the catalogues. All the illustrated plates were now marked 'W.& S. Jones...' together with the date, while the inscriptions on the advertised objects read 'W.& S. Jones'. It is possible that the copyright of Martin's popular textbooks was also purchased, because a number of these were revised by William Jones, and W.& S. Jones catalogues are bound in with them. There has been over the centuries a long and fruitful connection between printing and the instrument trade. The book trade's long-established networks into the provinces enabled London publishers to send their wares to be sold all over England, and instrument makers and sellers had long used these communication lines out from the metropolis.[100]

There is nothing to indicate that the Jones business was in any way special until, through the action of William Jones, it bought itself a form of advertising which laid its products, standardised by the firm, in front of customers it wished to dazzle with the comprehensiveness of its wares. The virtue of this type of marketing was that it enabled educational establishments which were being set up or re-equipped, particularly in the eastern United States, to purchase by mail order, a complete range of apparatus from a single supplier: 'one-stop shopping' it might be called today. The most prestigious of these colleges was Harvard, which had previously purchased apparatus from Martin, and continued to buy new equipment from London.[101] William Jones presented the American Philosophical Society, based in Philadelphia, with a pair of globes in 1799, remarking that: 'I am a sincere friend to all philosophical institutions & from much encouragement received from Americans am happy to make them these small but grateful acknowledgements.'[102] This seems to have been in part because of his warm feelings towards 'my friend Dr Priestley',[103] who at this time was resident in New York.

William Jones's high profile approach through advertising in this manner, together with private teaching and public lecturing in London 'introduced him to the society of the most eminent

100. This point has long been understood: see Taylor (1954); and for a more recent assessment of a slightly later period, see Walters (1992), in which she ably demonstrates that instruments followed the same routes as those of the long-established book trade, by quoting examples of sales by such booksellers in Reading, York, Liverpool and Berwick-on-Tweed.
101. See Wheatland (1968); Schechner (1982) and Schechner Genuth (1996).
102. American Philosophical Society Archives: Letter from William Jones to John Vaughan, Secretary, 24 June 1799.
103. *Idem.*, 3 November 1795.

mathematical and astronomical professors of the time, Drs. Priestley, Hutton, Maskelyne, Professor Vince and others',[104] his obituary noted. In turn, W.& S. Jones offered the works of these authors for sale in their catalogues. William Jones's own publications were fairly extensive, even aside from his editions of the work of others. He wrote several pamphlets about instruments, which ran to a number of editions, three articles about optics in *Nicholson's Journal*, and contributed to both the *Encyclopaedia Britannica* and Abraham Rees's technical *Cyclopaedia*. All of these opportunities were used to mention and thus promote apparatus which could be supplied by W. & S. Jones.

It is not known how large the Jones's workshop was at any point, although a number of individual subcontractors have been identified: most dramatically William Stiles, the workman who concealed his name inside the globe of a specially-commissioned Bohnenburger gyroscope, a demonstration device ordered for a wealthy American collector, Charles Nicholl Bancker.[105] In his Will, William Jones named 'William Russell our Assistant' and 'John Norton, our Under Shopman' as beneficiaries. Other workmen have been identified as William Eden, between 1818 and 1827; William Chitty, perhaps between 1834 and 1835; and John Dillon, probably a first cousin, in 1844.[106] By the time of Samuel Jones's death in 1859, his Will showed that between them the brothers had accrued considerable property and capital. Their only named relatives were female cousins, and the effects of the business were sold over four afternoons from 30 April 1860, comprising 714 lots.[107] Of Bidstrup's three tools essential for precision instrument making, none were mentioned, confirming that W.& S. Jones used the subcontractors scattered around workshops throughout London and possibly beyond. One lot was described as a '5-feet finely divided brass *Standard Scale*, by [John] *Bird*, with vernier and adjustments complete. N.B. In a Committee of the House of Commons upon Weights and Measures, this Instrument was used by them and highly prized, and has since been much desired to be purchased by the late James Bailey, Esq., the President of the Royal Astronomical Society.' Another was given as 'a large quantity of patterns in wood, various', and a third 'expensively made wood patterns for telescopes': these and other items demonstrate that some assembly and finishing of instruments took place in their

104. Anon (1831).
105. Simpson (1993) and (1995).
106. PRO PCC PROB/11/1784 Q.222: William Jones's Will; Clifton (1995), 155.
107. Samuel Jones's Will; Hammond (1860).

workshops.[108]

The trade catalogues of W. & S. Jones reveal no printer's name until the firm moved to No. 30 Holborn in 1800, and that year they were marked 'Dillon, Printer, Plough Court, Fetter Lane'. Fetter Lane is a street running off Holborn, and the Joneses appear to have had some financial stake in this nearby printing business: the brothers' father John Jones had married an Elizabeth Dillon. However, between 1801 and 1838 (after William's death), all W.& S. Jones catalogues were printed by William Glendenning of 25 Hatton Garden, master printer; but from 1843, these were printed by George Dillon of 77 Hatton Garden, premises mentioned in Samuel Jones's Will.

Some twenty-five different versions of W.& S. Jones's catalogues have been traced, spanning the years 1793 to 1855, and there may well be further variants. Comparison of the individual catalogues shows variation of layout and content, and also some price fluctuation. The W.& S. Jones catalogues, by and large, consisted of fourteen pages of instrument and book details, with a further two pages advertising books, in particular those by George Adams edited by William Jones. Over the years, the number of instruments in each category varied (as Table 3:5 shows), moving from just under 300 to 540. Prices of individual items remained relatively stable, despite war and recession [Table 3:6]. The cost implications of printing amendment sheets have to be considered, but having a printer in the family must have been useful. Often a new line of type appears to have been squeezed into existing text. The arrangement with Glendenning between 1801 and 1843 is unclear, but it is conjectured that members of the Dillon family worked for Glendenning during this period.

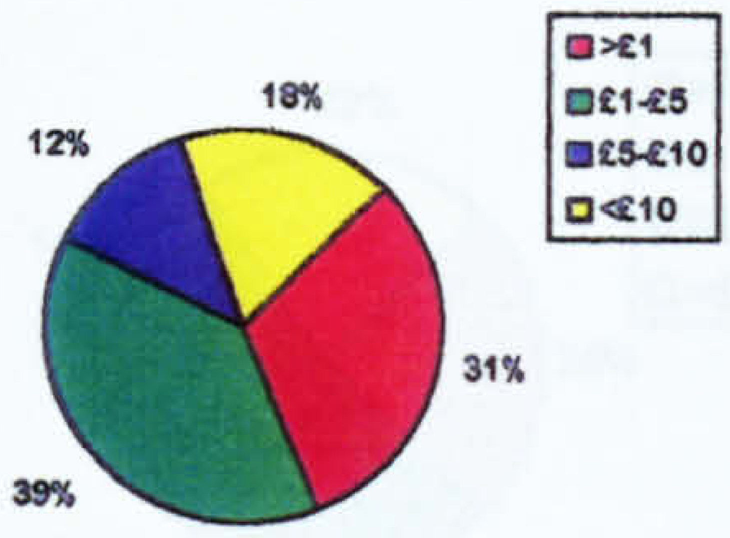
Briefly, to characterise the contents of the catalogues over time: in 1794, the final two pages of the Jones brothers' catalogue were dedicated to 'secondhand instruments', but of a particularly high quality. This was material bought, after his death, from the collection of John Stuart, third Earl of Bute. In fact, as Gerard Turner has pointed out, W.& S. Jones were chosen to draw up the descriptions in the auction catalogue, and they subsequently purchased thirteen of the lots, totalling £206 3s 6d.[109] It is evident from the sale of the business in 1860 that good

108. Hammond (1860), lots 90, 667 and 668.
109. Turner (1967).

	Date	<£1	£1-£5	£5-£10	>£10	total
[John]	1784	16	36	14	24	**90**
1	[1793]	89	109	35	50	**283**
2	[1794]	107	128	45	62	**342**
3	[1795]	104	129	44	68	**345**
4	[1797]	105	129	44	71	**349**
5	[1797]	106	129	45	71	**351**
6	[1797]	106	130	43	72	**351**
7	[1800]	105	125	46	72	**348**
8	[1801]	107	129	45	71	**352**
9	1804	103	131	45	72	**351**
10	1805	103	131	45	72	**351**
11	1810	104	128	44	74	**350**
12	1811	103	128	45	73	**349**
13	1814	101	155	67	87	**410**
14	1814	101	153	67	91	**412**
15	Nov.1817	101	162	65	95	**423**
16	Jan.1818	101	162	65	95	**423**
17	Oct.1825	100	157	72	94	**423**
18	Aug.1827	101	165	70	97	**433**
19	1830	101	166	71	97	**435**
20	1835	103	164	69	100	**436**
21	1836	101	165	69	101	**437**
22	1838	104	163	81	88	**436**
23	1843	118	216	81	117	**532**
24	1850	120	226	80	121	**547**
25	1855	119	219	78	124	**540**

Table 3:6 Analysis of contents of W.& S. Jones trade catalogues, c.1780-1855, showing breakdown of content by price.

1.



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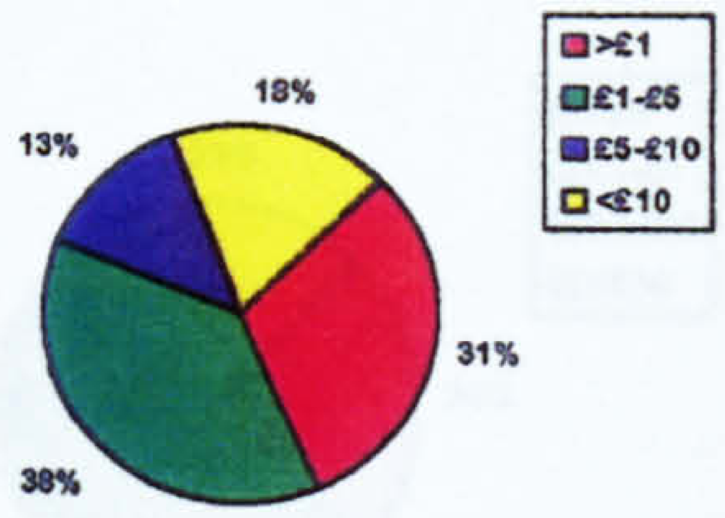

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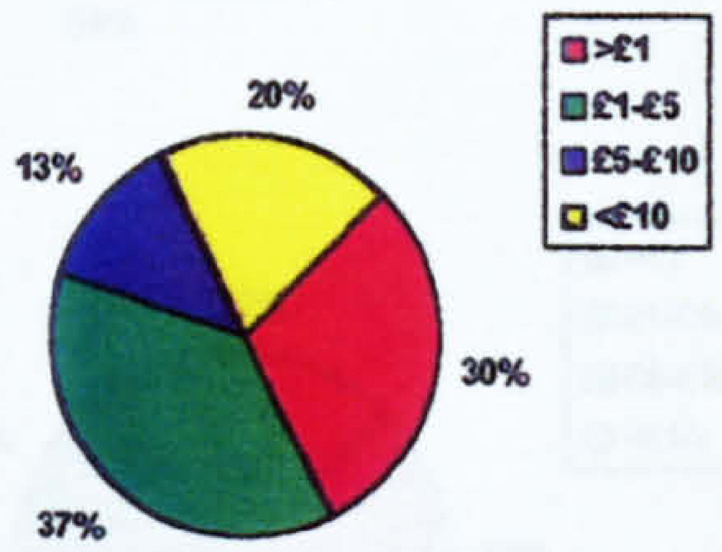

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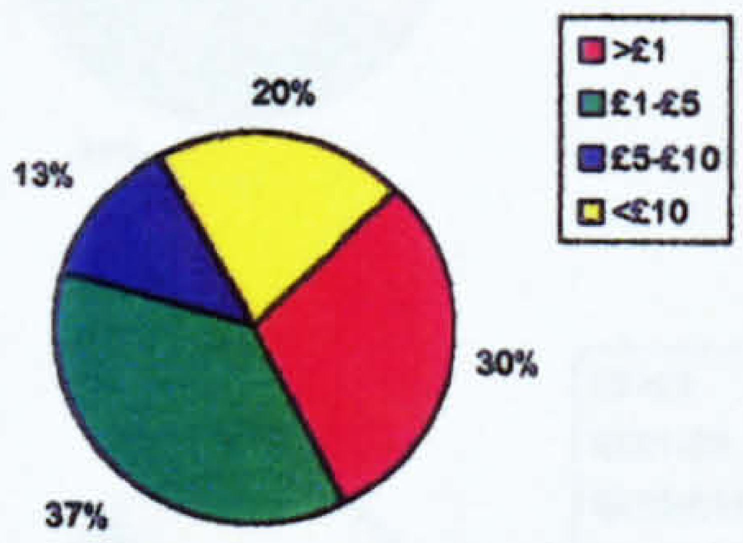

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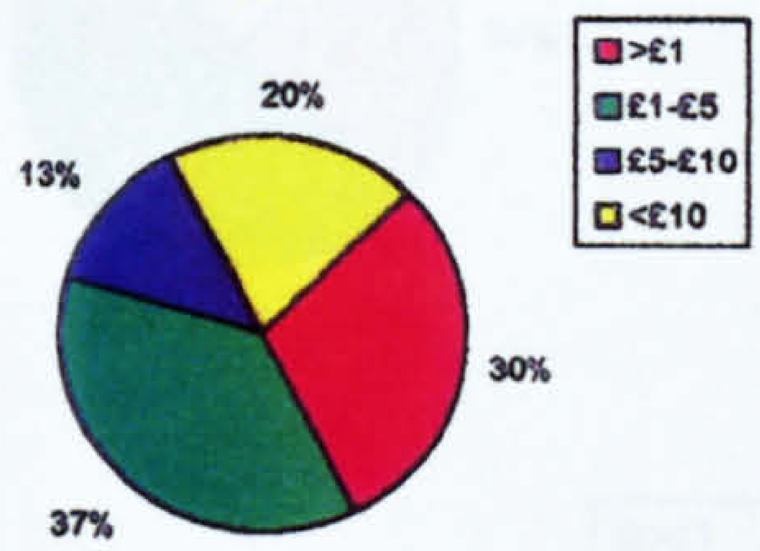

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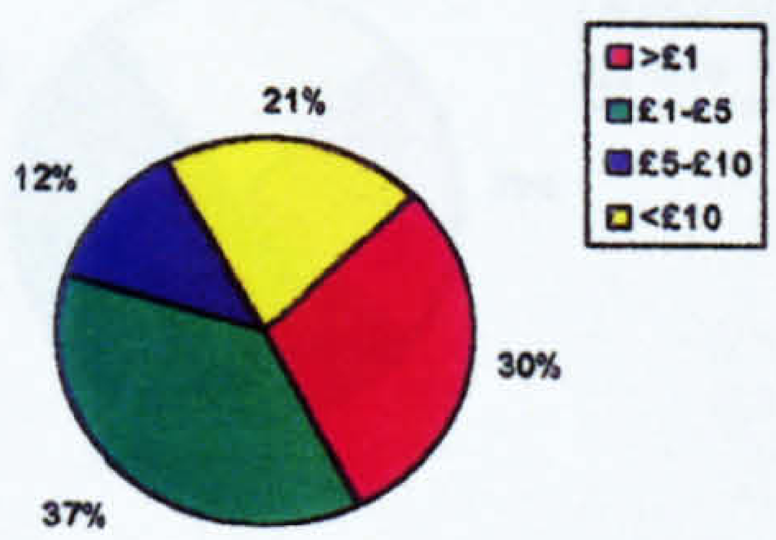

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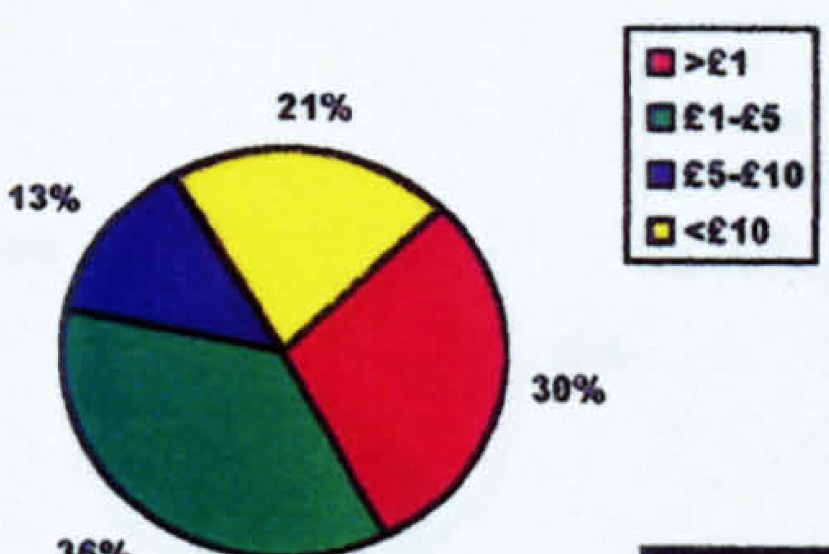

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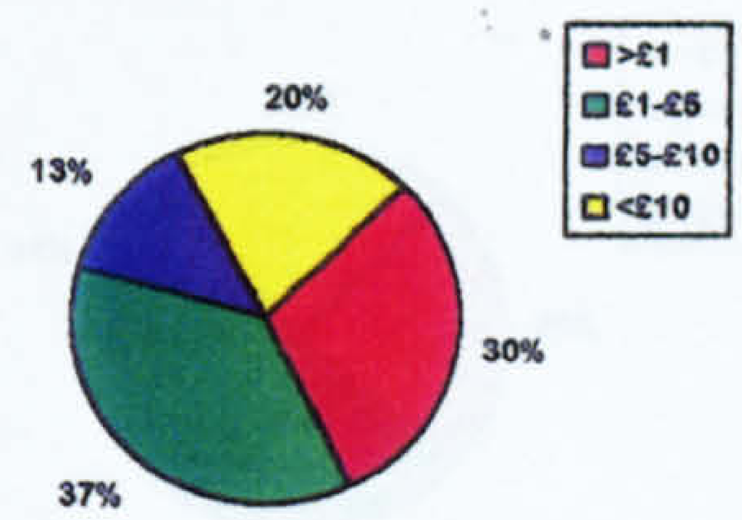

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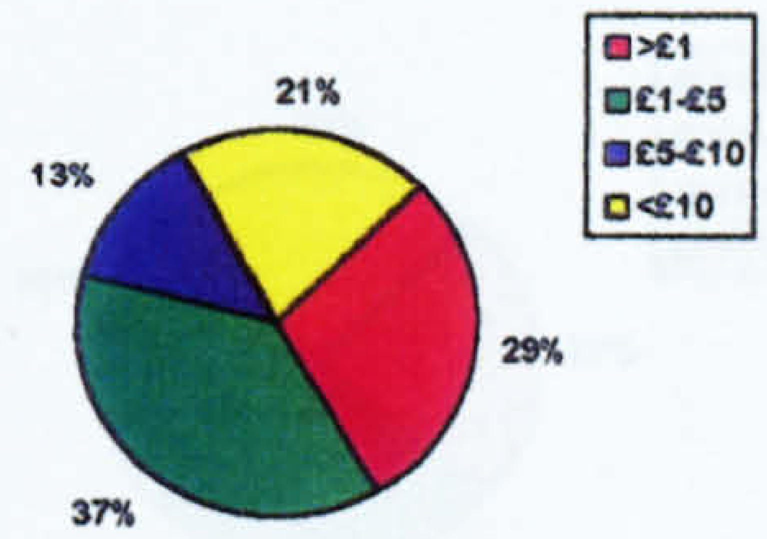

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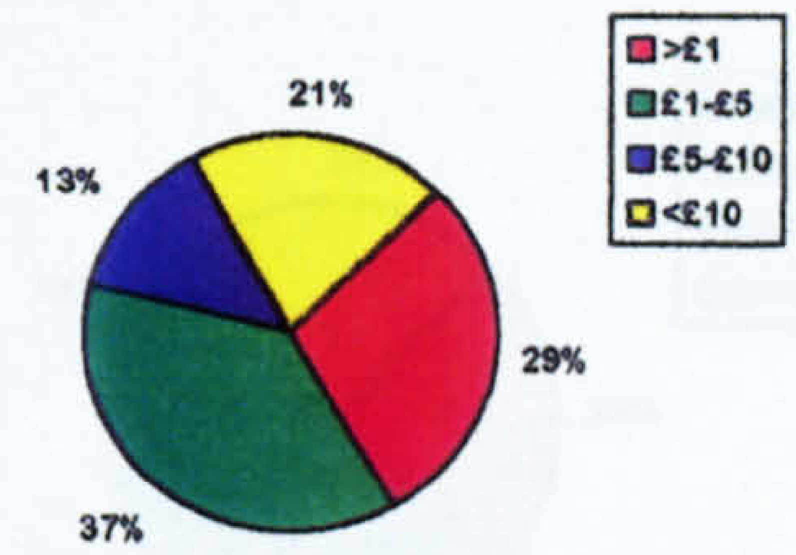

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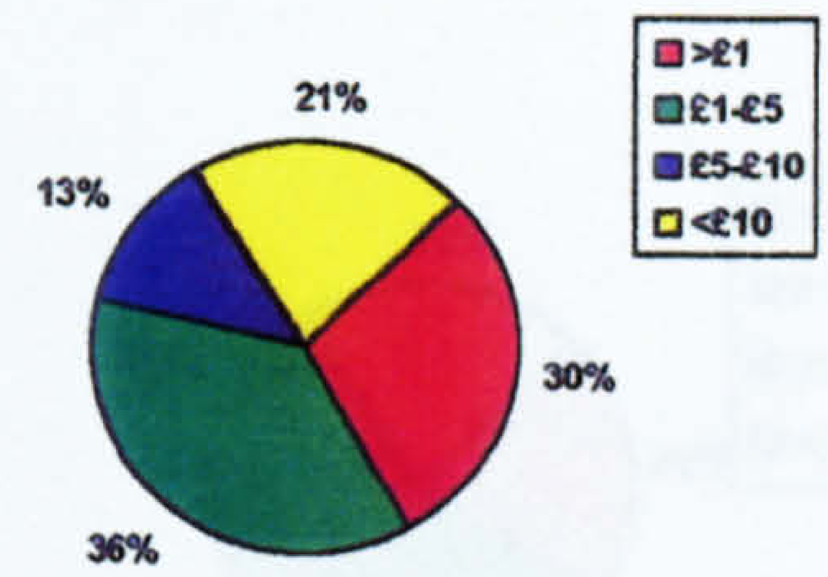

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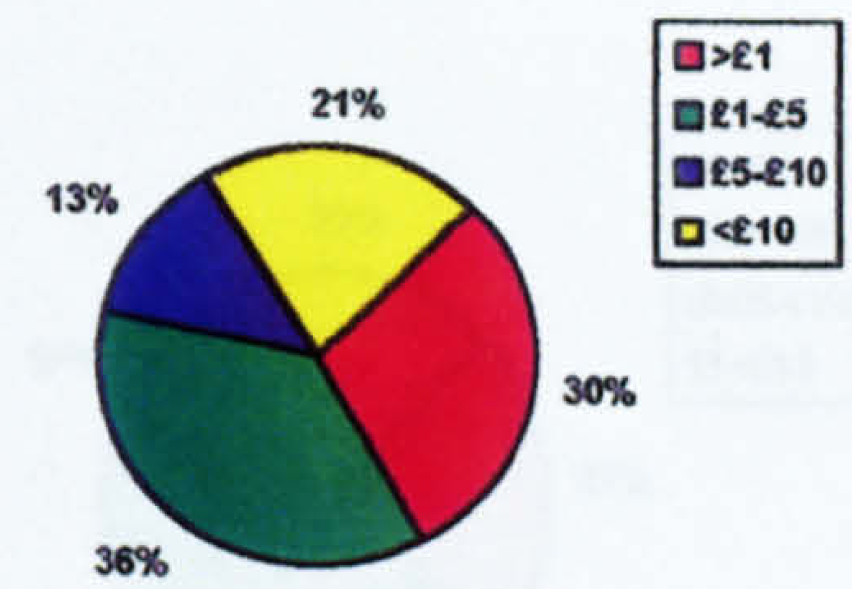

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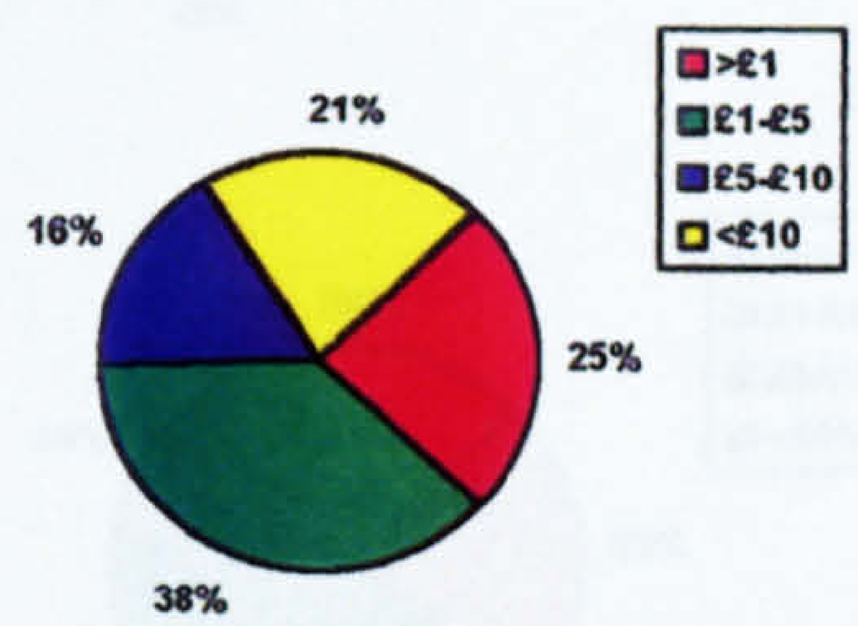
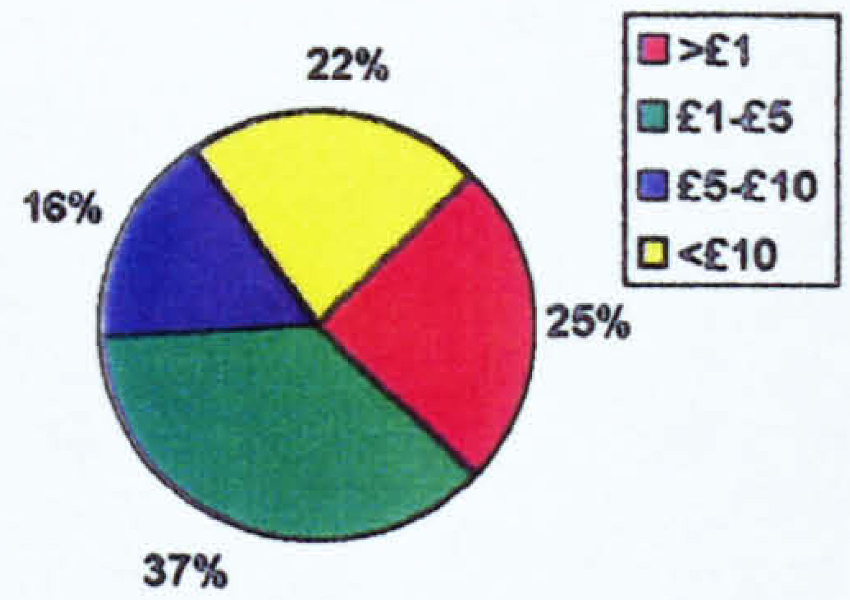


<£1 £1-£5 £5-£10 >£10

14.



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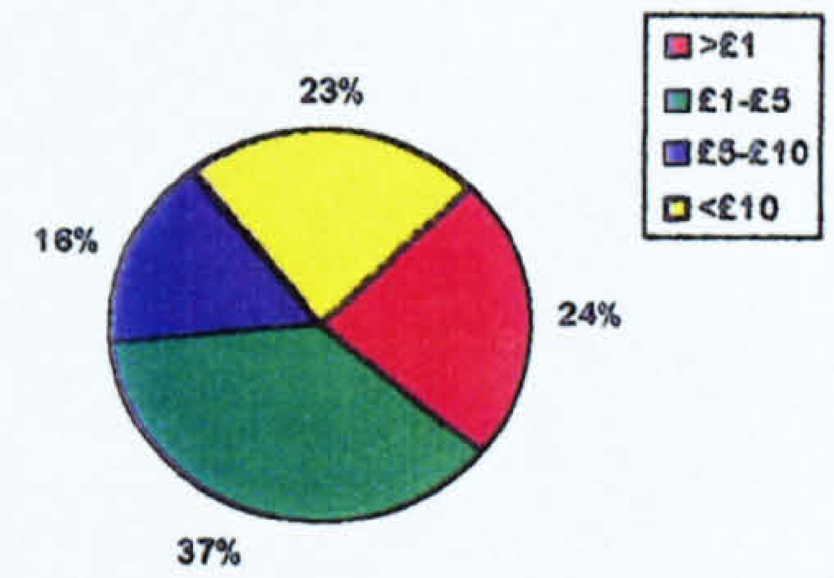

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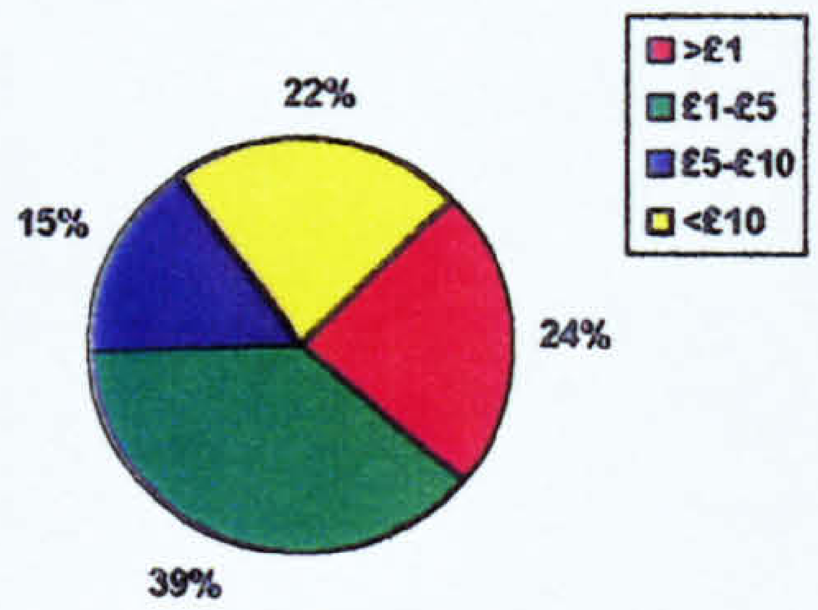

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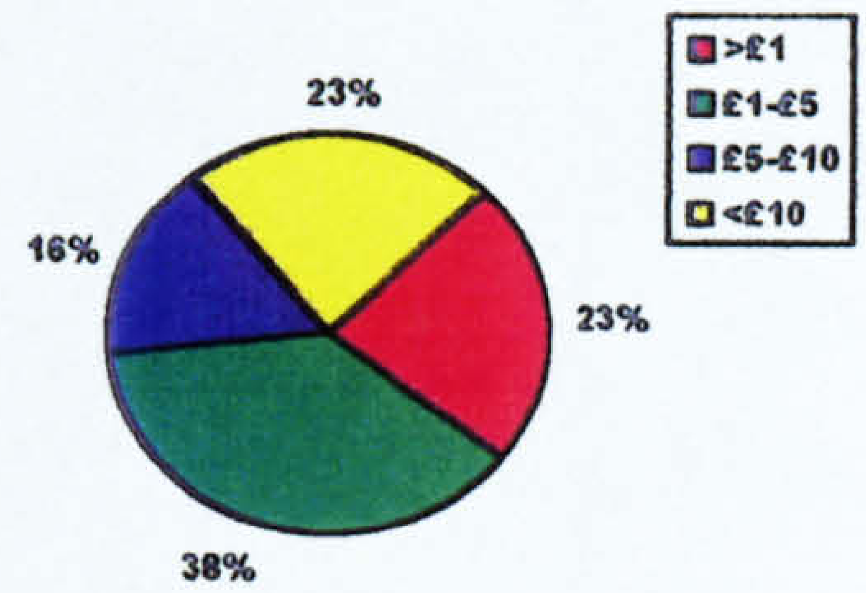

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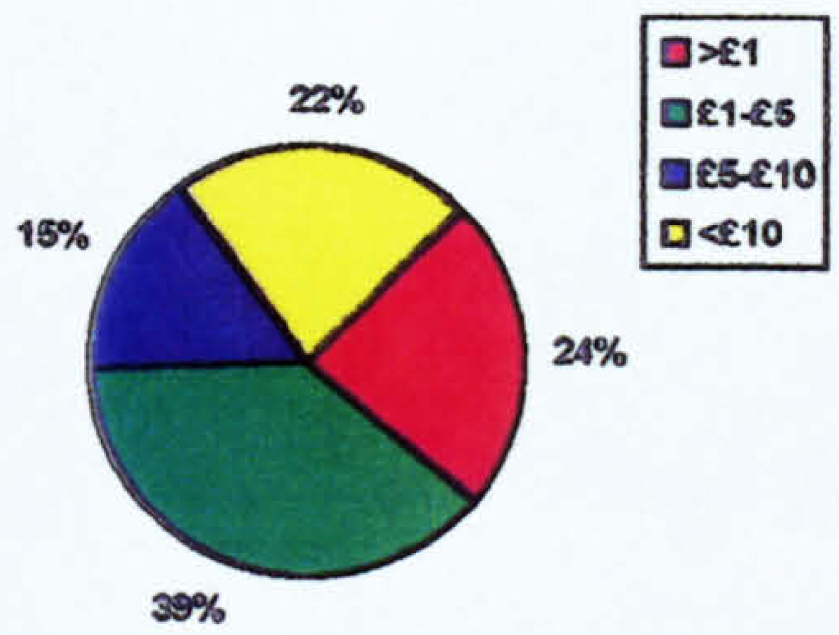

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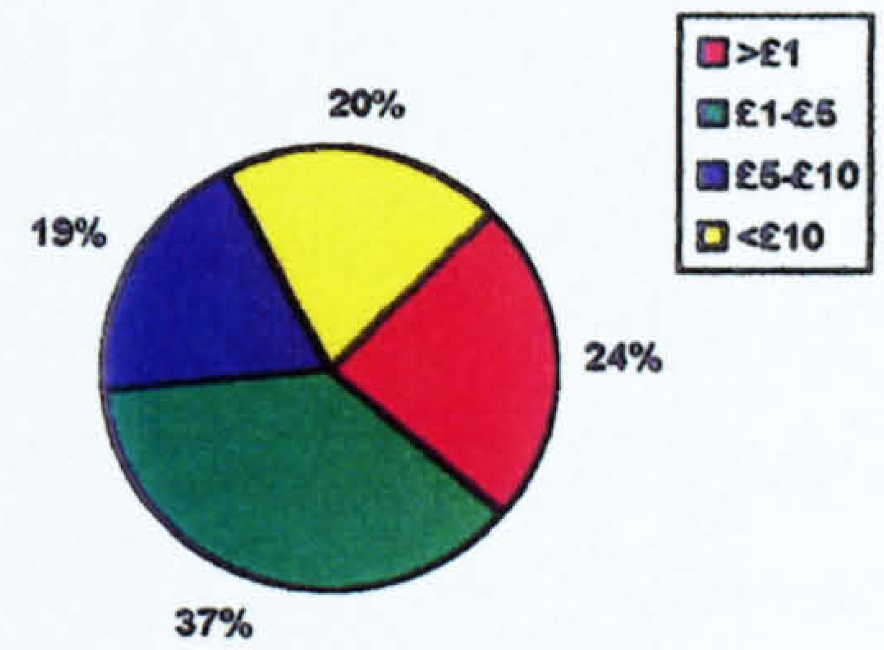

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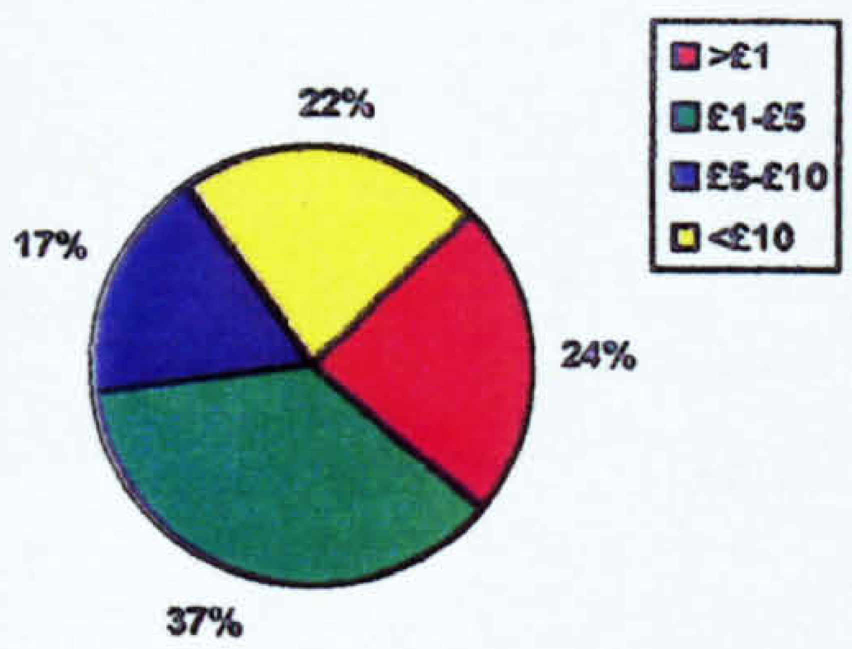

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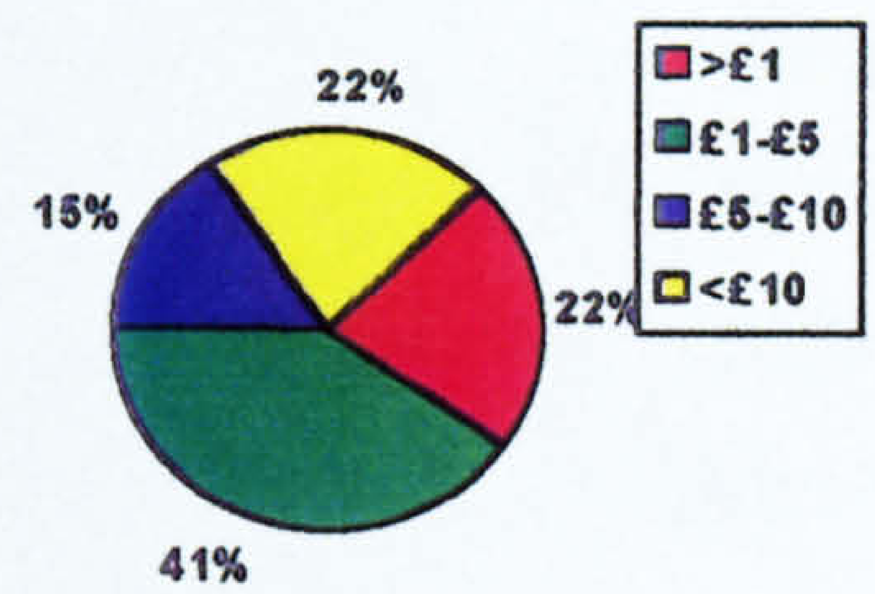

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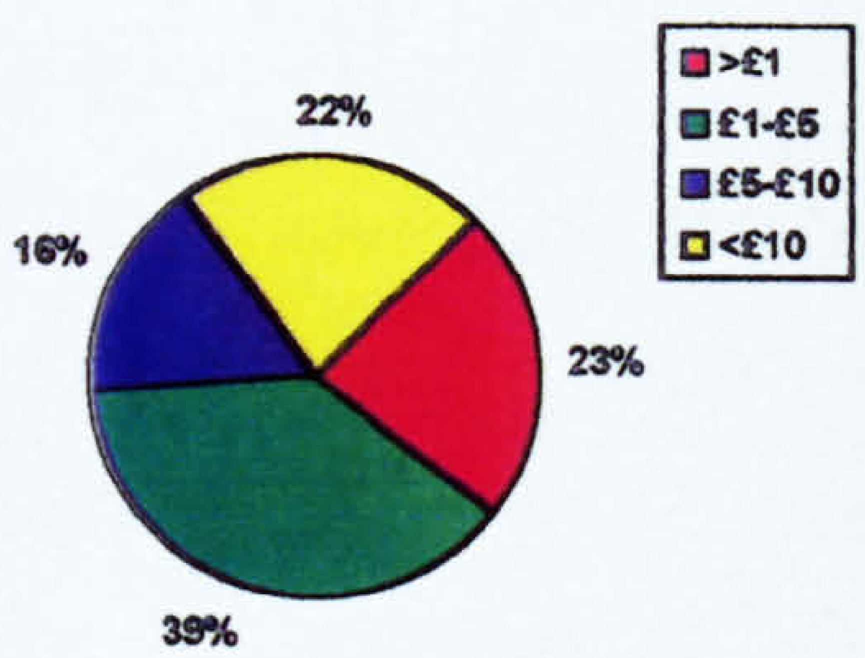

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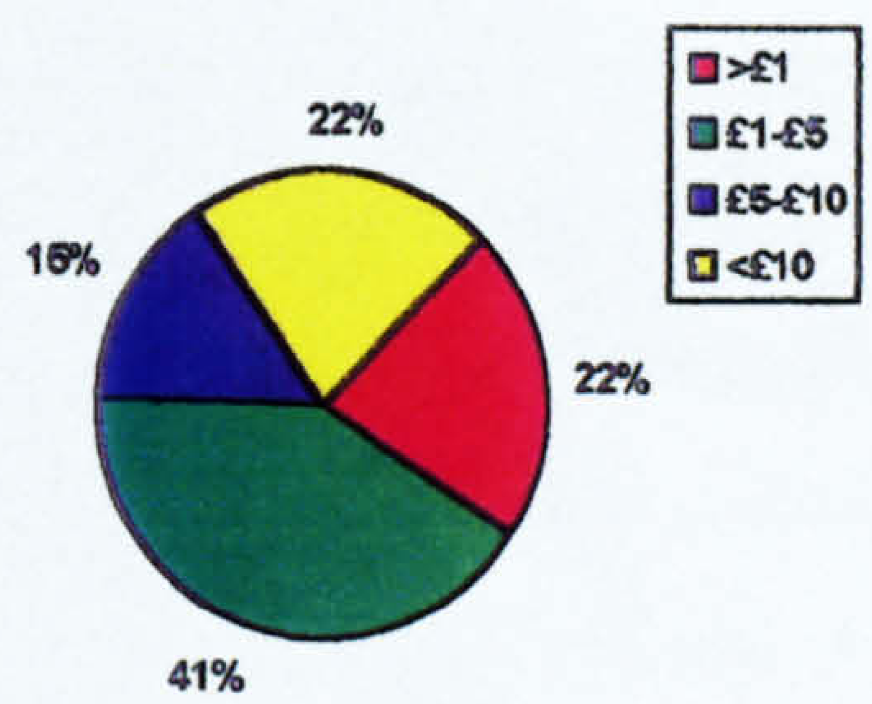

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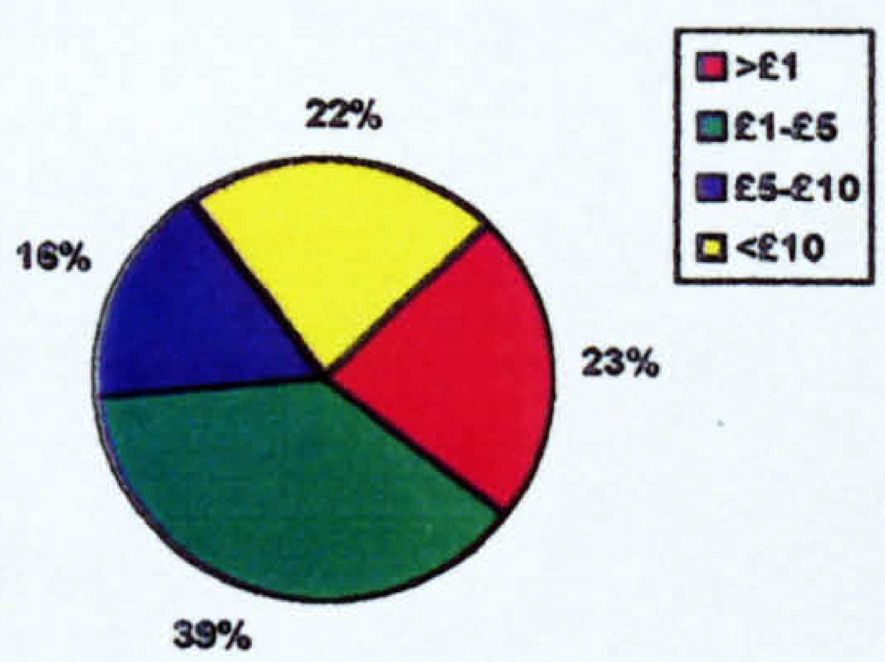

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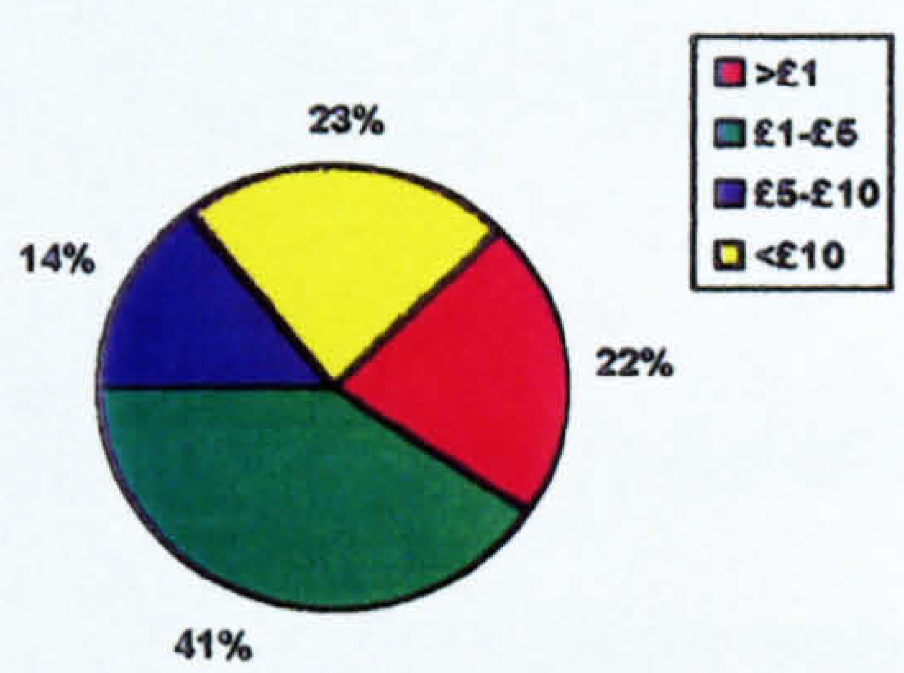

<£1 £1-£5 £5-£10 >£10

secondhand instruments remained part of their stock. This same 1794 trade catalogue extolled the firm's ability to provide 'a great variety of articles too numerous to be included', following this with the information in French. Indeed, as Allen Simpson has shown, they were able to provide almost anything on demand: the Bohnenburger gyroscope mentioned earlier was one example. Another was an example of William Henry Fox Talbot's colour photometer of c.1826, described briefly by Talbot in an article in 1834, and made for the same American collector.[110] However, the Jones brothers did not supply only private collectors: instruments signed by W.& S. Jones could also be found in serious teaching and research collections in institutions across Europe and North America.[111]

As might be expected, some types of instrument advertised by the Jones brothers were modified and improved over time. Other changes in the catalogue record technological advances, such as the introduction of the corrected objective optics in microscopes in 1830; the invention of photography in 1839/1840; and the gradual shift of emphasis in electrical goods from recreation into something much more serious. Other instruments fell from favour: for example, the 'sagacious swan' and the 'sensitive fishes', quaint descriptions of magnetic devices offered for sale at the turn of the century, to be found now only occasionally in collections. The category in which these had first appeared, 'Instruments for Recreation and Amusement' had become 'Instruments of Recreation' by 1805, and the entire class had been dropped from the catalogue altogether by 1814.

Other more serious workaday instruments, which must have formed the bread-and-butter for their trade are known to have been sold by the firm: a range of pantographs (for copying, enlarging or reducing drawings) varying from £1 16s to £6 16s 6d were offered from 1793; by 1855 the prices varied from £2 10s to £6 16s 6d. The 'new opake and transparent' solar microscope (a form of magic lantern), with 'improved apparatus', was offered in 1793 from between 12 to 16 guineas; by 1855, it was available only in the 12 guinea size. That numbers of these (and other instruments) survive in collections and are seen to pass through the salerooms

[110]. NMS.T.1995.31: illustrated in Morrison-Low and Simpson (1995) and discussed in Simpson (1996).

[111]. See for example, for Sweden, Pipping (1977); Ireland, Mollan (1995), and the north American examples discussed by Bedini (1964), 137, Schechner (1982) and Schechner Genuth (1996).

W. & S. Jones (1814)		**G. & W. Proctor (1815)**	
Refracting telescopes of various lengths	10s 6d to £1 18s 0d	Common telescope with four glasses	5s to 12s
		Best four glass telescopes	6s to 15s
		Trumpet telescopes with four glasses	8s 6d to 10s 6d
Second best two drawer telescope	£1 4s 0d	Two draw four glass telescope	9s 6d to 11s 6d
		One draw achromatic telescope	14s to £1 5s 0d
Achromatic stick telescope of various lengths	from £1 1s to £5 5s	Walking stick achromatic telescope	12s to £1 5s 0d
Two feet best three drawers [telescope]	£3 13s 6d	Most portable achromatic [14"]	6s to £1 10s 0d
		Middle size [18"] achromatic telescope	£1 to £2 0s 0d
		Military [28"] achromatic telescope	£1 5s to £1 16s
Four five feet draw best [telescope]	£8 8s	Large four draw achromatic telescope [40"]	£2 12s 6d to £5 5s
Two feet day and night best telescopes	£3 13s 6d	Night and Day telescopes	£1 16s to £2 8s
Achromatic perspective glasses...	12s to £3 3s	Achromatic perspective	12s to £1 11s 6d
		18" two draw achromatic telescope with stand and box	£3 13s 6d
2 1/2' achromatic telescope with stand and box	£10 10s		
		3' achromatic telescope with two eyepieces	£8 8s
3 1/2' achromatic telescope with two eyepieces	£21 0s 0d		
Common microscopes	5s to £1 1s 0d	Various common microscopes	9s per dozen to 10s 6d each
Botanical microscopes	9s to £1 11s 6d	Portable trunk microscope	£1 0s 0d
Pocket microscopes	16s to £2 12s 6d	Pocket microscope	£1 11s 6d
Compound microscope on common construction	£3 3s to £5 15s 6d	Culpepper's pyramidical microscope	£3 13s 6d
Camera obscura for the pocket	12s to £3 3s 0d	Camera obscuras	7s 6d to £2 2s
Optical diagonal machines	£1 5s to £2 2s	Diagonal mirrors	£1 5s to £1 8s
Perspective views	1s 9d each	Coloured/uncoloured prints	£1 4s a dozen
Magic lanthorns with various mechanical figures for phantasmagoria etc.	£1 4s to £6 6s	Magic lanterns	12s to £1 16s

Table 3:7 Comparison of prices of optical instruments offered by W. & S. Jones, London, (1814a) and G. & W. Proctor, Sheffield, 1815.

regularly, is perhaps a testament to the good businessmanship of both the high profile entrepreneur William Jones, and also to his less prominent, yet equally capable brother Samuel.

Some of the lower-priced optical items in their catalogues can be compared with those offered by the Sheffield firm of G. & W. Proctor, by looking at the prices listed in Proctors' 1815 pattern book and matching them with descriptions which W. & S. Jones used in 1814 [Table 3:7]. The Sheffield prices are consistently lower than the London ones, and help to sustain the argument that Sheffield instruments were being retailed in London by establishments such as W.& S. Jones.

Although it may not have been typical, the Jones business was demonstrably successful - Samuel Jones left an estate worth about £25,000, equivalent to several millions today - and some of its success was due to its marketing strategy. A huge variety of material was apparently available 'off-the-shelf', and a statement that other exceptional pieces could be provided 'at good terms' implied that the Jones' brothers had good contacts, whether formal or informal, with the large pool of skilled labour within London which could be called upon to provide extraordinary commissions, such as those required for individuals like Charles Nicholl Banker, or for institutions such as Harvard College. But perhaps the more important trick they had up their sleeve was good lines into the printing business, both through family and friends, so that their trade publications, however ephemeral in the longer term, did not cease to be regularly updated for the entire duration of their business.

Conclusions

In assembling a new suite of instruments for the national observatory - as in fact happened, when G.B. Airy ordered new instruments for Greenwich in the 1840s - would an observatory's governors have approached provincial instrument makers? In the case of Greenwich, the answer was emphatically negative: but this was because the long-standing pre-eminent firm of precision instrument makers Troughton & Simms was on the doorstep, or at least not far away, and Airy, as we have seen, treated members of the firm as personal mechanics, at his beck and call. But by mid-century, Troughton & Simms were no longer undisputed masters of their field: the more recent, and provincial, firms of Thomas & Howard Grubb of Dublin, and that of Thomas Cooke of York, both of which specialised in observatory kit-outs in the new technology of giant refracting telescopes, had good and growing international reputations.[112] By 1850 the markets which in 1760 had been concentrated in London, around the court, wealthy society and the City, had moved into the provinces: there were centres of local wealth which encouraged local markets; itinerant lecturers toured to entertain local philosophical societies; culture, including interest in science and its accoutrements had broadened. The following chapters will discuss how the provincial trade was organized, what it produced and how the mechanisms for supply and demand operated during this century.

[112]. For a list of the Grubbs' instruments, see Burnett and Morrison-Low (1989), 113-117, and Glass (1997), appendix c; for those of Cooke, see Brech and Matthew (1997) for a list of those sold to members of the Yorkshire Philosophical Society.

Chapter 4: The Industrial Organisation and Production of the Provincial Trade

Introduction

What had changed between about 1760 and 1850, to allow some instrument makers outside London to feel confident enough to display their goods in international exhibitions? Had there been significant changes in the organisation of the workforce, or marked differences in the products? Were there improvements in the tools which made the instruments? Did the changes associated with industrialisation - such as removal into the factory, the application of power - so evident in the textile industries at this time, impact at all on this industry? This chapter will look at the raw materials used in the instrument trade, the issue of finding a source for them, and some of the difficulties in their manipulation; the application of division of labour and the role of women and children; what evidence there is for ways in which the trade in the provinces was organised, and what it produced. Returning to Millburn's agenda for the effective investigation of instrument makers, this chapter will address the questions of the 'sources of materials and components, their tools, their relationships with their workmen, subcontractors ... and each other'.[1]

Source of Raw Materials

Instruments have been made of many different materials since medieval times, depending on customer demand, but the important basics for working instruments throughout the period of the Industrial Revolution were brass, glass and, in comparatively tiny quantities, high-quality steel.[2] As John Burnett has written:

> In the three centuries between 1500 and 1800 a wide range of materials was used in the manufacture of physical instruments. Almost all, however, were used to build the structure of the instrument, or to decorate it. Only a few were employed for what we may call the working parts. Examples of the structural and decorative substances were paper, vellum, leather, a variety of woods, ivory, and precious metals, particularly silver. For the working parts two materials had by 1800 become important beyond all others: glass and brass.[3] Brass alone was used in the making of the earliest mathematical instruments, the oldest category of instruments to be developed. This is because brass has a number of useful

[1]. Millburn (1986c), 84.

[2]. Wooden instruments, used in the American colonies where there was a scarcity of brass, are discussed by Bedini (1964), 65-79; in more recent times, special new materials, such as aluminium, have been used: see McConnell (1989).

[3]. Burnett (1986), 217.

characteristics, as R.L. Barclay has observed: 'It can be softened by heating, for ease of working in bending, hammering or drawing; it work-hardens producing tough, resistant components; it is free-cutting; it can be cast; it is easy to solder with both hard and soft solders; it accepts a very high polish with little labour; it tarnishes evenly to produce an attractive patina resistant to corrosion; and it is relatively inexpensive to produce.'[4]

The manufacture of brass - an alloy of copper and zinc, the latter usually from an ore known as calamine - was dependent upon the availability of the right sort of minerals; but more importantly, the right sort of energy to convert the raw materials into useful, workable metal. This required coal, which was found in abundance in the English Midlands, South Wales, North-east England and in the Forth and Clyde valleys. The treated copper and calamine ores needed to be fused at high temperatures, made possible by the development of the reverberatory furnace, first used, as Martin Daunton observes, in 1612 to heat sand and alkali to produce glass: 'a tall, cone-shaped funnel produced a fierce draught when a coal fire was lit at the base; a curved dome deflected heat back on to raw materials contained in covered pots for protection from smuts and soot; and raw materials and coal were not in direct contact, so that impurities did not affect the final product.'[5] In the 1680s this was applied to the smelting of copper and lead at Bristol, which in due course shifted to Swansea, closer to fuel sources, and ready access across the Bristol Channel to the Cornish ores, which accounted for 80%-85% of national output for most of the eighteenth century. Copper ore was discovered in Anglesey in the 1770s, where a local attorney, Thomas Williams, secured control of the largest mines, and, as J.R. Harris has shown, briefly dominated the industry until the source was exhausted.[6] Output of copper, thanks to technological developments in mining and smelting, rose from between 500 and 600 tons per annum in the early eighteenth century, according to A.E. Musson, to about 12,000 tons in 1850, with a corresponding rise in the number of people involved in its production: by 1851, 61,000 workers were involved in the mining and manufacture of copper, lead and tin, and there were 11,000 brassfounders.[7] By the early nineteenth century, the Cornish mine owners were smelting their own ores in competition with the Swansea smelters; during the 1820s copper ore was discovered in abundance in South America and Australia, and could be imported cheaply to be smelted in Swansea.

4. Barclay (1993).
5. Daunton (1995), 209.
6. Harris (1964).
7. Musson (1978), 103-4.

Copper and brass became increasingly important generally during the Industrial Revolution: copper sheathing was used to protect ships' hulls from worm penetration in the tropics from the late seventeenth century; copper stills were used in brewing and distilling; and copper plates used for engraving. Brass was increasingly used in a wide variety of Birmingham trades ranging from buckles to bedsteads, and was also used in the manufacture of clocks, instruments, guns, tools and aspects of some machinery.[8] As Daunton has noted: 'The development of labour-intensive hand trades in Birmingham and the Black Country, using hand-operated presses, punches, and lathes, and relying on minute subdivision into specialised trades, rested upon the availability of cheap copper and brass from the reverberatory furnaces.'[9] By the 1860s, a contemporary account could state:

> The total quantity of copper ore raised in the United Kingdom ... amounts now to about 350,000 tons per annum, and the fine copper obtained from this to about 25,000 tons, of an estimated value of from £2,500,000 to £3,000,000 ... The principal places where brass is manufactured on a large scale, in England, are Bristol and Birmingham, brass-founding being, in fact, one of the leading trades of the latter city...[10]

This account, which looks at a variety of metal workshops, goes on to outline the activities of the 'Brass Foundry and Tube Works of William Tonks and Sons, Moseley Street, Birmingham' who bought in the ingots of various quality copper and spelter 'principally foreign' to combine into brass, for use in various aspects of the trade. 'There is also a large stock of sheets of rolled brass, used for making tubes and for stamped and pressed work, and of brass wire. Both these articles are procured from mills, whose exclusive business it is to roll and draw for the trade.'[11] Good quality sheet brass had long been difficult to obtain for instrument makers: Barclay quotes the example of R.B. Gordon's examination of an astrolabe made in 1537 by the respected instrument maker Georg Hartmann of Nuremburg, where he concludes that defects in the brass were so common that Hartmann could not afford to reject a sheet. 'It should be kept in mind that pouring ingots of the quality required for making brass sheet with a good surface finish remained a problem for brass makers up through the first part of the present century.'[12]

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8. Daunton (1995), 210.
9. *Ibid.*, 211.
10. Strauss (1864), 50-51.
11. *Ibid.*, 52.
12. Barclay (1993), 35, quoting R.B. Gordon, 'Metallography of Brass in a 16th Century Astrolabe', *Journal of the Historical Metallurgy Society* 20 (1986), 93-96.

Quality of sheet brass was not the only problem encountered by instrument makers. Anita McConnell cites two examples of eighteenth-century London makers being unable to obtain brass bars in dimensions large enough for the instrument specified by the customer. In 1772, John Bird was constructing the pair of eight-foot mural quadrants for the Radcliffe Observatory, Oxford, and was unable to acquire brass in such lengths from an English foundry, and was forced to import eight-foot bars from the Netherlands. Similarly, Jesse Ramsden wrote to Matthew Boulton in 1786 to ask whether he thought it possible to have English-made brass bars sufficiently long for a nine-foot radius quadrant: the quadrant subsequently delivered to the Brera Observatory, Milan was eight feet in radius, McConnell suggests, perhaps because of these difficulties.[13]

After the supporting structure, the major component of instruments of this period is the smooth brass 'telescoping' tubes of precise internal and external dimensions which allow microscopes and telescopes to focus while in use, and compact together when not. This method was introduced during the early eighteenth century - by whom, it is not known. Allan Mills, citing Derek Price, states that the eminent London microscope maker, John Cuff, introduced an all-brass microscope in 1742, and that compound microscopes and refracting telescopes were commercially-produced from about 1750.[14] Taking sheet metal, and silver-soldering the edges together, this initial shell would be placed on a steel mandrel and drawn, with considerable force, sometimes amounting to several tons, through a steel hole or die. The inside diameter was set by the size of the mandrel, the thickness of the wall controlled by successive passages through dies of decreasing diameter. As Mills observes, this technique is related to wire-drawing, an activity which appears to have begun in fourteenth-century Nuremburg and was introduced to England in 1565. When polished, it is impossible to see the seam in well-made tubing; however, it is a weakness which becomes apparent if the tube is exposed to external or internal pressures, and thus 'seamless' tubing was adopted for use in steam boilers. This is made by casting the initial brass shell around the mandrel before drawing it through the die.

That the manufacture of brass tubing was regarded as a crucial component of instrument-

[13]. McConnell (1994), 43 n27, citing for Bird: Bodleian Library, DD Radcliffe e 2, pp.11-14, letter from Hornsby to Wetherell, 24 October 1771; n29, for Ramsden: Birmingham Public Library, Boulton letters, MB 251, 86, letter from Ramsden to Boulton, 6 September 1786.

[14]. Mills (1990).

production is shown in a specific instance of industrial espionage by the Scandinavian Jøns Matthias Ljungberg (1748-??). Between 1770 and 1780, he made three journeys to Britain, mainly to investigate newly-invented textile machinery, and in 1789 he made another visit, this time primarily to investigate the pottery industry, but attracted the attention of the authorities and his baggage - which included a large quantity of 'clockmakers' tools', a euphemism, according to D.C. Christensen, for the precision tools used for scientific instrument making, forbidden export by statute - was impounded by Customs. These were auctioned to cover the Customs officer's expenses, but Josiah Wedgwood was clearly more concerned about the destiny of his meticulous notebooks, as he expressed in a letter to Matthew Boulton dated 24 August 1789:

> What I am now principally anxious for is, the detention of the manuscript Volume of Drawings and Remarks, which it seems has been 13 or 14 years in composing. My opinion is, that the conveyance of information, which has been collected by so sensible a man as Mr Liunberg certainly is, during so many years, may injure our manufacture very materially and irreparably.[15]

One of these volumes was recently rediscovered by D.C. Christensen, and amongst the information within it, is an account of Jesse Ramsden's tube-drawing machinery.[16] Although unpatented, the design was evidently one kept secret from all but the most trusted workmen. Firstly, Ljungberg bribed a worker to describe the machine, but found that this was too imprecise. So he obtained from the mechanic an engineering drawing, together with a detailed technical description of the machine: 'As far as I know' comments Christensen, 'this drawing and description of a tube-drawing machine is the only existing piece of evidence illuminating a basic technology of production of scientific instruments left to the historian.'[17] Even so, the confiscation of Ljungberg's notebooks meant that this piece of industrial espionage was successfully thwarted.

By the time of the 1864 account of William Tonks's Birmingham brass-foundry and tube works, the national requirement for secrecy had gone (although commercial motives may have meant that individual instrument makers were concerned to keep production techniques to themselves), made redundant to some extent by political moves towards free trade, as shown by the 1825 Machinery Act. The techniques had also evolved:

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15. Quoted by Woolrich (1988), 37.
16. Christensen (1998). J.M. Ljungberg's notebook is in Stockholm, Riksarkivet: Kungliga Myntverkets arkiv, Varia I d.

... we proceed to the tube shop. The brass sheets procured from the rolling mills are here cut, by revolving shears, into strips of any required width; the metal is then partially curved in its length by means of a pair of rolls, and after this transferred to the draw-bench. ...[It is] passed through a steel hole or a die of the required gauge, a steel plug being inserted in a position to allow the metal to pass between it and the interior of the hole. The curved end is then laid hold of with a pair of huge nippers, attached to an endless chain, drawn by steam power. By this simple contrivance the flat sheet is in a few seconds converted into a tube, which requires only soldering along the seam to be ready for use. The slicing of the sheets to any required width is effected in the same compartment, by a cutting bench or machine, with circular shears, or cutting discs, revolving in opposite directions.[18]

Here, too, we must surmise, the casting of instrument parts must have been undertaken, before being sent out to the smaller workshops for assembly. The casting pattern room of Tonks & Sons's 'contains a bewildering number of metal patterns of every description...there are more than 10,000 regular trade articles made by the firm, besides thousands of articles made to special order, and patterns are kept here of all of them.'[19] The entire foundry was supplied with steam power 'made to do all the work of which it appears capable, the shafting being carried into every workshop in the building... The engine works also a fan ... supplying the necessary blast to the forges in the smiths' shops and in other departments, and also to the gas-soldering apparatus in nearly every room.'[20] Most tellingly:

All the tools used in the establishment are made here, in the engineers' fitting room, which contains various machines for working in iron; among these may be mentioned a self-acting compound slide-rest on a screw-cutting lathe, with wheel-cutting and slotting apparatus, and a combined drilling and surfacing machine of a novel construction.[21]

Although Tonks & Sons had a finishing department, in which the filing, turning, sanding, dipping, burnishing, polishing or lacquering was carried out, it appears that this firm did not undertake the complete making and assembly of instruments, although it seems that they supplied cast parts or drawn tube to other small workshops, and were thus part of the subcontracting support for the trade. A slightly later description of the production of optical and mathematical instruments in Birmingham, published in 1866, is disappointing in its lack of detail or explanation, although it lists the end-products:

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17. *Ibid.*, 7.
18. Strauss (1864), 45, 56.
19. *Ibid.*, 52.
20. *Ibid.*, 56.

> Mathematical instruments - the compasses, pens, sectors, &c. - have long been made in Birmingham in large quantities, but the manufacture of the commonest sorts has been much affected by the importation of cheap French and German goods, which are sold at very low rates. In consequence of the inland situation of Birmingham, nautical instruments are not produced to any great extent.[22]

In Sheffield, an eyewitness account recalling conditions in the first decade of the nineteenth century at the premises of Proctor & Beilby recalled that the brass-casting took place there, rather than the parts being bought-in:

> William Padley was the brass caster... the moulding and casting in "front sand" was to me the more interesting operation, and at this Padley was an adept. And, boy as I was, I was both surprised and sorry to see him put in the melting pot shovelsfull of the fine, plump pennies of George the Third's reign, which I thought might have been so much better used. But I lived to learn that each of these coins weighed nearly an ounce - while copper in the ingot was nearly two shillings a pound! And as "defacing the coin of the realm" was a penal offence, it were probable, had Mr Caster's offense against the law been witnessed by eyes less innocent than mine, he or his employers would have got "into a scrape!" [23]

This Sheffield 'workshop' apparently undertook the entire construction of a variety of scientific instruments and other brass items from casting the brass through to finishing. In an effort to keep prices down, instruments, especially the popular telescope (of which they produced 76 variations in their 1815 pattern book) included body tubes made of wood: 'the boring and turning of the sycamore and mahogany outsides of telescopes – "wood tubes" as they were called ... These bodies, which were beautifully French polished, have mostly been superseded by brass or leather-covered tubes.'[24] The most expensive telescope thus produced, according to the (incorrectly added) scribbled costs in the pattern book:

Mahogany Tube compleate	1--1-0
Brass for Telescope	0-10-0
Brass for Stand	0-15-0
Making Telescope	1-11-6
Making Rack Stand	1-11-6
Mahogany Box Wood & Work	1-15-0
Unglazed	[sic] £6--4-0
Make extra eyepiece	0--2-0
	£6--6-0

21. *Ibid.*
22. [Robert Field], 'Optical and Mathematical Instruments' in Timmins (1866), 534.
23. Holland (1867).
24. *Ibid.*

Plain mahogany or Sycamore	0--1-0
mahogany wood tubes, flowered [illeg]	0--3-0
Box with Wood & Work	1-15-0
Brass Work	1-11-6
Stand - weighs 10lb -1/6	0-15-6
	2--6-6

On the opposite page, this 'Four feet Achromatic Celestial & Terrestrial telescope', was sold - presumably wholesale to shops such as that of W.& S. Jones in London - at 12 guineas with the terrestrial eyepiece, and 16 guineas with the celestial eyepiece.[25] As we have seen, a three and a half foot achromatic telescope with two eyepieces was £21, as retailed by the Joneses at this date. As in the case of Birmingham-made instruments, few Sheffield-made pieces were retailed in the place of construction and thus few were engraved with their place of origin. The property of brass to be cold-engraved is the reason why the most important part of the instrument - that with the scale for precision measurement - was also constructed of brass and carefully divided, first by beam compasses, subsequently by a dividing engine, methods which will be discussed more fully below.

The other major component of precision scientific instruments was optical glass, used extensively in the contemporary instrument subdivision known as 'optical instruments', and those which used any form of telescopic or microscopic sight. Glass manufacture was another fuel-intensive industry requiring specialist plant - as did brass smelting - yet coal was a less significant element in total costs, as Martin Daunton has pointed out, than the skilled, labour-intensive working of the molten glass: in the eighteenth century the industry moved away from the local markets in London towards the coalfields, centring on St. Helens and Warrington.[26] The problem with optical glass was not so much the supply of it to the instrument makers, more the development of skills to provide it. The general changes in the industry affected all optical instrument makers, and were not resolved on an industrial scale until Chance Brothers imported foreign 'knowhow' as late as 1848.

Optical glass has different characteristics from domestic or 'crown' glass, usually having a higher lead content, named 'flint' glass. The demand for it has been always a tiny fraction of the

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[25]. Sheffield City Libraries, Special Collections no. 33237: Bradbury Record 293.

overall glass production, and it was extremely difficult to produce, as this account dating from 1919 explains:

> The glass from which are fashioned the lenses of telescopes, field-glasses, microscopes, photographic cameras and other scientific instruments is made in a different way from any other. It is neither gathered nor poured, but left, when melted and refined, to solidify in the pot. The block that results, or fragments of it, are moulded by reheating into forms suitable for the completing work of the optician... Messrs. Chance Brothers & Co. undertook it seventy years since [i.e. 1850], and ...they owed inception of this manufacture to Georges Bontemps.
>
> The function of the finished lenses is to refract the rays of light that traverse them. That they may perform this function perfectly the glass must be free from striae and other defects that may distort the rays in their passage. It cannot, like window glass, be limited to one simple composition; different purposes require glasses of different refractive and dispersive powers.[27]

In proposition III, experiments 7 and 8, in his extremely influential work on *Opticks* (1704), Sir Isaac Newton had demonstrated the apparent impossibility of suppressing chromatic aberration in telescope objectives by using two lenses of different refractive indices; this had resulted in Newton turning to reflecting telescopes and abandoning the refractor. Such was Newton's reputation as a giant in scientific thought that this conclusion went unchallenged for over thirty years.[28] Innovation in telescope optics was channelled into development of the metal specula of reflecting instruments - most successfully by James Short of London, and subsequently by William Herschel of Bath and Slough, as discussed in chapter 2. However, in 1758 John Dollond, a practical optician, was awarded a patent for the achromatic lenses made of different-density glasses which he had been constructing over the previous few years: these were made by cementing a convex lens of crown glass to a concave lens of flint glass.[29] In the subsequent trial over the patent, it became clear that Chester Moor Hall, an obscure Essex gentleman who dabbled in optical experiments, had stumbled upon this idea before Dollond: in 1733, he had asked two London opticians to grind individual elements, and they had sub-contracted the task to the same jobbing optician, George Bass, who had realised they were for the same person. Yet, as Henry King points out 'news of [t]his lens spread slowly among the London opticians, for none of them grasped its

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26. Daunton (1995), 209.
27. Chance (1919), 171.
28. Daumas (1972), 153. There is an extensive literature on this subject, including King (1955), 68; Bechler (1975); see also McConnell (1996).
29. Angus-Butterworth (1958); Derry and Williams (1960), 592.

full significance.'[30] On the Continent, the Swiss Leonard Euler and the Swede, Samuel Klingenstierna, both worked out mathematical alternatives to Newton's hypothesis, but it was John Dollond's perseverance and skill with grinding and combining lens elements which provided the acknowledged success of the new lens. His telescope and a short report were presented to the Royal Society in June 1758 by his friend the maker of reflecting telescopes, James Short, and Dollond's European reputation was established. He was admitted to the Royal Society and awarded their Copley Medal, its highest scientific distinction. Encouraged by his astute businessman son, Peter, with whom he was in partnership, John Dollond took out a patent, 'which did not' Daumas has observed, 'prevent people from copying him. Since he knew the truth concerning the priority of his discovery John Dollond refrained from using the means the law allowed him.'[31]

Peter Dollond was more hard-nosed, particularly after his father's death in 1761, and by 1764 thirty-three of his business rivals instituted proceedings to have the patent annulled, on the grounds that they were already selling the results of Hall's invention before Dollond announced it. Dollond's patent was upheld, until it expired in 1772, but the antecedents of Dollond's discovery - and the huge amount of bad feeling generated - were made public.[32] Yet the real problem appeared to be that optical glass was made in such small quantities of such variable quality that, as Anthony Turner noted, 'the best of this, Bernoulli explained, was reserved by the glass-houses for their favourite customers, the rest of the batch being sold to others. However, "... if their maker knows that one orders glass in order to imitate an invention of his country he will not be satisfied with himself unless one takes the worst possible." '[33]

For optical use, especially for large objectives, the glass had to be perfectly homogeneous; the decomposition of carbonated alkali could produce air bubbles; flint glass, observed Daumas, 'also had the peculiarity that it often presented a gelatinous structure as a result of excess of lead oxide ... the duration of the firing had to be accurately controlled; the difficulty lay in knowing when to stop it in order to avoid the beginning of devitrification. The reaction between the lead

30. King (1955), 145.
31. Daumas (1972), 155.
32. Daumas (1972), 153-6; King (1955), 144-52; McConnell (1996), 9-1 - 9-4; Robischon (1983), especially ch.IX.

oxide and the alumina of the crucibles caused flaws near the side walls.'[34] In addition, the glass within the crucible settled into layers, only gatherings from the middle portion being suitable for optical purposes; as this was a wasteful method of production, only the largest glassworks could afford to undertake this sort of hit-or-miss production.

Perhaps the greatest obstruction inhibiting the production of optical glass was the excise duty levied on all glassmaking until it was repealed in 1845: 'the constant supervision practised by the excise officers rankled with the manufacturers, and the effect of the duties themselves was tersely summed up by the economist J.R. McCulloch in 1833: "A man with 125 per cent duty over his head is not very likely to make experiments."' [35]

In fact, innovation came from the Continent, where P.L. Guinand, a Swiss clock-bell founder applied the technique (suggested by bell-founding) of stirring the molten flint glass in the crucible with a fire-clay stirrer, which distributed the heavy lead oxide more evenly, forming a much more homogenous mixture than previously. This also helped to disperse the air bubbles, which helped the quality of light transmission, and extended the range of flint glass density, with varying refractive indices. Most of this activity took place in great secrecy at the Bavarian works of Joseph von Fraunhofer in the early years of the nineteenth century; after the deaths of both Fraunhofer and Guinand, the secret was purchased by the French glass-maker, Georges Bontemps, who in 1837 agreed to share it with the Birmingham firm, Chance Brothers. In 1848 the revolution forced Bontemps into exile, and he set up a new plant for Chance Brothers, which helped to establish them in the forefront of the production of English optical glass.[36] An account, dating from 1864 describes this process:

> One of the most important operations in these works is the manufacture of that optical glass for which the Messrs. Chance have attained a high reputation. A single melting of the material from which this is made lasts five days, during which time the metal is constantly worked in order to clear it and free it from impurities. The whole mass is then allowed to cool, and a large lump of glass is drawn out, varying in weight from 6 cwt. to 12 cwt. This mass is polished and sawn in pieces of pure glass, varying in weight from a few ounces to several hundred pounds. These are again heated in a kiln, where they are moulded into the

33. Turner (1987), 222, quoting Jean Bernouilli, *Lettres astronomiques...* (Berlin, 1777), 68.
34. Daumas (1972), 157.
35. Derry and Williams (1960), 598.
36. *Ibid.*, 593. Also discussed in more detail by Chance (1919), chapter VIII, 'Optical Glass'.

> shape of discs of the required size and thickness. The principal points to be attained are complete freedom from veins, absolute homogeneity of the whole mass, and perfect annealing so as to avoid polarization of the rays of light. Rough discs only are manufactured by Messrs. Chance. These are afterwards ground and polished by the optician and vary in value from few shillings to £1000 each.[37]

As A.E. Musson has commented, by the mid-nineteenth century the growing demand for window, plate and bottle glass, together with the relaxation on heavy excise duty, allowed the firms of Pilkington's at St. Helens, Chance's in Birmingham, and Cookson's on Tyneside, advantageously-sited close to sources of chemicals and coal, to develop large glassworks; yet, in 1851, only ten glass-making firms had a workforce numbering over one hundred, while most had fewer than ten. 'The total labour force was relatively small, only 13,000 being returned in the Census, and these were mainly handicraft workers, for even in 1870 there was only 4,000 horse-power of steam in the industry.'[38] Although some developments had taken place in the optical glass industry during the time before the Great Exhibition of 1851, as we have seen output was small, inhibited by taxation until 1845. These developments will be discussed in the following section.

Tools and technological change

What were the changes in technology and tools in precision instrument manufacture during this period? Between 1760 and 1850, unlike the textile industry, but like other metalworking industries, the manufacture of precision instruments was not mechanised to any great extent; rather, there were changes in organisation, which will be discussed below. As Raphael Samuel has shown, hand technology continued to exist alongside mechanisation well into the mid-Victorian period, where in 'metalwork and engineering ... the production process was discontinuous, and depended on craftsmanly skill. Mechanisation and steampower ... were by no means inseparably linked, and a vast amount of nineteenth century work was affected by them only at second or third remove.'[39] However, there were a number of improvements to the tools used in constructing instrumentation, which kept the London makers at the forefront of innovation, earning them a world-wide market. Daumas has discussed these in some detail, and some of the reasons why momentum of

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37. Strauss (1864), 192.
38. Musson (1978), 126.
39. Samuel (1977), 19.

improvement was not more rapid:

> ... invention and the putting of invention into effect have been given expression only when there was some chance of a new object being attained by the users. Progress required the work of skilled craftsmen, the use of materials of the best quality, and costly instruments and machinery; in other words, it required relatively considerable human and monetary capital. If the capital thus tied up were not productive - that is to say, if there were no customers - the invention would languish for lack of means. In fact, customers were not numerous; they were not always prepared to use the new invention; and their financial state was variable.[40]

Handtools, Daumas explains, borrowed from other craft workshops, have not fundamentally varied since the introduction of good manufactured steel, at the start of the seventeenth century. These include the strap drill, the drill with crank and bevel gearing, chisels, gouges, dies, and vices. Mathematical and engraving instruments for the hand-division of circles and rulers have been in use from an early date; however, machinery borrowed directly or derived from clockmakers, was added to standard tools. 'New tools and special methods of working were devised; these were not only soon adopted by all clock-makers, but were used in all workshops where precision work was carried out.'[41]

As Nathan Rosenberg has demonstrated, the machine tool industry grew out of the incremental demands of 'a succession of particular industries'.[42] Although discussing a later period in a different country, many of his observations are applicable to the tools used for creating scientific instruments during the Industrial Revolution. Rosenberg looks at how the machine tool industry grew out of the requirements for a group of what he calls 'technologically convergent' industries as apparently diverse as 'firearms, sewing machines and bicycles ... if time and space permitted, a more comprehensive account would include also a wide spectrum of machine-tool-using industries ranging from watches and clocks, scientific instruments, hardware, and typewriters to agricultural implements, locomotives, and naval ordnance.'[43] As problems were solved for one industry, it was immediately realised that the solution was applicable in another where there was a close technical relationship; and this was transmitted to them through the machine tool industry, which 'may be looked upon as constituting a pool or reservoir of skills and technical knowledge

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40. Daumas (1958), 379.
41. *Ibid.*, 382.
42. Rosenberg (1976), 14.
43. *Ibid.*, 16, 18.

which are employed throughout the entire machine-using sectors of the economy.'[44]

Daumas showed that in the period up to and during the Industrial Revolution, new ideas were only slowly adopted in precision mechanics, perhaps because materials were unsuitable for particular techniques, or because there was little demand: however, the instrument-maker's workshop became equipped with tools borrowed from 'technologically converging' industries, such as the nascent mechanical engineering trade, the somewhat older trades of clockmaker, locksmiths and other metalworkers. The lathe was modified in the late seventeenth-century for use by optical workers, and by clockmakers for precision metal work. Clockmakers subsequently began to use mechanically-guided tools on lathes at the beginning of the eighteenth century. However, having listed improvements in lathes, screw-cutting machines and drills, Daumas adds that 'all these working methods were adopted by precision-instrument makers during the last quarter of the eighteenth century, but it is not possible to find out to whom the credit for any of these adaptations is due.'[45] It would thus appear that - as in other related industries, such as the manufacture of textile machinery, as discussed by Gillian Cookson, incremental improvements often occurred and were adopted without either the formality of patenting or the blueprints of written description or drawings, but through the expertise of the skilled workman.[46]

'One of the most essential operations in the construction of instruments for the measurements of angles' wrote Daumas, 'is the cutting of an accurately threaded screw.'[47] He mentions the two designs, dating from about 1770, credited to Jesse Ramsden; and the screw-cutting lathe of Henry Maudslay, designed in 1797 and subsequently used extensively in the machine tool industry, which had its genesis in Ramsden's published work. Recently this area of precision mechanics has attracted the attention of a number of instrument historians, who have undertaken extensive field-work on surviving examples. Randall Brooks notes that 'there were few makers capable of making screws well above the standard of the day'. He continues:

> Bird's micrometer screws, despite having been hand-made and of coarser pitch, could match or surpass in accuracy those made by Ramsden on his screw lathes during the overlapping periods of their careers. Ultimately, Ramsden's lathes achieved better

[44] *Ibid.*, 19
[45] Daumas (1958), 386.
[46] Cookson (1994), especially Chapter 4; Cookson (1996).
[47] Daumas (1958), 386.

accuracy. Testing the screws of the dividing engines (c.1762) by the Duc de Chaulnes (1714-69) in the Istituto e Museo de Storia della Scienza (Florence) has shown that the skill of Chaulnes surpassed all previous screw makers - including Ramsden. Test of Maudslay's screws have proved that his reputation as a fine screw-maker was justified. In his experimental screw taps and dies in the Science Museum can be seen the germs of Joseph Whitworth's (1803-1887) standards, which is not surprising since Whitworth was associated in his early years (1825-3?) with the firm of Maudslay and Field.[48]

Even more complex was the problem of mechanically dividing the graduated brass (or in the case of nautical instruments, ivory) limbs of instruments or rules. Daumas remarks that methods evolved slowly over centuries, 'but it took only some forty years for dividing- engines to be adopted in all workshops.'[49] Before this breakthrough, all division had to be done by hand, and could be done to an extremely high standard, perhaps reaching its peak with the mid-eighteenth century London maker, John Bird. He was rewarded by the Board of Longitude 'pursuing its brief to encourage the development of precision instrument-making', as John Brooks remarks, for the publication in 1767 of his *Method of Dividing Astronomical Instruments*.[50] Within ten years, however, Jesse Ramsden had

> ... despite the limited means available to him for precision machining ... found a precise and elegant means to ratch the teeth of his large wheel so that they matched both the division marks and the screw. In doing so, he constructed one of the first screw-cutting lathes with lead screw and change wheels, although in this he was anticipated by Hindley. Ramsden also introduced many other features, one of the most conspicuous being the ratchet mechanism which enabled the engine to be worked by treadle.[51]

Allan Chapman has recently traced the history of the mechanised dividing engine, back to a machine probably intended for horological gearing, described in Robert Hooke's diary for 1672. Although 'it had been a failure as a method of original division, its basic principle reappeared 70 years later, when Henry Hindley of York used a wormwheel to rotate the denticulated dividing plate of what became the first moderately efficient dividing engine.'[52] Hindley has been mentioned as a clockmaker in chapter 2, but it is apparent from what little is known about his work that he was highly competent in instrument-making and precision mechanics. As Chapman states:

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48. Brooks (1989) summary provided in Brooks (1989a), quote p.8.
49. Daumas (1958), 388
50. Brooks (1992); hand division pp.106-8.
51. *Ibid.*, 130
52. Chapman (1995), 124-5.

> Hindley himself was no failure, being a Freeman of the City of York, a leading provincial clockmaker, and a respected citizen. Though his occasional ventures into instrument making were not crowned with much commercial success, it must be remembered that, within the increasingly specialized world of the eighteenth century, he was not an instrument maker ... Hindley, furthermore, seems to have made no attempt to establish himself as an instrument graduator ... with the exception of enlisting [John] Smeaton in the attempt to sell one of his equatorial telescopes, Hindley made no effort to break into the London trade. As a maker of fine clocks in Yorkshire, his market was quite different from that of the mathematical instrument makers of Fleet Street.[53]

Both of Jesse Ramsden's dividing engines used an endless screw, and were recognised by contemporaries as being of outstanding design: they both won government prizes. Chapman observes that although the designs cannot be linked definitively with Hindley's machine, yet there were connections:

> Though Ramsden was neither apprenticed nor worked in the precision trades whilst resident in Yorkshire, he was nonetheless a native of Halifax and was probably aware of the work of his elder contemporary at York. But a more positive connection can be established through John Stancliffe, who first worked for Hindley in York before entering Ramsden's employ following his migration to London. It was Stancliffe, no less, who is alleged to have revealed to Ramsden the principle of the Hindley cutter and maybe other features as well. In 1788, Stancliffe was said to have built his own engine, though nothing is known of its performance.[54]

This would appear to be a transfer of technology through the practical skills of an intermediary, from Yorkshire to London, rather than the expected movement from the capital to the provinces.

Ramsden's first machine, completed in 1767, did not entirely satisfy its creator, who went on to produce a second dividing engine. This won a prize of £615 from the Board of Longitude, not because it was in itself a method of finding the longitude, but as Chapman explains, it was a way of simplifying a part of the method. With Ramsden's machines, the new nautical sextant could be produced in larger quantities, because it speeded up the method of division, which no longer needed be the highly-skilled performance that it had been. As a condition to the reward, Ramsden published a description of his machine in 1777, 'to enable any intelligent workman to construct and use engines of the same kind', and for two years, Ramsden was charged with training ten

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[53] *Ibid.*, 127
[54] *Ibid.*, 130

apprentices in its use, as a condition of the prize.[55] The development of the dividing engine in the ensuing century, with improvements by the Troughtons, William Simms, James Allen and Andrew Ross has been discussed in detail and at length by both Chapman and Brooks: but the significance of Ramsden's engine was indicated in the *Edinburgh Encyclopaedia* in about 1815 that 'there may be ten or twelve [engines] in London, generally copies of Ramsden's second engine.'[56] It is not known whether there were any in the provincial centres at this date, and if so, who had them. It is possible, on the watch-finishing model, that instruments were sent to London to have their scales divided before reaching their point-of-sale (either in the metropolis, or in a port elsewhere) anyway.

Other innovations in the manufacture of instruments occurred on the optical glass side of construction. As we have seen, glass was manufactured in some quantities around the country for use in the building trade, but its status as a luxury commodity which attracted increasing taxation also inhibited development of machinery as well as investigation and exploitation of its chemical composition. As A.E. Musson has observed, quoting Theo Barker, the industry remained heavily dependent on imported skilled craftsmen, and when new methods of production were introduced these were usually of foreign origin. 'But,' remarks Musson, 'although the original processes and skills were mostly French, British glass-makers made significant improvements in their large scale industrial development, especially in coal-fired furnaces, in mechanical grinding and polishing and in the application of steam power.'[57] Even where there was only a small demand, such investments in improved plant were made, an example being John Holland's description of the optical glass manufacture in the early nineteenth-century Sheffield premises of Proctor & Beilby:

> ... Thomas Stovin the glass caster ... melted pieces of broken glass - more valuable in those days than now - on a red-hot iron plate; then, with a spotula [sic], transferred the plastic mass from a mould under a screw press, out of which it came ready for grinding as a "spectacle eye." ...then there was the still more important and curious operation of glass grinding, comprising the production of lenses of every size and curve, from the hemispherical "bull's eye" of the magic lantern to the convex or concave "spectacle eye" ground in or upon "tools" of a large radius. Surtees, in his History of Durham, claims for the town of Darlington the credit for having invented "the machinery for grinding optical glasses." Whatever that may mean, I have always understood that the method of grinding them "by power" - of water or steam - was first practised on the Rivelin by Samuel Froggatt, who afterwards went to London, and established at Hackney-Wick one of the

55. *Ibid.*, 130; Brooks (1992), 102.
56. Quoted in Chapman (1995), 134; Brooks (1992), 102.
57. Musson (1978), 126.

largest glass-grinding works in the world.[58]

This priority dispute over the introduction of power machinery into grinding optical glass is difficult to resolve: Robert Surtees claimed a Darlington textile machinery patentee, John Kendrew, as the undated inventor, who on this occasion at least did not take out a patent.[59] However, members of the Froggatt family of Sheffield opticians migrated to London, as Holland described, and there was a 'Froggatt's Mill' in Hackney Marshes on maps dated 1831 and 1836.[60] In 1850, Henry Mayhew recorded the following statement in London from a camera obscura maker, which doubtless describes the Proctor & Beilby establishment:

> I have known the camera obscura business for twenty-five years or so; but I can turn my hand to clock-making, or anything. My father was an optician, employing many men, and was burnt out; but the introduction of steam machinery has materially affected the glass grinding - which was my trade at first. In a steam-mill in Sheffield, one man and two boys can now do the work that kept sixty men going.[61]

Unlike the glass-grinding of later years, done to mathematically-devised spherical curvatures, it is apparent from Holland's description that lens-making in provincial England was based on a more empirical approach:

> I need hardly say that the "glazing" or fitting the higher class of instruments with glasses was in no degree scientifically conducted: of the doctrine of optics, in the abstract, the men and women engaged, of course, knew nothing. They knew that a telescope was called a *chromatic*, which had a compound object glass; and they could measure, in a rude way, the focal length of the lenses used; so that by adhering to a special formula, they succeeded in practically producing a good telescope, the test of which was its revelation of the figure on a watch face fixed on chimney half a mile off. As to microscopes, Beck had not then won his fame as a maker, nor Pritchard his reputation as an observer.[62]

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58. Holland (1867).
59. 'It should be observed, that Mr John Kendrew, an inhabitant of Darlington, was the ingenious inventor and patentee of the machinery for spinning flax, hemp, tow, &c. now of such importance to the manufacturing interest ... Mr John Kendrew was also the inventor of an ingenious machine for grinding and polishing spectacle and other optical glasses, which is now in general use': Surtees (1823), 360.
60. 'Plan of the parish of St. John at Hackney ... from an actual survey made by order of the Vestry by W.H. Ashpitel' (n.d., c.1831); Greater London Record Office [GLRO]: THCS/P/12, Tower Hamlets Commission of Sewers, large scale atlas of Hackney, surveyed by James Beek, c.1836. A Samuel Froggatt appears in the Hackney Sewer Rate books as early as 1818, and is mentioned in the census of 1821. My thanks to Dr Anita McConnell for this information.
61. Thompson and Yeo (1973), 355.
62. Holland (1867). Richard Beck (1827-66) and Andrew Pritchard (1804-82) were pre-

Indeed, even by the mid-nineteenth century, the production of glass lenses - whether for spectacles, telescopes or microscopes, was (at least for the mass-market) left to the unskilled hands of female labour:

> This trade [optical and philosophical instruments] is extensively carried on in Sheffield, and in its various processes affords the visitor opportunities of witnessing highly ingenious applications of machinery to manufacturing purposes. This is especially the case in the grinding of lenses and glasses for telescopes, microscopes, spectacles, &c., many thousands of which are produced every week at the manufactory of Messrs. CHADBURN Brothers, by whom the process was courteously exhibited and explained to us. The glasses are cut out of the required size with a diamond, and the corners are then nipped or broken off with plyers. This branch of the work is performed by females, and an experienced hand will nip or round from sixty to eighty gross per week. The glasses are then taken to the grinding room, where they are placed by women on concave or convex dishes, technically called "blocks," which will hold from six to twelve dozen glasses, according to their sizes. The glasses are attached to these dishes by means of pitch, and the dishes so prepared are placed on a machine which causes a number of blocks, constantly supplied with emery and water, to travel over them in regulated curves. The radius and curve of the tool are graduated to the focus of the glass, the magnifying power being increased or diminished by shortening or lengthening the curves or radii. When the glasses have been ground into the required form on the one side, they are smoothed with the finest emery, and polished with a preparation of the oxide of iron. They are next subjected to the same process on the other side, and are then ready to be put into the frames of spectacles. Machine-ground glasses are better polished, and are superior generally to those ground by hand, while the cost of production is reduced by 75 per cent.[63]

The change that has taken place here, and been remarked upon, has been one of scale: moving up from a small production unit to a larger one with initially water-power and subsequently steam-power on hand. However, the quality of the finished product, now put together by unskilled female labour to a formula which required neither literacy nor numeracy, still seems to have been good enough for an uncritical expanding market. Together with the growth in unit size of production, there were corresponding changes in the organisation of the industry.

Organisation of workshops and the development of the factory

What happened to the organisation of the instrument trade during the Industrial Revolution? There exist a number of accounts dating from after this period of transition, describing provincial premises and what occurred on them, such as the one quoted above: in particular, there are two descriptions

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eminent makers of achromatic microscopes in mid-nineteenth century London.

[63]. Billing (1858), 30.

dating from the 1890s describing the interior of famous and substantial instrument works, that of Grubb in Dublin, the other of Kelvin & White in Glasgow.[64] It is apparent from both of these that by the end of the nineteenth century all of the very different processes which went into constructing any of a variety of items which can be described as scientific instruments, were by under one roof. How had this happened? What made a factory at this earlier period? It was not merely a large building in which power was laid on, so that the workforce was compelled to change its earlier workpatterns to produce a particular commodity, although for the textile industry in particular this is how it came to appear in the popular imagination.[65]

The factory also served as the explanation why this change had occurred: through technological necessity, innovations in textile manufacture had obliged manufacturers to move from a domestic economy into a more centralised form of production, and with this a workforce which was bound 'by the impersonal forces of wage labour, their pride in old craft skills having been beaten out of them by the relentless march of the machine'. In fact, as Roderick Floud goes on to demolish his own caricature, by the 1851 census, half of the 'men' employed by 'masters', were in establishments of less than thirty employees.[66] As we have already seen, unskilled female labour was there to undertake the more repetitive tasks by this date, counted or not by the Census enumerators.

Even in the seventeenth century women were not excluded completely from crafts or trades, and that while unmarried women had a measure of independent economic status, the position of married women was that they assisted their husbands, and could assume his position in business upon widowhood, subject to certain restrictions.[67] Ivy Pinchbeck claimed that by the late eighteenth century 'the craftsman's wife was usually so well acquainted with her husband's business as to be "mistress of the managing part of it," and she could therefore carry on in his absence or after his death, although she herself might lack technical skill.'[68] Indeed, in technical

64. Fitzgerald (1896); Anon. (1898).
65. Tann (1970), 3-7,27-29.
66. Floud (1997), 111.
67. Clark (1982), 150-235.
68. Pinchbeck (1981), 282-305, especially 284: 'It is only when we come to the skilled artisan and trading classes, however, that we find women still taking a share in their husbands' concerns as a matter of course, and in almost every trade innumerable instances can be cited of

trades, 'a widow usually engaged able workmen to assist her, whilst retaining the management in her own hands.'[69] As Robert Shoemaker and Mary Vincent have recently pointed out:

> The problem of change and continuity in the history of women's work has much exercised historians, ever since the classic works of Alice Clark and Ivy Pinchbeck introduced the argument that, in England, women's work opportunities were far more equal to men's before fundamental changes in the structure of the economy (the spread of capitalism in the seventeenth century, according to Clark, and the industrial revolution, according to Pinchbeck) pushed them out. While such arguments continue to be influential, they have been rejected by some historians who have stressed the continuities in women's exclusion from the more prestigious jobs, arguing that the so-called 'golden age' of women's work posited by Clark and Pinchbeck never existed.[70]

Katrina Honeyman and Jordan Goodman, in an important article, suggested that the pattern of women's work is underpinned by two systems: the sex-gender system, and the economic:

> historically, these systems have interacted, sometimes in opposition and confrontation, at others in unison to create a specific gender division of labour ... The sex-gender system and its principal component, patriarchy, remain in the background so long as changes within the economic system do not impinge on the operation of the system. But when changes in women's economic position threaten to upset the equilibrium of the sex-gender system, the response of the patriarchal component is to establish a new set of rules defining the acceptable gender division in the workplace.[71]

Only twice between 1500 and 1900 have these two systems come into conflict, say Honeyman and Goodman; one of these protracted occasions being the Industrial Revolution.[72] Maxine Berg and Pat Hudson have demonstrated that the number of women working and the types of jobs they performed expanded during the early years of the Industrial Revolution, contracting after 1850; because the sources used for measuring the amount of work and who did it are deficient, this implies that the Industrial Revolution was indeed more revolutionary than hitherto recognised.[73]

As is the case today with small family businesses, the wife's role was often hidden until she was forced through her husband's death or bankruptcy to assume a more visible role. Perhaps an important part of the work of an instrument maker's wife was to 'keep the books', actually to run

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widows and single women in business.'

69. *Ibid.*, 285.

70. Shoemaker and Vincent (1998), 349.

71. Honeyman and Goodman (1998), 367.

72. *Ibid.*

73. Berg and Hudson (1992), 35-38; Hudson (1992), 225-230.

or maintain the finances of the business for which her husband made or assembled the stock. Trading could continue with the widow employing journeymen after her husband's death, and certainly in an earlier period when the guild structure in London was more effective, a widow was held responsible for the training of existing and new apprentices. M.A. Crawforth has commented that there

> are several implications consequent to the succession of a widow. It suggests that her husband had been running a business in which she had been involved to such an extent that she could continue the business. The training of apprentices infers the employment of at least one journeyman with formal training in the industry, and the approval of the guild officials in binding an apprentice to a widow indicates their confidence that she could reasonably be expected to continue in business for at least seven years.[74]

Widowhood could bring with it privileges not otherwise accessible to single or married women: property rights, the trusteeship of children and apprentices, and responsibilities which would otherwise have been exclusively male.

It is seldom known why individual women went into business, but it would appear from most of the examples found in the provincial directories that widows would carry on their late husband's firm, probably because they were already involved and could offer some form of continuity, sometimes to allow a young son time to grow up and enter the trade. One such example is that of Elizabeth Rabone, née Smith, described as a rule-maker, of Snowhill, Birmingham, widow of Michael Rabone who died about 1803; their son John took over the business in 1817 at the age of 22. During his mother's trusteeship, the firm was called Elizabeth Rabone until 1808, and Elizabeth Rabone & Son from then until 1817. Even so, Mrs Rabone continued to be listed as a rule-maker until 1835, so she must have retained an interest in the firm's affairs after her son assumed his father's position as head of the business.[75] Other examples show the enterprise of daughters: Mary and Ann Dicas were both daughters of John Dicas, who was a Liverpool liquor merchant. His hydrometer, a device for measuring the specific gravity of liquids and therefore of interest to the Excise, was patented in England in 1780,[76] and adopted that year by the United States government for estimating the strength of imported liquors. In London, a Board of Enquiry of the Royal Society was set up in 1802 to investigate the rival merits of a number of

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[74] Crawforth (1987b), 331.

[75] Hallam (1984), 17-20.

[76] British patent 1259, 27 June 1780, 'Constructing hydrometers with sliding-rules, to

different hydrometers then in use throughout the British Isles with a view to choosing the most effective for revenue use by the Excise. Because her father had died by this time, Mary Dicas submitted his instrument, travelling to London to explain its principles before the Board.[77] She must, therefore, have had some degree of technical understanding. She appears in the street directories as a hydrometer maker from 1797 to 1806, and the following year with George Arstall, a scale beam maker, whom she married. Ann Dicas, her sister, appears as a patent hydrometer maker between 1818 and 1821, and after her marriage to Benjamin Gammage in May 1821, he became the 'only proprietor of the patent.[78]

Former apprentices who married their master's daughters could find themselves inheriting a profitable business; but while it is fair to say that marriage was considered more of an economic contract than it is today, it is not possible to say whether it was entirely mercenary.[79] Two immigrant Italian barometer-making families, that of Casartelli based in Liverpool, and Ronchetti based in Manchester, appear to have intermarried in at least two generations with implications for the inheritance of their businesses.[80] In this particular instance, and no doubt, with other immigrant Italians, a common non-conformist religion played a large part in keeping the business within the extended family. Thus through the act of marriage, it is possible that women played a central, but invisible role, in cementing and extending a close-knit scientific and business community, and ensured the cultural reproduction of trade knowledge. Throughout this period, women were evidently much involved in the instrument trade. Their roles, however, varied immensely. The most readily identifiable women were those running a business, since they were listed in trade directories. But often they took over only when widowed, whilst a youthful son and heir completed his apprenticeship. The unseen role that they may have played before their husbands'

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ascertain the strength of spirituous liquors, malt worts, and wash for fermentation'.

77. Tate and Gabb (1930), 7-8.

78. For the trading enterprises of the Dicas, Arstall and Gammage families, and their premises in Liverpool and Manchester, see Morrison-Low (1996a).

79. See, for example, Davidoff and Hall (1987), 321-329; Stone (1985); and the chapter 'Marriage' in Thompson (1988), 85-113.

80. Wetton (1990-91), 48; ms. copy of 'Brief History of the Firm of Joseph Casartelli & Son', dated August 1915, in Manchester Museum of Science and Industry: 'After some time Baptist Ronchetti Meringio sent to Italy for his son Charles Joshua Ronchetti and also for his nephew Louis Casartelli...In 1851 Jane Harriet Ronchetti marries Joseph Louis Casartelli, of Liverpool, and the latter succeeds Charles Joshua Ronchetti at 43 Market Street [Manchester].'

deaths is difficult to assess, but if they had a long-term involvement in the financial side of the business this would certainly have enabled them to run the firm successfully when widowed. The succession of running a business, if there was no apparent male heir, might pass through a female heir to her husband's family. A number of instruments engraved with an apparent woman 'maker's' name survive, but whether the woman in question ever turned at the lathe, or fitted or adjusted the optical parts, is a matter for speculation. Other women, less readily identified by name, drew glass, worked in the cabinet shops, and generally undertook less skilled work.

Apart from being a family enterprise, the other network which might have drawn people into the business was that of religion. However, this does not appear to have been the case: although there were Quakers who were also instrument makers - for instance, in the early period, the royal clockmaker Thomas Tompion (1638-1713), his apprentice George Graham (1675-1751) - who married into Tompion's family - and Daniel Quare (1649-1724), maker of royal barometers. Although all were primarily London clockmakers, all are known to have made mathematical instruments, and, given the common ground between the two trades at this date, precision clockmaking can be seen as a specialist subsection of mathematical instrument making. Arthur Raistrick makes the point that the Quaker 'simplicity of living, and moderation in spending, freedom from luxury, and the general literacy which found relaxation and pleasure in learning and pursuit of knowledge ... made it easier for them to apply much of their abundant returns to experiments in the processes of their trade, and to promoting the welfare of their employees.'[81] However, religion does not appear to have worked as a network, in the way that the family operated: a later enterprise with Quaker roots was that of the Irish telescope makers, Thomas and Howard Grubb, but it is not clear that they remained non-conformists, and Howard certainly married outside the sect.[82] The incidental knowledge of an instrument maker's religion does not appear to add significantly to our understanding of other networks which may have had a bearing on the overall operation of the trade: the Dollonds, immigrant Huguenots, did not work within a Huguenot community. Nor did the Birmingham Carpenters, all Unitarians, work exclusively within a Unitarian network, although the entire family clearly took their religion seriously.[83] The Roman Catholics appear to have been mostly recently-arrived immigrant Italians, attracted to the new

81. Raistrick (1950), 221-242, 339.
82. Glass (1997), 10.
83. J. Estlin Carpenter, 'Introductory Memoir' in Carpenter, (1888).

industrial centres as well as London, some of them en route to the United States; again, as with the Jews, most appear to have worked with people like themselves when family ties failed. Most provincial instrument makers were apparently members of the established church - they can be found in church registers - and the trade as a whole formed a cross-section of religious convictions.

Workshop production

Were there changes within the workshop during this period? The division of labour has only ever been hinted at by instrument historians, primarily through lack of evidence. Holland's account confirms this practice in the Sheffield manufactory of Proctor & Beilby:

> I may remark that the variety of articles manufactured was very great, comprising generally telescopes of all sorts, from the four feet achromatic on brass stand, to the little simple spyglass of a few inches in length; and microscopes ... But besides articles which might be called *optical* in a sense more or less strict, the workshop turned out an immense quantity of other things: two may be mentioned, viz., tinder-boxes and inkpots ... These articles being made of brass, were all polished by old Daniel Vaughan... Microscopes of all sorts, as well as various optical and other knic-knacs, were mostly made by Dickey Hobson, a Birmingham man, who was accounted an excellent user of a file ...[84]

Particular individuals had specific tasks, although the output of the firm was clearly extremely varied:

> There was a systematic distribution of work throughout the establishment, one man being mostly employed on a special class of articles, in the making of which he acquired great dexterity. Each, too, had his own "side," or work-board, and "engine," as his lathe was called, about which were arranged "chucks" of all shapes. Prime, as a workman, was George Hadfield; and not less remarkable as a toper than a turner. I used to wonder at the desperate dash with which, after his weekly drunken fit, his trembling hand applied the tool to a brass-casting, used in the successful production of large "day and night" telescopes. John Holland [the author's father] was also employed in similar work; and his brother Amos, in making accurate imitations of the 14, 18 and 27 inch telescopes of the celebrated Dolland [sic].[85]

Holland names the workman identified with the production of each particular instrument through the workshop: William Eggington with 'trumpet' telescopes; Johnny Coe with reading glasses, although formerly employed in producing sundials, while 'of the spectacle makers I remember but little, though they formed a broad feature in "the works" - their "templets," "visuals," "noseys," and

[84] Holland (1867).
[85] *Ibid.*

"goggles," being produced gross upon gross'.[86] As with W.& S. Jones in London, the large amounts of spectacles available helped to underpin the cost of constructing other less essential optical instruments.

Many of the circumstances of these people's working lives are what one would expect from evidence from other trades, such as the methods used by the employers to tie the men to their particular business through what Holland described as 'stuffing', elsewhere called 'trucking'.[87] Also, the very rural aspects - the bee-keeping, the cows, the bird-fanciers - meant that the employees were kept aware of the seasonal cycle, in a way similar to the better-documented case of the hand-loom weavers, whose work on their small-holdings appears to have been seasonal.[88] All these details seem obvious when stated; but this first-hand account provides direct confirmation to replace what have previously only been scattered clues about the nature of the daily lives of workers in the provincial scientific instrument trade.

Holland's description of the social aspects of workers' lives included the bleaker side. Like all good Victorians, he was by 1867 concerned in his retrospective view with the 'excessive drinking' of his colleagues. The temperance movement first appeared in the north of England in the early 1830s, initially as an attempt to reform the drinking habits of all classes. It has been commented that during the 1820s: 'it was among the skilled craftsmen, with their exclusive initiation ceremonies, that drink customs had their strongest hold'.[89] Similarly, by 1867, Holland could see with the benefit of hindsight how godless the shop floor had been. He regretted the lack of education and literacy at a time when, as another eminent historian has put it: 'almost the entire skill or "mystery" of the trade was conveyed by precept and example in the workshop, by the journeyman to his apprentice. The artisans regarded this "mystery" as their *property*, and asserted their unquestionable right to "the quiet and exclusive use and enjoyment of their ... arts and trades"'.[90] Education, both for the skilled and the unskilled, was to come much later.

Although Holland had started life as an optical instrument maker, he subsequently moved

[86] *Ibid.*
[87] The system in Sheffield is discussed by Leader (1905), 109-112.
[88] E.P. Thompson (1968), 297-346, discusses the 'myth of the golden age'.
[89] Harrison (1971), 40.

into journalism, contributed three volumes to Dr Dionysius Lardner's *Cabinet Cyclopaedia*, a cheap and popular work consisting of 133 volumes produced between 1829 and 1849, aimed at those who could not afford the expense of a *Britannica*. Holland's writings for Lardner were on the manufacture of metals - two volumes were concerned with iron and steel, while the third treated other non-ferrous metals including brass. These also discussed the uses to which the finished metal might be put. In a chapter discussing the manufacture of 'Optical Instruments', he wrote the following paragraph, which perhaps sums up the essence of his later 1867 articles:

> During the century which followed the invention of telescopes, a proper share of the attention of the philosophic world was directed to the improvement of the instrument. It is, however, little more than within about fifty years since [i.e. since c.1785] that the progress of scientific investigation, together with the cheapness of brass, as well as economical and improved methods of fabrication, laid the foundation in this country of an extensive trade in telescopes and microscopes of all descriptions, along with a vast variety of apparatus for philosophical purposes, in which brass is the principle material. Thus, while the more opulent patrons of the science gratified their taste by the purchase of unique instruments at any price from the first makers, the curiosity, and indeed the convenience of the public in general, created a considerable demand, to meet which, *ingenious workmen were set to produce, according to established data, instruments, the theory of which the manufacturer sometimes little understood, and still seldom extended beyond the articles so successfully copied, in vast quantities for the metropolitan houses, and presently, for more direct sale on their own accounts.* [My italics.] Not only in London, but in Birmingham, and particularly in Sheffield, the business of optician has been carried on with success; at the latter place there existed, between thirty and forty years since, the largest optical manufactory in the world; so extensive, indeed, were the operations, that the power of the steam-engine was applied to the grinding of glasses, a process which, as there conducted, is one of the most interesting that a stranger can witness. There are, at present, some extensive works of this description in the last-named town; and there, as well as in other places, instruments, at the sight of which some of the old scientific investigators of this and other countries would have felt no little surprise, are daily produced in a beautiful style at exceedingly low prices. The combination of neatness, efficiency, and cheapness has led to the almost universal possession of some one or more articles of this class.[91]

The italicised passage, describing how Midlands entrepreneurs produced in large numbers instruments to satisfy the demands of the buoyant London market at the lowest prices, only subsequently selling material on their own account, is central to our understanding of the rise of provincial instrument manufacture. Here, spelled out, is contemporary confirmation of what

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[90]. E.P.Thompson (1968), 279.
[91]. Holland (1834), 260-1.

several instrument historians have long suspected - not everything with a famous London signature was necessarily made in that workshop. Long before the Midlands manufacturers marketed their instruments overtly, they had captured a substantial slice of the London market and were manufacturing on an industrial scale.

Chapter 5: Supply

Marketing strategies: getting the goods to the market place

Manufacturing desirable consumer products in the provinces for good economic reasons was only a first step: but somehow these had to be brought to the attention of the would-be customer, who then had to be persuaded to purchase. John Millburn identified 'marketing techniques' as one aspect of instrument making which has barely been studied.[1] This chapter will outline some of the more obvious methods used to attract sales by instrument makers during this period, culminating with the case-study of the promotion by the Society of Arts of a cheap microscope manufactured in Birmingham. This has some illuminating detail. At the start of the period under discussion, there were two principal markets for the provincial trade: the local one, already discussed in chapter 2, which was never large; and the London one, into which the larger part of the provincial output must have anonymously vanished, reappearing inscribed with a 'London' address or signature. In 1851, Henry Mayhew wrote:

> An experienced tradesman said to me: "All these low-price metal things, fancy goods and all, which you see about, are made in Birmingham; in nineteen cases out of twenty at the least. They may be marked London, or Sheffield, or Paris, or any place - you can have them marked North Pole if you will - but they're genuine Birmingham. The carriage is lower from Birmingham than from Sheffield - that's one thing."[2]

The London market acted as the gateway to the international market overseas. There is some information on the methods of supply to both these markets, but very little about pricing arrangements, particularly wholesale versus retail costs. This chapter will outline the supply of products of the instrument trade to its markets; the subsequent chapter will deal with demand.

With industrialisation came a number of changes in the economic climate which helped both local and international markets to grow. The revolution in transport meant that with increasingly improved internal communications, it became possible to move manufactured goods from the growing industrial cities in the Midlands and the North to the marketplace in London, and from thence to captive imperial markets overseas. Not only were instruments a part of that traffic, but

1. Millburn (1986c), 84.
2. Mayhew (1861), 333.

they also helped to shape the transport revolution itself: the armies of surveyors who mapped these islands for valuation purposes were succeeded by younger generations who surveyed the landscape with a view to altering it with cuttings and embankments for canals, roads and subsequently, railways. Overseas, parts of the Empire were surveyed and linked together: the growing Royal Navy - Britain was at war for much of the period of the Industrial Revolution - and merchant navy both needed instruments to navigate them into safe harbours. There were 12,464 ships registered in the United Kingdom in 1788, rising to 15,734 in 1800, 20,253 in 1810 and 21,869 in 1815; thereafter numbers remained at about 20,000 until the end of the 1830s when after a gradual rise, by 1851 there were 26,043 vessels: each of these would have required at least two sextants or octants, a compass, and a chronometer.[3] Government contracts for the supply of instruments, usually awarded to London instrument makers, were eagerly sought after: for instance, the supply of standardised hydrometers to the Excise. The competition for this was held in 1802, and ten makers from throughout the United Kingdom responded.[4] In order to satisfy this rapidly increasing demand for instruments, the London makers enlarged their local subcontracting circles in Clerkenwell, before turning to metal-workers elsewhere, who were able to turn their production skills from more general manufacture, to something more specific; and just such workers and conditions were to be found in the rapidly expanding towns of Sheffield and Birmingham. Demand for nautical instruments, and especially the skills necessary for their repair, generated this type of service in Bristol and Liverpool: it would take too long to send an instrument back to London for adjustment.

Public interest in science had grown, reaching new audiences, and permeating down the social scale.[5] The growth in literacy meant that provincial newspapers, reporting events in the capital, led to local emulation of cultural events in London. The popularisation of science by travelling lecturers, such as those seen in the vivid paintings of Joseph Wright of Derby, were increasingly noted in the newspapers of the larger market towns.[6] The geographical circuits covered by individuals could be country-wide, while their subjects encompassed much of natural

[3]. Numbers from Mitchell (1988), 535-6. For the chronometer, see Davies (1978).
[4]. Tate and Gabb (1930), 1-13; McConnell (1993a), 9-18.
[5]. There is a considerable literature on this subject: good bibliographies are given in Inkster and Morrell (1983), and Averley (1989).
[6]. See Fraser (1990); Schofield (1963).

philosophy and were accompanied by lecture demonstrations.[7] Some of these, notably Benjamin Martin and James Ferguson, marketed instruments by publishing their lectures in textbooks; catalogues of available instruments would be listed at the end of the volume.[8] Increasing numbers of provincial literary and philosophical societies were founded, often acquiring their own suite of demonstration apparatus along with collections of natural history or antiquarian content.[9] With the rise of a consumer society, aspiring members of the middle classes would be happy to acquire the cheaper products of the instrument-makers' workshop: small eyeglasses (too low-powered to be graced with the name 'telescope'), simple magnifying glasses or 'microscopes', or basic box cameras obscura to assist one's clumsy daughters learn the gentle art of sketching. The catalogues of instrument retailers demonstrate that these could be supplied, at prices to suit the new consumer.

After the Napoleonic Wars, public interest in science moved beyond the middle classes to the level of the artisan: the founding of the Mechanics' Institutes in the 1820s provided further lecture circuits on a national scale. This movement was fostered by philanthropic middle-class interests, among them that of the Society of Useful Arts, founded earlier in 1754, which besides providing premiums for useful inventions, began a series of exhibitions in London from 1760 and in the provinces from the 1840s. The British Association for the Advancement of Science, in its peripatetic annual meetings, held from 1832, soon began to stage displays of 'philosophical instruments, models of invention, products of national industry' from their first exhibition in Newcastle-upon-Tyne in 1838.[10] These were the native precursors of the Great Exhibition of All Nations, held in London in 1851, which reinforced British belief in the success of imperialism, while advertising her commercial expertise to markets overseas. There was also a series of national exhibitions held by the post-revolutionary French government to encourage manufacturers to improve their products commercially: eleven of these were held between 1798 and 1849, and clearly had some impression, albeit unacknowledged, on the mid-nineteenth century British exhibition movement.[11] This chapter will show how instruments were peddled in the streets, sold in

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7. See, for instance, Harrison (1957), which re-creates an Edinburgh-based itinerant lecturer's career covering America, Ireland and the English Midlands, principally traced from provincial newspapers.

8. For Martin, see Millburn (1976), (1986a) and (1986b); for Ferguson, see Millburn (1988b).

9. Brears (1984).

10. *Catalogue...* (1838).

11. Turner (1989), 24; Beauchamp (1997), 10-11.

shops, and generally brought to the attention of a wide range of potential customers. It will look at the supply chain of wholesalers, retailers and agents, investigate the methods by which provincial instrument manufacturers managed to attract the attention of customers, so that by the time of the Great Exhibition they were no longer entirely reliant on London middlemen.

Getting instruments to the point-of-sale

How were instruments made available to customers during the period of the Industrial Revolution? Changes in retailing during this period helped to open up new markets by stimulating demand by creating what Maurice Daunton has called 'a constant market drawing goods from a wide range of suppliers.'[12] From the late seventeenth century, hawkers and pedlars carried a small number of goods to regularly-held markets or fairs, or touted them around the countryside. In a detail of the 1824 painting of 'St. James's Fair, Bristol', by Samuel Colman, an unidentified stallholder offers an hourglass to a woman admiring herself in a mirror, while in the background a pair of globes and two barometers can be seen amongst the items for sale.[13] As late as the mid-nineteenth century hawking remained a method of selling instruments outside the largest cities: the Dundonian instrument maker George Lowdon wrote:

> There was when I commenced business [in 1850] no regular manufacturing optician in Dundee. One Balerno, who lived in Yeaman Shore, and another, Antony Tarone, who had his house in Murraygate, gave themselves out as 'barometer and mirror makers'. The former hawked his goods about the street, and usually had a barometer under one arm.[14]

Another earlier example of such a peripatetic hawker was the Italian Peter Rabalio, based in Birmingham for a time, but whose trade card, printed in Worcester in about 1790, stated that:

> Mr RABALIO informs the Public, That whoever has bought, or buys a Barometer of him, he will warrant to be good, and will repair them Gratis, at the Sign of the Barometer, in Edgbaston-street, Birmingham; in Coventry, at the Sign of the Dolphin; in Leicester, at the Sign of the Golden Lion, in Hamston Gate; and in Worcester, at Mr Dewce's, in High-street, near the College-Gate.[15]

Rabalio's peregrinations around these Midland towns can be traced in the local press, where he advertised his arrival, and before his departure from Birmingham offered his stock for sale by

12. Daunton (1995), 270.
13. Greenacre (1973), 203-6.
14. Quoted in Clarke et al. (1989), 147.
15. Trade card at the Whipple Museum of the History of Science, Cambridge.

lottery.[16] Jenny Wetton comments on the conviction in 1823 of a Manchester man, Jeanno Cocino, servant of the barometer maker Antonio Peduzzi, for hawking Peduzzi's wares without a licence: Peduzzi took no responsibility for his servant's actions, and so Cocino went to prison for three months.[17] Neil McKendrick discusses at some length the 'many other unsung heroes in the spread of fashion to a new market of consumers - the new class of itinerant salesmen and the provincial shopkeepers.'[18] He highlights the obscure figure of the 'Scotch Draper' or 'Scotch Pedlar', who 'specialized in the products of the new industrial centres ... sold on credit ... [and] had his special area in which he called on his customers every week for cash by instalments.' McKendrick concludes that 'without the service of these new itinerant salesmen much of the provincial market would have been stifled for want of opportunity to buy.'[19]

By the mid-nineteenth century, Henry Mayhew reckoned that 'during the last century, and for the first ten years of the present, the hawker's was a profitable calling', and found that the Census return for 1841 gave a total of 17,270 hawkers for Great Britain.[20] He also devoted a section to 'cheap-Johns', or hawkers peddling hardware goods manufactured in Sheffield or Birmingham (not always honestly) around the country and on the edge of the capital, and another to the 'swag-shops of the metropolis', or wholesalers. These contain cheap goods to be resold on the street, and amongst 'the useful and the "fancy" goods' included 'Spectacles..., Telescopes - one, two and three draws [and] Mathematical Instruments.' Mayhew detailed these further: '...dials and clocks, combs, optics, spectacles, eye-glasses, telescopes, opera glasses, each 10d to 10s...'.[21] He calculated that there were one hundred and fifty 'swag-shops', and that half of these were 'the warehouses described by their owners as "Birmingham and Sheffield" or "English and Foreign", or "English and German". It is in these ... that the street-sellers of metal manufacturers find the commodities of their trade.'[22] Mayhew spoke to an employee of one of the largest and most longstanding of these establishments:

> ... about 200 "hands" are employed, in the various capacities of salesmen, buyers, clerks,

16. *Aris's Gazette*, 2 June 1788; 9 March 1789; 10 and 17 August 1789; 29 September 1789; he died in Italy at the end of 1790: *ibid.* 10 January 1791.
17. Wetton (1990-91), 41.
18. McKendrick (1982), 86.
19. *Ibid.*, 88-89.
20. Mayhew (1861), 376.
21. *Ibid.*, 335.
22. *Ibid.*, 336.

travellers, unpackers, packers, porters, &c., &c. ... In one week, when my informant assisted in "making up the books", the receipts were upwards of £3000.[23]

Mayhew calculated the profit on this £3000 at 35%. Several of the manufacturers based in Sheffield and Birmingham known to have produced instruments, advertised themselves as 'Wholesalers'. For instance, Peter Frith & Co. appeared in the Sheffield directories from 1814, in the Birmingham directories between 1818 to 1825, and in the London directories from 1822. Friths' maintained London premises into the 1870s, with a named agent from 1838. In the Birmingham directory for 1818 the firm was described, not as instrument makers, but as 'manufacturers of bronzed copper, fire proof and other powder flasks, improved shot belts, shot chargers etc. etc. etc. Sheffield, and at No. 6 Cross-street, Hill-street, Birmingham. J. Godfrey agent' J. Godfrey appears in his own right in the Birmingham directory from 1823 until his death in 1842 as a 'manufacturer of all kinds of spectacles etc.' By 1860, 'Peter Frith & Co., wholesale opticians, of 81 Arundel Street, Sheffield and 5, Bartlett's Buildings, Holborn, established 1790', were taking large advertisements in the Birmingham street directories [Fig 5:1].[24]

From these examples it can be seen that there was a reasonably complex supply chain. One of the difficulties is the language, as there was no compulsion to tell the truth, especially in advertisements: for instance, Frith's claim, cited above, to have been 'established 1790' when there is no trace of the firm before 1805, is merely one to give the venerability (and by implication, integrity) of age. Firms claimed to be 'real' manufacturers, 'makers' 'working optician' in order to try to make the distinction between themselves and retailers; but as Michael Crawforth has pointed out, the name marked on an instrument was a form of free advertisement, and gave the impression 'not unintentionally' that the owner of the name had made the instrument.[25] It is evident, however, that by the mid-nineteenth century, wholesalers were supplying many retailers who had no making skills themselves. This is a situation which can be traced back in time to the 1760s at least, when a number of the London shops were merely retailing premises. The role of the agent, based in another city, often London, geographically remote from the manufacturing centre, was important to the firm, although his full purpose remains unclear: was he securing orders, or protecting credit? That the agency may have acted as retail premises for instruments manufactured in the Midlands is

[23]. *Ibid.*, 336.
[24]. Sheffield and Birmingham street directories, *passim*.
[25]. Crawforth (1985), 477-8.

PETER FRITH AND CO.,

WHOLESALE OPTICIANS,

81, ARUNDEL STREET, SHEFFIELD,

And 5, Bartlett's Buildings, Holborn, London, E.C.

Manufacturers of all kinds of Military, Naval, Tourists', & Deer-Stalking

TELESCOPES;

ASTRONOMICAL INSTRUMENTS;

SINGLE AND DOUBLE ACHROMATIC PHOTOGRAPHIC LENSES,

MATHEMATICAL INSTRUMENTS,

MICROSCOPES, OPERAS, READING GLASSES, STEREOSCOPES, SPECTACLES,

And all Descriptions of Convex, Concave, and Meniscus Spectacle Eyes and Pebbles.

FOR HOME AND EXPORTATION. ESTABLISHED 1790.

PETER FRITH AND CO.,

MANUFACTURING OPTICIANS, &c.,

ARUNDEL STREET, SHEFFIELD,

And 5, Bartlett's Buildings, Holborn, London.

ESTABLISHED 1790.

P. F. & Co. would call the attention of the Trade, Merchants, & Shippers to their Improved

SPECTACLES;

CONVEX, CONCAVE, AND MENISCUS SPECTACLE LENSES;

Military, Marine, and Tourists'

TELESCOPES;

ACHROMATIC MICROSCOPE AND TELESCOPE OBJECTIVES;

MICROSCOPES;

WOOLLEN & LINEN PROVERS, &c.;

Twin Photographic Stereoscopic View Lenses; Camera Lucidar, Right Angle, & Compass Prisms, Rifleman's Telescopes;

EXHIBITION OPERA GLASSES, LENSES, &C.

Astronomical & Surveying Instruments made to Order.

Fig. 5:1 Advertisements for Peter Frith & Co., from Birmingham directories, 1860 and 1865.

supported by the existence of items with provincial 'names' and London 'addresses'.[26]

As T.S. Ashton wrote in his classic account of *The Industrial Revolution*, 'large-scale production required not only division of labour and specialized appliances, but also the support of an organised system of transport, commerce and credit.'[27] Even before the period under discussion, there had been improvements in communications between London and the provinces, producing a more integrated economy: 'investment in roads and the greater efficiency of stagecoach services and road carriers made road transport "a dynamic force in agricultural marketing in the century before 1850"'.[28] Indeed, the idea of a 'transport revolution' as a necessary concomitant to that in industry, now rests less on the heroic ages of new canal and railway construction than on general improvements in all forms of transport. Martin Daunton sees 'the crucial point for understanding the chronology of British economic growth [was when] transport costs [fell] sufficiently to make a difference to specialization and competition.'[29] He mentions the piecemeal but unspectacular achievements of the predecessors of the great engineers, who 'devised better road surfaces, altered the design of coaches, modified the rigging or hull design of sailing ships, or improved access to harbours and rivers', and points out that the more modest sums invested in these improvements may well have repaid bigger dividends than the 'investment of large sums in impressive feats of engineering.' The real revolution here, was not merely in solving the technical problems, but in producing a new infrastructure which could organise investment in change. Thus, investment in the canals, turnpikes and coastal shipping improved these networks, while producing changes in organisation and efficiency, and this was continued by the railways: 'above all, investment in transport reduced transaction costs in the economy'.[30]

Yet the 'impressive feats of engineering' mentioned above brought with them armies of the

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26. For example, National Museums of Scotland, inv. NMS T.1993.119: small single draw telescope, signed 'Frith, London'; NMS.T.1993.120: small three draw telescope, signed 'Proctor, Beilby & Co., London'; a Culpeper microscope, signed 'Proctor, Beilby & Co., London', was offered for sale by Christie's South Kensington, 16 September 1982, Lot 81; another microscope, signed 'G. & W. Proctor, London', was offered for sale by Sotheby's, 23 June 1987, Lot 209. Frith had London premises from 1838, but those of Proctors have not been located.

27. Ashton (1968), 34.

28. Hudson (1992), 77, quoting J. Chartres, 'The Marketing of Agricultural Produce', in J. Thirsk (ed.), *The Agrarian History of England and Wales* vol. V (Cambridge, 1985), 446.

29. Daunton (1995), 285.

practical users of instruments, and the solution of the 'technical problems' produced variations on the types of instrumentation. Both surveying and navigation are intensely practical professional activities. While some of the increased demand for more accurate surveys, or for finding the longitude at sea, or being able to measure the alcohol content of spirits, came from government (and will be discussed more fully in chapter 6), other markets were to be found in the professions themselves, while they were making possible the changes in Britain's internal transport infrastructure.

Shops, advertisements and trade literature

What methods were used to attract the attention of potential buyers of scientific instruments? As we have seen in chapter 4, purchases of off-the-shelf items, as reported by visiting foreigners, could be made in shops in London from at least the early eighteenth century: as John Millburn noted, 'Though not such a localized trade as (say) silk-weaving or clockmaking, the instrument makers tended to congregate along the main shopping streets from Cheapside to Charing Cross; Fleet Street in particular was a favourite location.'[31] D.J. Bryden has examined the advertising material concerning mathematical instrument making in London from 1556 to about 1714, and concludes that 'advertising was aimed at informing professional users from whom particular instruments could be purchased, but not on informing customers in specific terms of the range of instruments manufactured ... until the early eighteenth century most mathematical instruments were commissioned. Only [then] ... is there evidence of over-the-counter sales, and advertising aimed at encouraging the growing consumer market to buy mathematical instruments for the practice of science as a social or recreational activity.'[32] It would appear that buying off-the-peg instruments for pleasure was a part of that 'consumer boom' in which 'those making and selling such consumer goods ... as a result of their earnest commercial endeavours, played a substantial and a positive role in bringing [these changes] about.'[33] The rise of fashion, and other aspects of consumer demands will be examined in the following chapter; but there were also developments on the supply side, especially marketing, in particular those pioneered by the master potter, Josiah Wedgwood and his contemporary in the manufacture of metal goods, Matthew Boulton, as demonstrated by Neil

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30. *Ibid.*, 285-314.
31. Millburn (1986c), 82.
32. Bryden (1992), 301.
33. McKendrick (1982), 2.

McKendrick.[34]

McKendrick shows that both these entrepreneurs aimed to reach the 'middling' people: 'like Wedgwood, Boulton sought royal and aristocratic patronage to give a lead to the rest of society in the confident knowledge that social emulation would ensure emulative spending in the rest of society.'[35] Some of the greatest figures in the kingdom owned and used scientific instruments: the King himself (unusually for his family) was extremely interested in astronomy and practical mathematics, and owned a large cabinet, and he ensured that the royal children were instructed in scientific demonstration by a special tutor.[36] The third Earl of Bute, perhaps the most important politician of his generation and a considerable influence on the young George III, put together an important collection of outstanding instruments, although these were subsequently dispersed at auction in 1793.[37] Patronage of this nature was exploited by the instrument makers, some of whom held Royal Appointments: perhaps most famously, the London maker, George Adams the elder, although as John Millburn has shown, these appointments were not always as truthful nor as well-regulated as today.[38] Naturally, this phenomenon occurred first in the capital. However, by the early nineteenth century the advertisements of even relatively obscure provincial instrument makers proclaimed royal and noble customers: for example, Alexander Alexander of Exeter is known to have produced an improved drawing device, the 'Graphic Mirror', and claimed in advertising the patronage of 'the King, the Duchess of Kent & Princess Victoria' (his brother was a physician in attendance at Kensington Palace). By 1851, the Sheffield opticians Chadburn Brothers proclaimed their patronage by H.R.H. Prince Albert, while their rivals, J.P. Cutts, a few streets away stated that they were 'by special appointment optician to Her Majesty'. J. Abraham, who had shops in the fashionable spa towns of Bath and Cheltenham just before the accession of Victoria, declared on his trade card that he was 'Optician and Mathematical Instrument Maker to His R.H. the Duke of Gloucester and His Grace the Duke of Wellington'.[39] Whether this was true or not - the provision of a Royal Warrant was not well-controlled at this period - it clearly held

34. McKendrick (1960); Robinson (1963); McKendrick (1982), 69-78.
35. McKendrick (1982), 71.
36. Morton and Wess (1993).
37. Turner (1967); Morrison-Low (1995a).
38. Millburn (1991).
39. Crawforth (1985), 493, 491 and 500; Calvert (1971).

immense snob appeal.[40]

McKendrick demonstrated 'how new methods of display excited not only occasional impulse buying, but more sustained and regular buying than could have possibly occurred without them'.[41] As Dorothy Davis has shown, during the early stages of the industrial revolution shop premises were to be found mainly in fashionable parts of London and subsequently in the main thoroughfares of growing cities outside.[42] 'They were almost invariably small, independent shops, owned and run by the shopkeeper on the spot... Shopkeepers were regarded as skilled men - skilled, that is, in their particular trade and no other.'[43] The shop premises of the instrument trade contained material made by the shopkeeper, but also by other suppliers: 'where to buy, from wholesalers or manufacturers or individual craftsmen, how to bargain with them for the right purchase and mix ... a stock suitable to their particular custom - these formed, as always the most important and the most difficult part of their skill in any trade.'[44] Thus 'shopkeeping' then was as complex a business as it is today. For instance, in Liverpool in 1795, an advertisement by a retailing wholesaler states: 'Robert Preston has on sale at his wholesale commission warehouse in Lower Castle street, Port, Madeira, ..., Turnery Wares, Brushes, Brass Wares and Furniture, Optical Instruments, Coffin Furniture, Carpenters', Shoemakers', and Smiths' Tools ...',[45] all of which would be bought by eager Liverpudlian consumers. But these wholesale premises were to give way to specialist shops, often, McKendrick asserts, using 'new methods of advertising [which] excited a new eagerness to consume, and made known and desirable goods which would otherwise languish unbought.'[46]

Using trade cards, inventories, plans and contemporary comment as evidence, Claire Walsh has shown how the design of London goldsmiths' shops in the early eighteenth century played an important part in the marketing techniques of the retailer.[47] Unfortunately, few instrument makers' trade cards illustrated their premises, although some are known. One London example illustrates

40. Millburn (1991), 2.
41. McKendrick (1982), 97.
42. Davis (1966), 252.
43. *Ibid.*, 255-6.
44. *Ibid.*
45. *Gore's Liverpool General Advertiser*, 23 July 1795.
46. McKendrick (1982), 97.

the interior of Thomas Blunt's establishment in about 1800 at 22 Cornhill, and 'shows a shop with two windows displaying an octant, telescope, protractor, spectacles, microscope, and many other items unrecognizable because of their small size' comments Michael Crawforth [Fig. 5:2].[48] Walsh explains that goldsmiths put high-value items into 'show-glasses', which were glass display cases which could be either hung in the window or outside the shop where they were placed to attract the attention of passing customers: the glass fronts were an attempt at preventing the expensive, and usually small, contents from being stolen. It would appear that instrument shops also used these to attract passing custom. A paragraph in a Bristol newspaper in 1758 reveals that:

> Last Wednesday, at six o'clock was stolen from the shop window of John Wright, Mathematical instrument Maker, St. Stephen's Lane, a glass case two feet four inches by one foot eight inches, containing about 12 dozen steel bow spectacles, 3 dozen metal ditto, 1 dozen or upward of temple ditto, 7 cases opera glasses, some neat vellum draw'd ditto, 3 hydrostatic instruments, tortoiseshell books, 1 silver name piece, (John Wright, Maker, Bristol) Capt. James McTaggart engraved upon it, with divers other things.[49]

Another interior, produced for the Great Exhibition in 1851 [Fig. 5:3], is as Crawforth comments, 'the frequently reproduced interior view of the Chadburn Brothers' shop in Sheffield ... [which] shows a great many instruments in recognizable detail ... it seems justifiable to assume that the firm sold everything that was illustrated.'[50] Although no description of a London shopfloor has been found from the mid-nineteenth century, there is a fictional description of a shop interior, given by perhaps the most famous and prolific novelist of his day, Charles Dickens, in 1848:

> Just around the corner [from the premises of Dombey and Son] stood the rich East India House...Anywhere in the immediate vicinity there might be seen ... little timber midshipmen in obsolete naval uniforms, eternally employed outside the shop doors of nautical Instrument-makers in taking observations of the hackney carriages.
>
> Sole master and proprietor of one of these effigies ... and proud of him too, an elderly gentleman in a Welsh wig ...
>
> The stock-in-trade of this old gentleman comprised chronometers, barometers, telescopes, compasses, charts, maps, sextants, quadrants, and specimens of every kind of instrument used in the working of a ship's course, or the keeping of a ship's reckoning, or in the prosecuting of a ship's discoveries. Objects in brass and glass were in his drawers and on his shelves, which none but the initiated could have found the top of, or having once examined, could have ever got back again into their mahogany nests without assistance...[51]

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47. Walsh (1995).
48. Crawforth (1985), 482. The card is from British Museum, Ambrose Heal Collection, 105.14.
49. *Bristol Weekly Intelligencer*, 25 February 1758.
50. Crawforth (1985). The original is in the Science Museum collection.
51. Dickens (1970), 88.

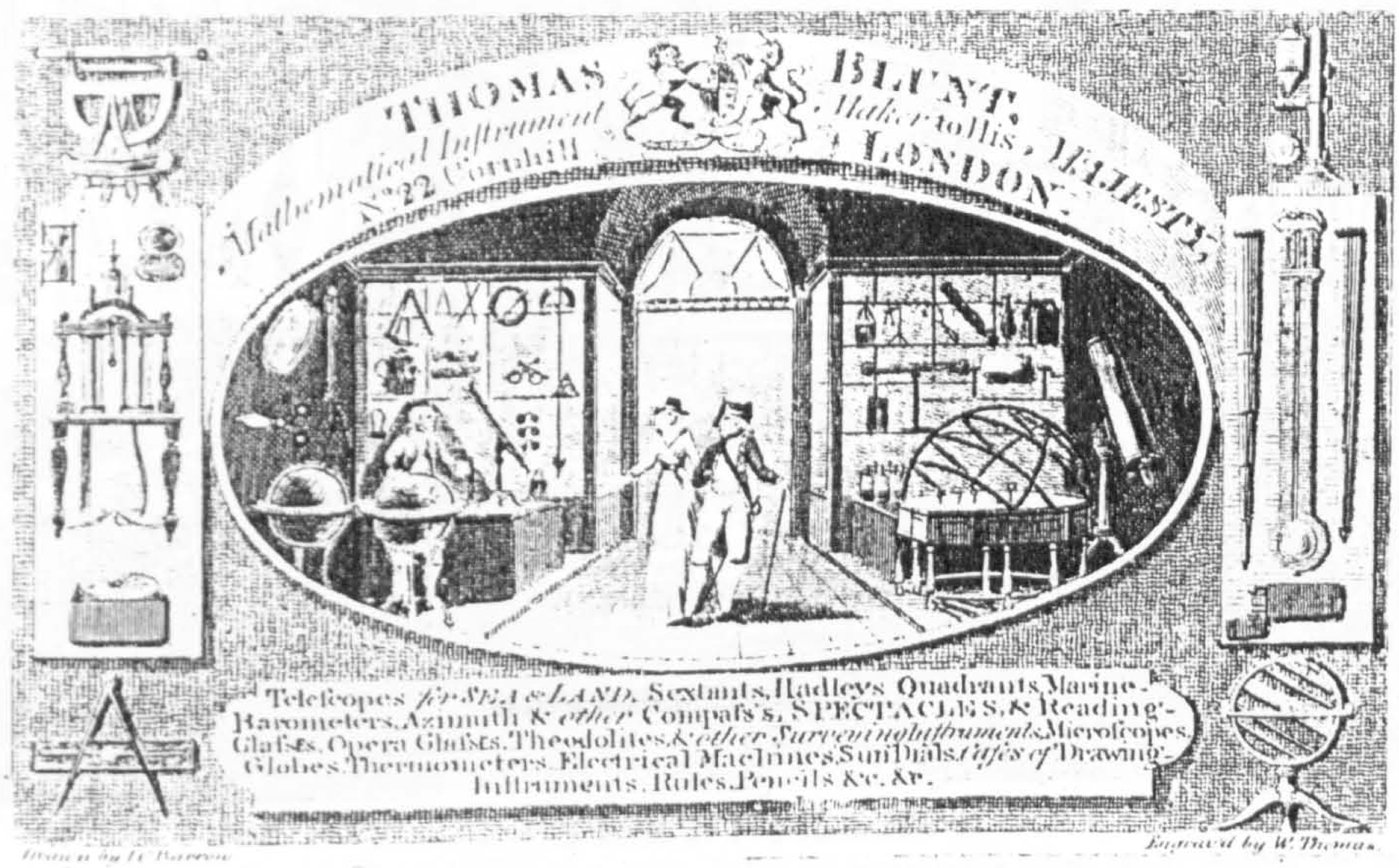


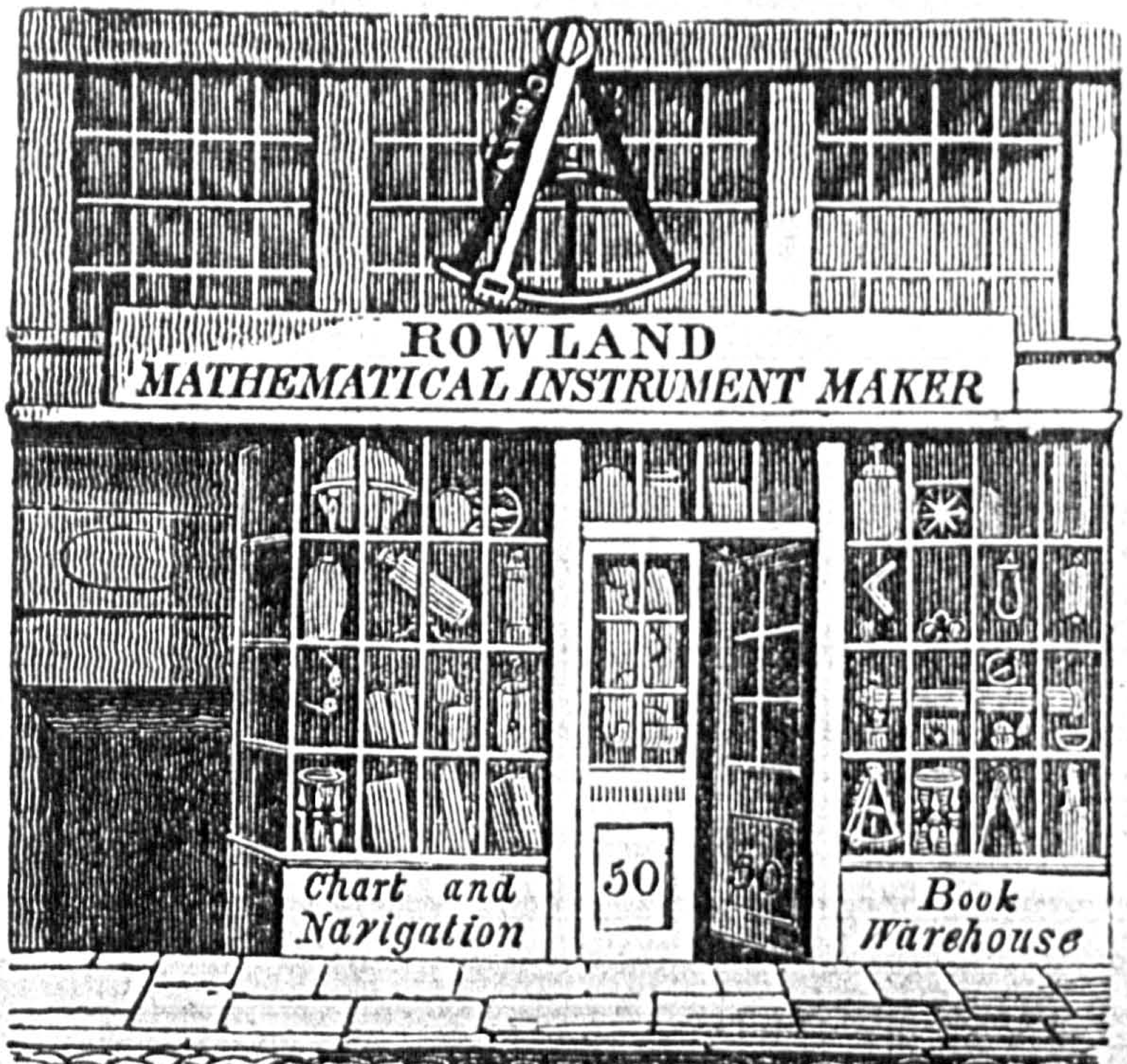
Fig. 5:2 Trade card for Thomas Blunt, London, showing interior of the shop. British Museum.

Fig. 5:3 Advertisement for Chadburn Brothers, Sheffield, 1851.
Science Museum.

Exterior views are more common, although even they number a mere handful. That of Alexander Mackenzie's London premises, dating from about 1822, is dismissed by Crawforth as 'a commonplace shop'.[52] A series of sketches of the exterior of Philip Carpenter's Regent Street shop has survived from the mid-century,[53] while the bill-head of D. Cohen in Newcastle-upon-Tyne shows a corner site on a major thoroughfare.[54] Ambrose Heal comments that in general, for London 'in the nineteenth century illustrations of shop fronts became a much more common feature of the tradesmen's cards, and the transition from the old-fashioned shop fronts, which persisted into early Victorian times (as shown in Tallis's Street Views of 1838) down to the present day [1925], can be traced.'[55] Outside the capital, trade cards of the Gardner business of Glasgow, and of that of Rowland of Bristol, show the exterior of their respective shop premises.[56] The illustration of the Rowland card shows the pertinent shop sign - the Quadrant - and the windows crammed with a large variety of items which presumably could be bought over the counter; significantly, the penultimate line of the advertisement states that 'old instruments [are] bought, sold or exchanged', and this may have formed a substantial part of the shop business [Fig. 5:4]. The Rowland business was at this address from 1805.

For provincial producers, the first apparent evidence for commercial activity is the appearance of advertisements in the local press. As with trade directories, the appearance of these has to be treated with some caution: presumably, not everything advertised was instantly available, nor was it necessarily constructed on the premises but could be bought-in, perhaps from London. For instance, John Wright's initial advertisement in the Bristol press in 1756 offered 'in Silver, Brass, Ivory, Wood, &c.' a huge range of devices from demonstration pieces such as orreries, practical instruments such as theodolites and quadrants, mathematical instruments such as rules and sun dials, philosophical instruments such as air pumps and barometers and optical instruments, including telescopes, microscopes and 'Magic Lanthorns'. Wright was, however, insistent on his abilities as a maker, stating that 'Gentlemen, upon signifying the Plate and Figure of any Instrument

52. *Ibid.*, 482; original Heal 105.69.
53. Delehar (1989).
54. Crawforth (1985), 482; Banks collection 105.11.
55. Heal (1925), 29.
56. The Gardner image is illustrated in Clarke et al. (1989), 165; the Rowland card is in the collections of the Blaise Castle House Museum, T8303.



ROWLAND,
Mathematical Instrument
MAKER,
SIGN OF THE QUADRANT,

No. 50, Broad Quay, Bristol,

Makes, cleans, repairs, & accurately adjusts

Sextants, Quadrants, Compasses, Telescopes, and Time-Glasses.

CHARTS AND NAVIGATION BOOKS.

All kinds of Nautical Stationery, Pens, Ink, Paper, &c.

OLD INSTRUMENTS BOUGHT, SOLD, OR EXCHANGED.

***** BURT's New Patent BUOY and NIPPER for Heaving the Lead, constructed on such a Principle that the Depth is ascertained with the greatest correctness without heaving the Ship to.**

T8303 *J. Chilcott, Printer, 6, High Street, Bristol.*

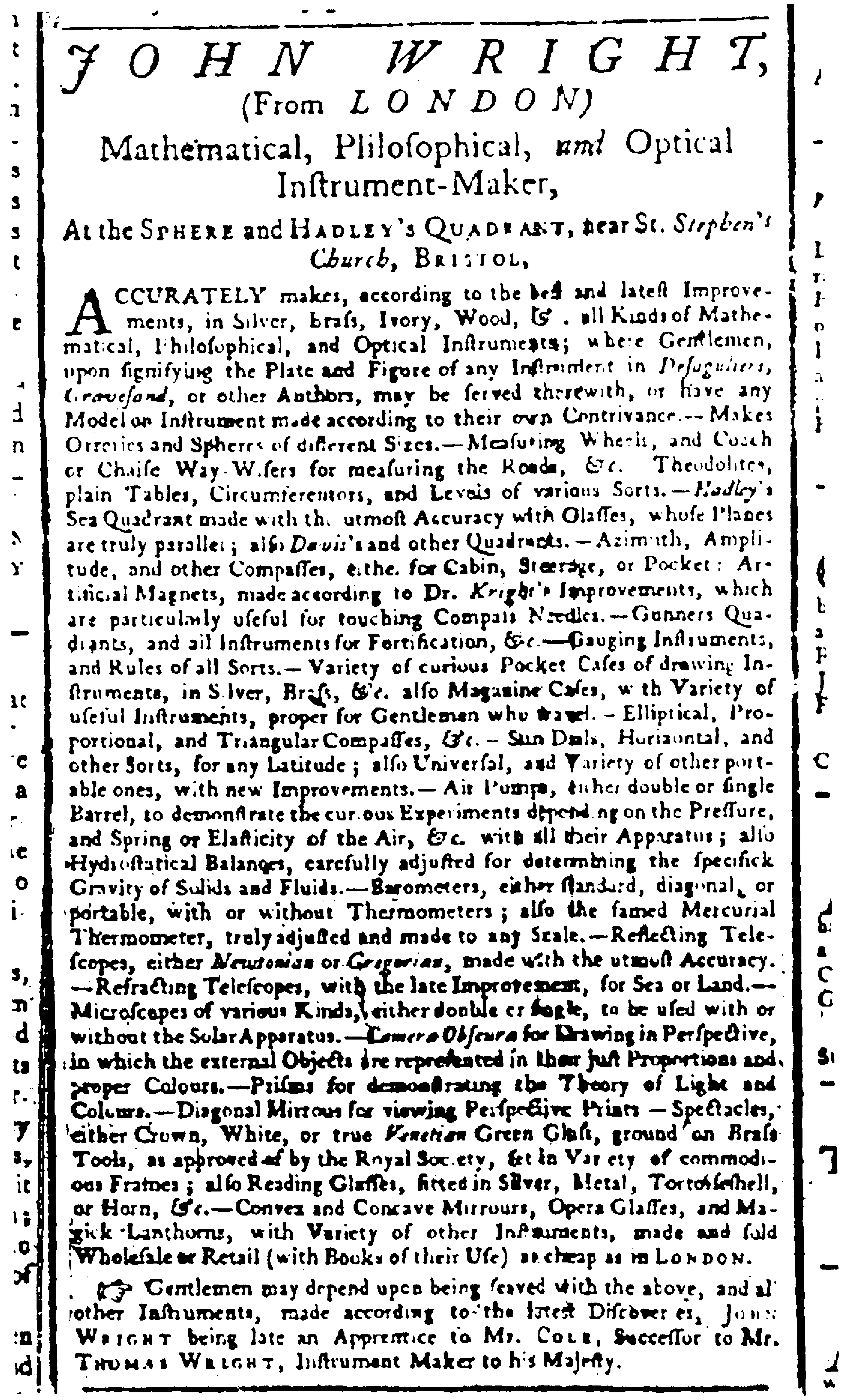
Fig. 5:4 Trade card for Rowland of Bristol, showing exterior of shop. Bristol Museums and Art Galleries.

in *Desaguliers, Gravesand,* or other Authors, may be served therewith, or have any Model or Instrument made according to their own Contrivance.' [Fig. 5:5].[57] Both J.T. Desaguliers and W. s'Gravesande were popularisers of Newtonian physics with richly-illustrated textbooks in many editions to their names.

Such a variety of items could presumably be ordered, but would not necessarily be obtainable on demand. The growth of the provincial press at this period provides examples of advertisements for instrument makers, such as Wright in Bristol, moving out from London to try to tap into local markets. As seen in chapter 2, other examples were John Leverton, in Liverpool in 1766; Richard Eggleston in York in 1740; and Joseph Oakley in Birmingham in 1758; and the cachet of being 'from London' was used in advertising to denote quality, for instance by William Holliwell of Liverpool, for whom no London connections have been uncovered.[58] However, Sheffield instrument manufacturers in particular did not bother to advertise in their local press, and this suggests that their markets were not local. Other instrument makers remained based in London, but used the time-honoured and fruitful connection between printing and the instrument trade to get their wares out into the country. As seen in chapter 2, John Wright had set up in his Bristol business for less than a year when the London opticians, James Ayscough and Henry Gregory advertised that 'they have furnished Mr JAMES TEAST, Bookseller in *Cork-street*, with a large assortment of Telescopes, *Hadley's* and *Davis*'s Quadrant and other Instruments for Use at Sea'. John Wright appears to have been warned about this before publication by the newspaper proprietor, and his own advertisement, just below theirs, is over twice as long.[59] John Brewer has noted a bookseller in eighteenth-century Rye, Sussex, selling 'maps, prints, mathematical instruments, spectacles and globes,'[60] and there are instances elsewhere.

Advertisements appearing in the local press in the provinces appear to have been more concerned with points of information for business associates than to attract customers: for instance, the notification of a business changing hands, as we have seen in the Bristol press with the successors to John Wright, Joshua Springer, Henry Edgworth and a number of others. Other

[57]. *Felix Farley's Bristol Journal*, 13 March 1756.
[58]. Calvert (1971), 26.
[59]. *Felix Farley's Bristol Journal*, 4 December 1756.
[60]. Brewer (1997), 174.



JOHN WRIGHT,
(From LONDON)
Mathematical, Philosophical, and Optical
Instrument-Maker,
At the SPHERE and HADLEY's QUADRANT, near St. *Stephen's Church*, BRISTOL,

ACCURATELY makes, according to the best and latest Improvements, in Silver, brass, Ivory, Wood, &c. all Kinds of Mathematical, Philosophical, and Optical Instruments; where Gentlemen, upon signifying the Plate and Figure of any Instrument in *Desaguliers*, *Gravesand*, or other Authors, may be served therewith, or have any Model or Instrument made according to their own Contrivance.--Makes Orreries and Spheres of different Sizes.—Measuring Wheels, and Coach or Chaise Way-Wisers for measuring the Roads, &c. Theodolites, plain Tables, Circumferentors, and Levels of various Sorts.—*Hadley*'s Sea Quadrant made with the utmost Accuracy with Glasses, whose Planes are truly parallel; also *Davis*'s and other Quadrants.—Azimuth, Amplitude, and other Compasses, either for Cabin, Steerage, or Pocket: Artificial Magnets, made according to Dr. *Knight*'s Improvements, which are particularly useful for touching Compass Needles.—Gunners Quadrants, and all Instruments for Fortification, &c.—Gauging Instruments, and Rules of all Sorts.—Variety of curious Pocket Cases of drawing Instruments, in Silver, Brass, &c. also Magazine Cases, with Variety of useful Instruments, proper for Gentlemen who travel.—Elliptical, Proportional, and Triangular Compasses, &c.—Sun Dials, Horizontal, and other Sorts, for any Latitude; also Universal, and Variety of other portable ones, with new Improvements.—Air Pumps, either double or single Barrel, to demonstrate the curious Experiments depending on the Pressure, and Spring or Elasticity of the Air, &c. with all their Apparatus; also Hydrostatical Balances, carefully adjusted for determining the specifick Gravity of Solids and Fluids.—Barometers, either standard, diagonal, or portable, with or without Thermometers; also the famed Mercurial Thermometer, truly adjusted and made to any Scale.—Reflecting Telescopes, either *Newtonian* or *Gregorian*, made with the utmost Accuracy.—Refracting Telescopes, with the late Improvement, for Sea or Land.—Microscopes of various Kinds, either double or single, to be used with or without the Solar Apparatus.—*Camera Obscura* for Drawing in Perspective, in which the external Objects are represented in their just Proportions and proper Colours.—Prisms for demonstrating the Theory of Light and Colours.—Diagonal Mirrours for viewing Perspective Prints.—Spectacles, either Crown, White, or true *Venetian* Green Glass, ground on Brass Tools, as approved of by the Royal Society, set in Variety of commodious Frames; also Reading Glasses, fitted in Silver, Metal, Tortoiseshell, or Horn, &c.—Convex and Concave Mirrours, Opera Glasses, and Magick Lanthorns, with Variety of other Instruments, made and sold Wholesale or Retail (with Books of their Use) as cheap as in LONDON.

☞ Gentlemen may depend upon being served with the above, and all other Instruments, made according to the latest Discoveries, JOHN WRIGHT being late an Apprentice to Mr. COLE, Successor to Mr. THOMAS WRIGHT, Instrument Maker to his Majesty.

Fig. 5:5 John Wright's advertisment in *Felix Farley's Bristol Journal*, 13 March 1856.

JOHN WRIGHT,
(From *LONDON*)
Mathematical, Philosophical, *and* Optical
Instrument-Maker,

At the SPHERE and HADLEY'S QUADRANT, near St. *Stephen's Church*, BRISTOL,

ACCURATELY makes, according to the best and latest Improvements, in Silver, Brass, Ivory, Wood, &c. all Kinds of Mathematical, Philosophical, and Optical Instruments; where Gentlemen, upon signifying the Plate and Figure of any Instrument in *Desaguliers*, *Gravesand*, or other Authors, may be served therewith, or have any Model or Instrument made according to their own Contrivance. -- Makes Orreries and Spheres of different Sizes. - Measuring Wheels, and Coach or Chaise Way-Wisers for measuring the Roads. &c. Theodolites, plain Tables, Circumferenters, and Levels of various Sorts. - *Hadley's* Sea-Quadrant made with the utmost Accuracy with Glasses, whose Planes are truly parallel; also *Davis*'s and other Quadrants. - Azimuth, Amplitude, and other Compasses, either for Cabin, Steerage, or Pocket: Artificial Magnets, made according to Dr. *Knight*'s Improvements, which are particularly useful for touching Compass Needles. - Gauging Instruments, and Rules of all Sorts. - Variety of curious Pocket Cases of drawing Instruments, in Silver, Brass, &c. also Magazine cases, with Variety of useful Instruments, proper for Gentlemen who travel. - Elliptical, Proportional, and Triangular Compasses, &c. - Sun Dials, Horizontal, and other Sorts, for any Latitude; also Universal, and Variety of other portable ones, with new Improvements. - Air Pumps, either double or single Barrel, to demonstrate the curious Experiments depending on the Pressure, and Spring or Elasticity of the Air, &c. with all their Apparatus; also Hydrostatical Balances, carefully adjusted for determining the specifick Gravity of Solids and Fluids. - barometers, either standard, diagonal, or portable, with or without Thermometers; also the famed mercurial Thermometers, truly adjusted and made to any Scale. - Reflecting Telescopes, either *Newtonian* or *Gregorian*, made with the utmost Accuracy. - Refracting Telescopes, with the late Improvement, for Sea or Land. - Microscopes of various Kinds, either double or single, to be used with or without the Solar Apparatus. - *Camera Obscura* for Drawing in Perspective, in which the external Objects are represented in their just Proportions and proper Colours. - Prisms for demonstrating the Theory of Light and Colours. - Diagonal Mirrors for viewing Perspective Prints - Spectacles, either Crown, White, or true *Venetian* Green Glass, ground on Brass Tools, as approved of by the Royal Society, set in Variety of commodious Frames; also Reading Glasses, fitted in Silver, Metal, Tortoiseshell, or Horn, &c. - Convex and Concave Mirrours, Opera Glasses, and Magick Lanthorns, with variety of other Instruments, made and sold Wholesale or Retail (with Books of their Use) as cheap as in LONDON.

Gentlemen may depend upon being served with the above, and all other Instruments, made according to the latest Discoveries, JOHN WRIGHT being late an Apprentice to Mr. COLE, Successor to Mr. THOMAS WRIGHT, Instrument maker to his Majesty.

Fig. 5:5 John Wright's advertisment in *Felix Farley's Bristol Journal*, 13 March 1856.

advertisements concern change of address - such as that placed by the Sheffield firm Chadburn & Wright, who 'removed from No 85, Lady's Bridge, Wicker, to the Premises, No 40 Lady's Bridge, Nursery, lately occupied by James Greenwood, Cabinet Case and Razor Strop Manufacturer, where they carry on their Manufactory in all its various branches...'[61] - or a change in business circumstances, such as the partnership between Abraham Abraham, optician of Liverpool, and John Benjamin Dancer of Manchester, who 'propose OPENING the above PREMISES [at 13 Cross Street, Manchester]...and in soliciting public patronage, respectfully state, that all work emanating from their manufactory or sold at their establishment, shall be of guaranteed accuracy, and every instrument combining all recent mechanical and scientific improvements.'[62]

New devices were occasionally promoted at a local level. For example, the invention, and piracy, of Edinburgh scientist David Brewster's patented kaleidoscope in 1817 led to a variety of contradictory advertisements in local newspapers around the country in an attempt to capture new markets while the craze for the device still raged.[63] The Bristol press, for instance, carried an advertisement in April 1818 from a number of unidentified businesses:

> The *Genuine Kaleidoscope* to be had only *at the Manufactory, No 25 Broadmead*; P. Rose, Broadmead; Mintorn, College Green; Barry & Son, and Rees, High-street; Cookworthy, Corn-street; Prosser and Richardson, Clare-street; Frost, Broad-street; Hillyard & Morgan, and Huntley, John-street, and Wood, Castle-street - *All others are spurious.*[64]

In July, a member of the Bristol instrument trade, Charles Beilby, used the columns to state that where the 'Patent Kaleidoscope' was concerned, 'he has extended into an agreement with Dr Brewster the Inventor and Patentee of the above very amusing Instrument, for the Manufacture of them, and that he is the only Person in the West of England who is authorised to make them...'. In the same newspaper, a Mr J.W. Hall, Broadmead, announced that he 'has this day received a supply of the PATENT KALEIDOSCOPES, with the *new Improvement* as found out by the *French.*'[65] By early September, despite Brewster's attempts to regulate distribution and make some profit from his design, Edward Bird & Son, Bristol watchmakers and jewellers, advertised that they had been appointed by Philip Carpenter, the Birmingham 'Optician and Sole Maker of the

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61. *Sheffield Independent*, 18 May 1822.
62. *Manchester Courier*, 12 June 1841.
63. Morrison-Low (1984), 60-62.
64. *Bristol Journal*, 25 April 1818.

Kaleidoscope, during the term of the patent, his Agent for the sale of these Instruments in this City; they may be had at their Shop, at various prices, from 10s to 6 guineas, accompanied with books of description.'[66] Incensed, Beilby retaliated by advertising in the Birmingham press.[67]

By the time Brewster regained some control of the situation by appointing 'approved' makers and retailers in about 1819, the craze for his device was dying away: he estimated that some two hundred thousand instruments were sold in London and Paris during three months. The more common telescopic instruments appear to have been manufactured in the Midlands by wholesalers such as Philip Carpenter of Birmingham, a firm known to have been providing telescopes to large London firms, such as Dollond. In Birmingham, 'Mr [Philip] Carpenter soon established a large trade, and supplied even Dollond himself with large numbers of telescopes bearing his famous name'.[68] However, Carpenter was able to provide only a part of the unexpectedly substantial overnight demand for kaleidoscopes, as Brewster wrote to his wife from Sheffield about his visit to

> Cam & Cutt, who have undertaken to manufacture the kaleidoscope for Mr Ruthven [of Edinburgh.] They have agreed to make and sell the instruments under my patent on the same terms as Mr Carpenter, provided I get his permission to allow them to be employed. This I must do, as he cannot possibly supply the demand.[69]

Examination of dismantled examples show that the ends of the kaleidoscope, which are stamped pieces of brass, which could easily have been produced by, for instance, a button manufacturer: 'the tinmen and the glaziers began to manufacture the detached parts of it, in order to evade the patent', as Brewster growled.[70] The partnership between James Cam and John Cutt or Cutts lasted only one year, that of 1818, and was probably brought about solely to deal with this single lucrative contract.[71] The example of the kaleidoscope demonstrates an instance of an instrument - really no more than a toy - which rapidly captured the public imagination, but did not require enormous skill

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65. *Ibid.*, 4 July 1818.
66. *Ibid.*, 5 September 1818.
67. *Aris's Gazette*, 28 September 1818.
68. [Robert Field], 'Optical and Mathematical Instruments' in Timmins (1866), 534.
69. Gordon (1869), 96.
70. Morrison-Low (1984), 61, quoting [D. Brewster], 'Kaleidoscope' in *Edinburgh Encyclopaedia* XII (1830), 410.
71. Supported by the entry in [Pigot's] *Commercial Directory for 1818-19-20* ... (Manchester: James Pigot, 1818) for 'Cam and Cutt opticians Norfolk street', and a trade card for 'Cutts & Camm Manufacturers of Table Knives' noted by Calvert (1971), 20.

to make. Brewster had failed to anticipate market demand, understandably, but despite his precaution of a patent there was not yet the means to harness market forces in favour of the inventor.

The trade literature of the scientific instrument industry has been studied by instrument historians, because it can provide working dates of a firm or a particular instrument bearing their name. Unfortunately, much of this material is ephemeral: the bills, catalogues and trade cards appearing less worthy of attention by those who care for the instruments themselves. Trade cards, which appeared as early as the late seventeenth century, were not, as Ambrose Heal admits, strictly speaking 'cards' at all, and their purpose has changed over the years.[72] As we have seen, their illustration can help to give some idea about the retail premises of a business; Michael Crawforth used examples to uncover 'many small pieces of information [which will] gradually build a complex picture of an important... industry.'[73] For instance, some members of the trade were linked with others with the same name in different locations, or indeed, were the same person who had moved. Gloria Clifton's *Directory* cites a number of businesses with the name Abraham, and the trade card of Jacob Abraham, with shops in both Cheltenham and Bath, appears to be separate from his namesake, Abraham Abraham, who appears in the Liverpool street directories in 1818. However, judging from an advertisement almost ten years later, it would appear that he, too, came from Somerset:

> A. ABRAHAM (from Bath), OPTICIAN and MATHEMATICAL INSTRUMENT-MAKER to the ROYAL FAMILY, *No. 7, Lord-street, Liverpool*, impressed with the gratitude for the liberal encouragement he has received since his establishment in Liverpool, trusts, by adhering to that assiduity and attention which have hitherto been his study, to merit a continuance of public patronage.[74]

Another trade card links a business in Liverpool with a shop in Cheltenham, that of the 'Messrs. Davis'. The street directories corroborate this, with Edward Davis running an 'instrument repository' at 65 Bold Street, while his brother John, who had been with him in 1839, by 1843 was at 101 High Street, Cheltenham.[75] John and Alexander Walker, who had a navigation & stationery

[72]. Heal (1925), 1-3.
[73]. Crawforth (1985), 453.
[74]. *The Albion*, 14 May 1827.
[75]. Calvert (1971), 20; *1841. Gore's Directory for Liverpool and its Environs* (Liverpool: J. Mawdsley, n.d.); *The Cheltenham Annuaire and Directory ... for the year 1843 ...* (Cheltenham: H. Davis [1843]).

warehouse at 33 Pool Lane, Liverpool, from 1824, also advertised premises at 47 Bernard Street, London.[76] In chapter 2, we have already seen business, apprenticeship and family associations between the Liverpool and London firms of John Gray and Charles Jones: this is surely evidence of a distribution network, tying the place of production and point-of-sale of instruments.

A wider market was reached by what are now called 'trade catalogues', priced lists of available instruments, subsequently illustrated. Often bound in the back of illustrated textbooks, they had considerable novelty appeal: again, the London houses of Benjamin Martin, George Adams and W. & S. Jones led this field in the late eighteenth century. Catalogues advertising products issued by instrument makers outside London appeared much later than those produced in London. A bibliographic listing of 1,570 surviving catalogues dated between 1600 and 1914 compiled in 1990 found that 'over three-quarters of the catalogues listed could only be found as single copies',[77] demonstrating their ephemeral nature (catalogues were usually destroyed when superseded by later editions): but because of these only one - by Parkes of Birmingham, 1848 - was from a pre-1851 English provincial maker, it does not mean that others were not produced. Amongst those who exhibited at the Great Exhibition, was Chadburn of Sheffield, who stated that their 'Catalogue with prices of optical, mathematical, philosophical, and other instruments, manufactured and sold by them at their exhibition & sale rooms, Albion Works, Nursery Street, Sheffield, 2d each:- with engravings, 1s. each. Any single engraving may be had at 1d. each'. As early as 1833 they advertised their illustrated trade literature - 'Chadburn & Co. have published a book, with copperplate engravings, describing the property and use of each article...'[78] - none of which have been traced. Their Great Exhibition prospectus covers twenty-four closely printed pages of items. Another exhibitor, Abraham Abraham & Co. of Liverpool, produced an eighty-one page *Descriptive and Illustrated Catalogue...* in 1853, for the following reasons stated in the preface:

> We have been induced to publish the present Catalogue, from continued enquiries at our Establishment for a description and prices of the various Instruments manufactured by us... Although we do not profess to manufacture cheap or inferior articles, yet we venture to assert that all Apparatus made by us will be found considerably lower in price than usually charged for goods of best quality. Our aim has hitherto been to obtain the confidence of our

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[76]. Calvert (1971), 44.
[77]. Anderson et al. (1990), i.
[78]. *History and General Directory of the Borough of Sheffield ... By William White* (Sheffield: printed by Robert Leader, Independent Office, for W. White, 1833), advertisement.

> friends and patrons, by supplying only articles of superior construction and of guaranteed workmanship, combining all the latest improvements... Scientific Institutions, Lecturers, and Merchants, favouring us with their orders, will be allowed a very liberal discount from our Catalogue prices... carriage free, to any part of the United Kingdom.[79]

Although sounding a tentative note - 'we do not profess to manufacture cheap or inferior articles' - perhaps still gaining new confidence in their own abilities, yet the firm is proud of the skill of its workers, demonstrated by the standards of their 'goods of best quality'. Clearly pitched at a new and growing educational market, by the mid-nineteenth century this Liverpool-based firm was prepared to pay the transport of any sale within the United Kingdom, a measure of their growing confidence in competing against the large London wholesalers. There is also stress on 'the latest improvements', the advertiser's emphasis on novelty.

McKendrick points out that 'the manipulation of fashion made many consumer goods obsolete long before mere use would have made them so',[80] and this can be observed at the dilettante end of the market, where instruments were acquired for entertainment or as status symbols rather than for practical or scientific use. Taking the example of the microscope, during the period from 1760 until the 1820s there was no technological improvement in the optics - the working part - at all; and yet, the mechanical characteristics provided an excuse for a proliferation in design, as any illustrated twentieth-century 'history of the microscope' will show.[81] In the only known surviving pattern book from the instrument-making trade, that of G. & W. Proctor, of Sheffield and Birmingham, and dated 1815 [Fig 5:6], there are described and illustrated eleven different sorts of microscope, at prices varying from 5s. (for a 'Gardener's microscope in ivory') to £3 13s 6d (for a 'Culpepper's Pyramidical Microscope, with Mahogany Box').[82] This same pattern book has on its outside cover the remains of a paper manuscript label, 'GENERAL PATTERN and ...', implying that the designs inside were once used as a guide for retailers buying wholesale from the firm. Perhaps of even more interest are the manuscript notes on the pages opposite the engravings, which appear to be the prices given by the firm for piece work: for instance, the

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79. Abraham (1853), 'Preface'.
80. McKendrick (1982), 97.
81. For instance, Turner (1981).
82. Sheffield City Archives, Special Collections no 33237, Bradbury Record 293: pattern book for *G.& W. Proctor, Opticians, No. 11 Market Street, Sheffield and No. 23 New Hall Street, Birmingham ... 1815*. This lists 39 plates of instruments produced by the firm, but has no provenance. The contents have been reproduced, without discussion, by Crom (1989), 357-370.

G. AND W. PROCTOR,

OPTICIANS,

No. 11, Market Street, Sheffield,

AND

No. 23, New Hall Street, Birmingham,

Manufacturers

OF

SPECTACLES READING GLASSES OPERA GLASSES COMMON TELESCOPES ACHROMATIC TELESCOPES	MICROSCOPES SINGLE & COMPOUND DIAGONAL MIRRORS AND MAGIC LANTERNS:

ALSO,

MATHEMATICAL AND PHILOSOPHICAL INSTRUMENTS.

SHEFFIELD:

PRINTED BY C. & W. THOMPSON, WESTBAR AND CORNMARKET.

1815.

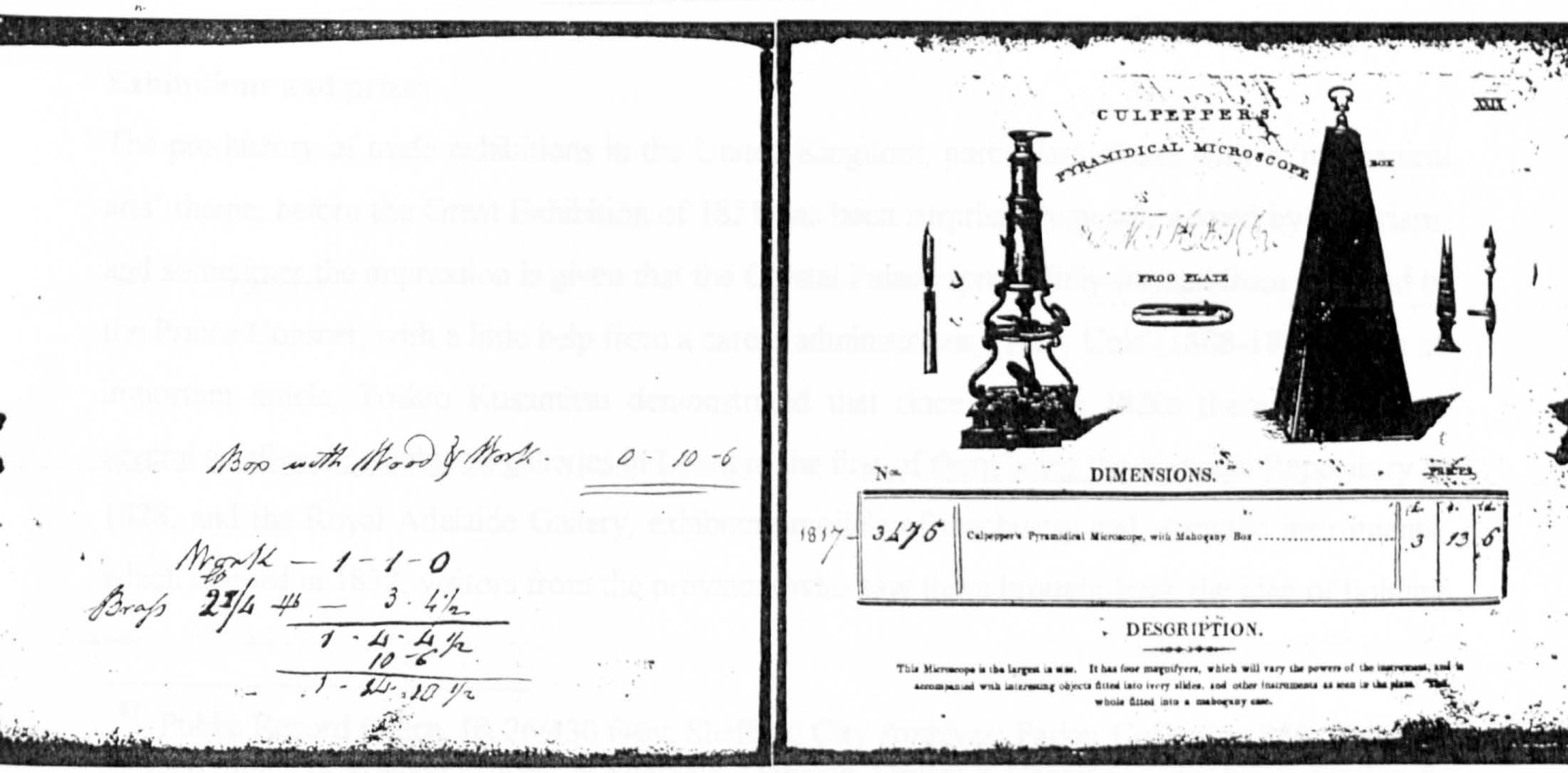

Fig. 5:6 Title page and Plate XXIX from G.& W. Proctor's pattern book of 1815, with manuscript annotations of materials and costs.
Sheffield City Libraries and Archives.

'Culpepper's Pyramidical Microscope' just mentioned, is annotated 'Box with Wood & Work 0-10-6', whereas the instrument is 'Work 1-1-0 Brass 3-4½' adding in the box, materials and labour came to '£1-14-10½', giving G.& W. Proctor £1-18-7½ profit. Naturally, they were supplying considerable overheads, such as their manufactory, tools for their workmen, and presumably paying the cost of transport to the London market, rates which are so far unknown. The firm prospered under its first owner, Charles Proctor, who was worth just under £12,500 at his death in 1808, but his son, some ten years later, went bankrupt.[83]

Perhaps one of the most effective ways of appealing to the 'middling people', was one pioneered with enormous success by both Wedgwood and Boulton: by displaying the latest, and therefore the most fashionable, wares in an exhibition. As Malcolm Baker has recently shown, this proved an entertaining and popular method of ensuring a wide London audience: he quotes Horace Walpole's remark of 1770, that 'We have at present three exhibitions ... The rage to see these exhibitions is so great that sometimes one cannot pass through the streets where they are.'[84] Exhibitions of instruments were to become an important method of demonstrating that there were skilful workmen in the provinces who could compete with the best London makers; in turn, visitors to London exhibitions returned home, inspired with what they had seen.

Exhibitions and prizes

The pre-history of trade exhibitions in the United Kingdom, particularly those with a 'mechanical arts' theme, before the Great Exhibition of 1851 has been surprisingly poorly served by historians, and sometimes the impression is given that the Crystal Palace sprang fully-formed from the head of the Prince Consort, with a little help from a career administrator, Henry Cole (1808-1882).[85] In an important article, Toshio Kusamitsu demonstrated that since the late 1820s there had opened several small-scale exhibition galleries in London, the first of them being the National Repository in 1828, and the Royal Adelaide Gallery, exhibiting models of machinery and scientific instruments, which opened in 1832; visitors from the provinces who saw these brought back the idea of holding

[83]. Public Record Office, IR 26/430 f46v; Sheffield City Archives: Parker Collection 859, 'Petition for bankruptcy of William Proctor of Sheffield, Optician, Dealer & Chapman ... by James Deakin & Thomas Deakin of Sheffield, dated 27 January 1818'. The Deakins were Proctor's brothers-in-law.

[84]. Walpole to Horace Mann, 6 May 1770, quoted by Baker (1995), 118.

[85]. For example, Briggs (1975), 49; Strong et al. (1977).

similar shows, against a background of 'flourishing bourgeois culture'.[86] In a revised version of his article, Kusamitsu demonstrates that from the mid-eighteenth century small-scale exhibitions of the industrial arts were fostered by literary and scientific societies, but for visiting by their members only.[87] Kenneth Beauchamp reckoned that the first industrial exhibition in Britain was held in Edinburgh in 1755;[88] while Brian Gee awarded the London-based Society of Arts the honour of holding a 'week-long event in 1761 when machines and models were exhibited.'[89] As with other aspects of this subject, the catalogues of these exhibition have proved ephemeral, and specific information, especially about individual exhibits, is hard to find.

The London-based Society of Arts, which became the Royal Society of Arts in 1908, was formed in 1754 (as the Society for the Encouragement of Arts, Manufactures and Commerce) by a body of interested enthusiasts, who attempted to encourage the exploitation of natural resources. By the 1840s, the Society was forced to reassess its the emphasis of its aims with the runaway economic success of British industry towards the end of its first century. The award of a premium of a few guineas and publication of an idea in the Society's *Transactions* had became less appealing as industry provided its own rewards. With declining revenues and an unbusinesslike constitution, the Society came close to extinction, but managed to reform itself with a new Council and Charter, and became a forum for the dissemination of information about the industrial arts and sciences. In particular, it organised exhibitions: Henry Cole was Chairman of the Council in 1850 and 1852, and the Society was deeply involved in the Great Exhibition at the Crystal Palace, as well as other international exhibitions later on, besides the lower-key annual exhibitions held by the Society itself.[90] At these last, among other prize-winning instruments, awards had been presented in 1810 for James Allan's dividing engine; in 1830 for another by the specialist microscope-maker Andrew Ross; and in 1831 for Cornelius Varley's microscope for examining pond-life: however, all these individuals were members of the London trade, and the Society wished to extend its influence into the provinces.

Kusamitsu dated the real English genesis of the 'exhibition movement' - which saw its first

86. Kusamitsu (1980).
87. Kusamitsu (1985).
88. Beauchamp (1997), 11.
89. Gee (1998), 11.

international manifestation in the Great Exhibition of 1851 - to December 1837, when the directors of the Manchester Mechanics' Institute advertised in the columns of the *Manchester Guardian* their intention of holding a

> POPULAR EXHIBITION of Models of Machinery, Philosophical Instruments, Works in Fine and useful Arts, Objects in Natural History, and Specimens of British Manufacture, &c. &c. In the Exhibition the Directors are desirous of affording to the working classes a convenient opportunity of inspecting the present state of our arts and manufactures and to present them with a source of rational and agreeable relaxation...[91]

He went on to demonstrate that this idea soon spread amongst other mechanics' institutes throughout the country, especially in the Midlands and the North of England. Between 1838 and 1842, he estimated there were at least thirty-five exhibitions held there and that probably 'several million people visited these exhibitions'.[92]

The Mechanics' Institutes movement began in the early 1820s, although its origins stretched further back into the eighteenth century: the idea was to make education accessible to the working classes, principally through lectures (at a cheaper rate than through the Literary and Philosophical societies), but also through lending libraries and exhibitions.[93] 'The flavour of all Mechanics' Institutes exhibitions,' wrote Paul Greenhalgh, 'was philanthropic rather than economic, the aim being principally to stimulate working class consciousness and to generally advance industrial culture.'[94] Although somewhat politicised through their obvious links with the trades union movement, this was not enough to cause conflict with central government, and 'the achievements of these exhibitions as a whole were to render the urban-industrial environment less despicable in the eyes of the educated classes, and to provoke debate on the nature of working class culture.'[95]

Philosophical instrument makers, especially those involved in the new science of electricity, were amongst those most deeply involved in exhibiting their wares in the permanent London

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[90]. For histories of the Society of Arts, see Wood (1913) and Hudson and Luckhurst (1954).
[91]. *Manchester Guardian*, 9 December 1837, quoted in Kusamitsu, (1985), 34.
[92]. Kusamitsu (1985), 34.
[93]. Inkster (1991), 79-80.
[94]. Greenhalgh (1988), 8.
[95]. *Ibid.*

galleries from the 1820s. Amongst them was the Dubliner Edward Marmaduke Clarke, who exhibited at both the National Repository and at the Royal Adelaide Gallery. Brian Gee has shown that he used these exhibitions for publicity in selling his wares, to the extent that his claims on occasion involved him in priority disputes.[96] As these were usually aired in the press, this gave him further exposure.[97] J.A. Bennett reminded his readers that the Great Exhibition 'was very much a competition as well.' The thirty classes were each assigned an international jury, and there was a 'scale of possible awards.'[98] The jury for Class X, philosophical instruments, was chaired by the distinguished physicist Sir David Brewster, and the Reporter (who wrote the Jury's report) was James Glaisher, superintendent of the magnetic and meteorological department at the Royal Observatory, Greenwich. There was an equal number of foreign and British jurors. The class was well-subscribed, and the United Kingdom won sixteen of the thirty-one Council Medals awarded; but as Bennett has shown this apparent success masked a lack of investment in technical training and quoted Lyon Playfair's contemporary remark that 'our manufacturers were justly astonished at seeing most of the foreign countries rapidly approaching and sometimes excelling us in manufactures, our own by heredity and traditional right.'[99] This may have been a contributory idea behind the 1855 Society of Arts Prize for Microscopes.

The Society of Arts Prize microscopes, 1855

Although the first award for the design of an instrument cheap enough to be purchased by people previously considered too poor and ignorant to become consumers did not occur until a few years after the Great Exhibition, nevertheless it is included here as a case study: aspects of what happened illuminate the workings of the instrument trade and how it reached - or failed to reach - its customers. It also sheds light on three individual Birmingham firms of instrument makers, and how they responded to changing market conditions. In the *Quarterly Journal of Microscopical Science* for early 1855, there appeared the following statement under the heading 'Cheap Microscopes':

> The President of the Microscopical Society [J.S. Bowerbank] in his late address [published in February 1847] drew attention to the general impression, that in order to make good observations it was necessary to have a high-priced microscope. He denied this ... As the use of the microscope is now becoming a matter of educational importance, and as in order that it may be used by all, it must be sold at a price obtained by all and at the same time a

96. Gee (1989), especially chapters 3 and 4.
97. Gee (1998a) and (1998b).
98. Bennett (1983), 2.
99. Quoted in *ibid.*, 11.

> good instrument insured, the Society of Arts has offered two prizes for the best microscopes at stated prices.[100]

In effect, the microscope was being driven down-market: it was no longer to be a gadget within the exclusive preserve of wealthy amateurs. In fact, it was those very same 'amateurs' who were attempting to make the instrument more accessible and open up new domestic markets, for philanthropic and possibly other less altruistic reasons. One of these new markets was to be its first professional market: that of medicine, reached through its students.

The Council of the Society of Arts resolved to appoint a committee to discuss 'offering a prize for and promoting the production of a good serviceable microscope for school purposes at a low price' on 22 November 1854.[101] All the eminent members of the Prize Committee were drawn from the membership of the Microscopical Society of London, the forerunner of the Royal Microscopical Society which received its Royal Charter in 1866; and all but two served as its President. In particular, William Benjamin Carpenter subsequently gave an account of how this had all come about:

> If there be one class more than another, which especially needs to ... [be kept] ... free from the grovelling sensuality in which it too frequently loses itself, it is our Labouring population ... It was from feeling very strongly how much advantage would accrue from the introduction of a form of Microscope, which should be at once *good* enough for Educational purposes, and *cheap* enough to find its way into every well-supported School in town and country, that the Author suggested to the Society of Arts in the summer of 1854, that it should endeavour to carry-out [this] object.[102]

At its first meeting, this Committee agreed that a simple microscope, costing about £1, was what was required.[103] But subsequently, this was revised by Dr Carpenter,[104] so that the Committee subsequently recommended to the Council that the prize should be offered for two microscopes, one to be called the school microscope, priced at 10/6d or less, being mechanically and optically simple; the other to be called the student microscope, costing three guineas or less, and having two eyepieces and objectives and a limited range of stipulated accessories: 'That the

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[100]. 'Memoranda' (1855).
[101]. Royal Society of Arts [R.S.A.] MS Minutes of Council, vol. 6, November 1854-January 1856, p.7.
[102]. Carpenter (1856), 33-4.
[103]. R.S.A. MS Minutes of Committees 1853-1855, p.345.
[104]. *Ibid.*, p.359.

medal of the Society be offered, and that the Council should take 100 of the smaller and 50 of the larger microscopes.'[105] Competition entries were to be delivered to the Society before 1 May 1855,[106] and there were twelve submissions, referred to the Prize Committee.[107]

The Committee met on 7 May to hear that the following instruments had been received: three simple microscopes (from Parkes & Co. and Field & Co., both of Birmingham, and W. & F. Newton of London); and nine compound instruments (from W.J. Salmon, J.J. Solomon, William Ladd, M.A. Cooper, W. & F. Newton, and Samuel Highley, all of London, the so-far unidentified firm of Bland & Long, and, again, Parkes & Co. and Field & Co. of Birmingham).[108] The Committee met again on 18 May to test the instruments, and the simple microscopes were dealt with first. That offered by Parkes & Co. was deemed 'unfitted'; that by W. & F. Newton 'rejected'; while the example from Field & Co. was 'approved', although suggestions were made for its improvement, and it was observed that 'the mirror does not work either'. Next, the Committee looked at the compound instruments, and 'rejected all except [those by] Salmon, Field & Co. & Ladd', and then tested the one with the best resolution; with a Nobert's test plate, Field's was best; with a diatom slide, that by Ladd.[109] The Committee 'resolved unanimously to recommend to the Council [that] sent in by Messrs Field & Co. as deserving the prize offered', although with some minor mechanical alterations, which Field agreed to accept.[110]

In June, the Society of Arts heard from Henry Cole, who asked that examples of the winning design be sent to be displayed in the Paris Universal Exhibition (of 1855), where they were shown alongside those of other British makers such as T.D. King of Bristol, William Ladd, Moritz Pillischer, Andrew Pritchard, Joseph Solomon, and Smith & Beck, all of London.[111] This would

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105. *Ibid.*
106. 'Special Prizes' (1855); also noted in 'Memoranda' (1855).
107. R.S.A. MS Minutes of Council, vol. 6, November 1854-January 1856, p.89.
108. R.S.A. MS Minutes of Committees 1853-1855, p.429; identification of the makers has been made from Clifton (1995).
109. Nobert's test plate and the diatom slide were methods used to test the optical resolution of microscopes. The German, F.A. Nobert (1806-81) mechanically produced micro-ruled lines with a diamond on a glass-plate; diatom slides were made from the naturally-occurring minute plankton found in the sea.
110. R.S.A. MS Minutes of Committees 1853-1855, pp.433-7.
111. R.S.A. MS Minutes of Council, vol. 6, November 1854-January 1856, p.132; *Catalogue...* (1855), 23-4.

appear to have been a great commercial success for Field of Birmingham, and this exposure should, if carefully exploited, have led to increased orders and prosperity. Yet, despite winning this prestigious prize, very little is known about Robert Field & Son of Birmingham. According to a local account of 1895:

> Field had been a foreman at Philip Carpenter's factory in Bath Row, and he afterwards started business on his own account in Navigation Street. After Philip Carpenter removed to London, Field bought the business at 111 New Street, which, being a building one storey high only, was taken down to make room for other buildings, and the business removed.[112]

A surviving trade card, dating from between 1826 and 1837 demonstrates that the London and Birmingham businesses were being run by the same people [Fig. 5:7]. Philip Carpenter was born at Kidderminster on 18 November 1776, into a Unitarian family. Although he claimed to have been trained 'in London', it is not clear to whom he was apprenticed, nor why he decided to move back to the Midlands. A later Birmingham account stated that:

> Philip Carpenter was a scientific optician, and had a house and manufactory in Bath Row, and a retail shop at 111 New Street, Birmingham. In July 1826, he removed to 24 Regent Street, London. The Birmingham business in New Street was continued till 1837, when it was transferred to the late Mr R. Field. Philip Carpenter died at Regent Street, April 30, 1833, the business being continued by his sister Mary in partnership with Mr William Westley.[113]

Perhaps the most famous member of the family was Philip's brother, Dr Lant Carpenter, the Unitarian divine, whose own family of six children included the naturalist William Benjamin Carpenter, a great promoter of the microscope, and who apparently saw no conflict of interest in judging a competition where the winner was his uncle's trade successor.[114] By association - and like his nephew, William B. Carpenter, whose text on *The Microscope and its Revelations* was to run to eight editions (six revised by himself) through the nineteenth century - Philip Carpenter was particularly interested in microscopy:

> He paid considerable attention to the manufacture of microscopes ... He opened an exhibition of the solar microscope in the large drawing room (at Regent Street). The images of the objects magnified were projected on a large screen, and great interest was excited by its revelations ... When the novelty wore off the attendance declined, and it was discontinued in 1835.[115]

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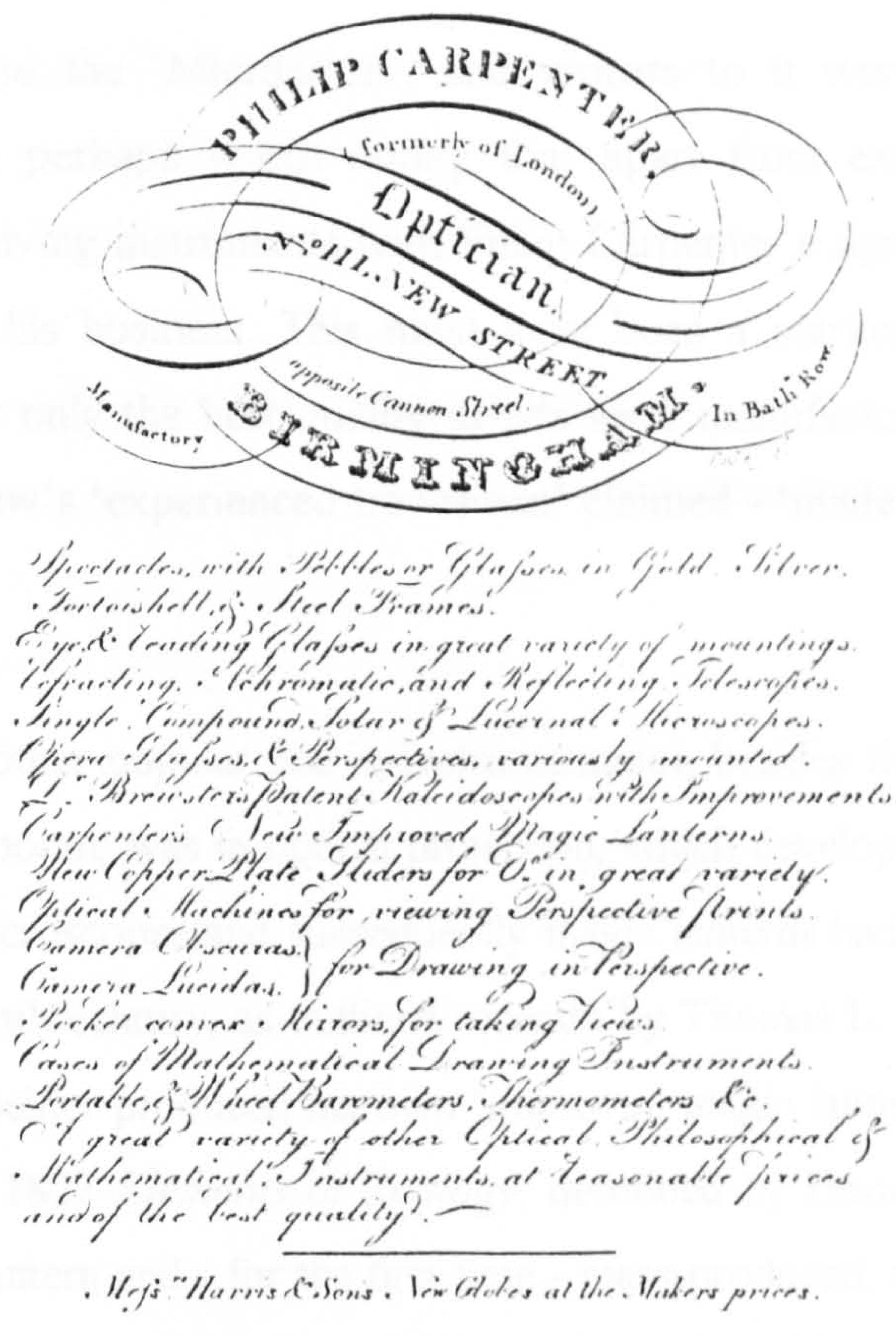
112. 'H.B.' (1895).
113. Matthews (1895).
114. For W.B. Carpenter, see J. Estlin Carpenter, 'Introductory Memoir' in Carpenter (1888), which explains Carpenter's lifelong devotion to the microscope.
115. Matthews (1895); for Carpenter's solar microscope, see Nuttall (1976).



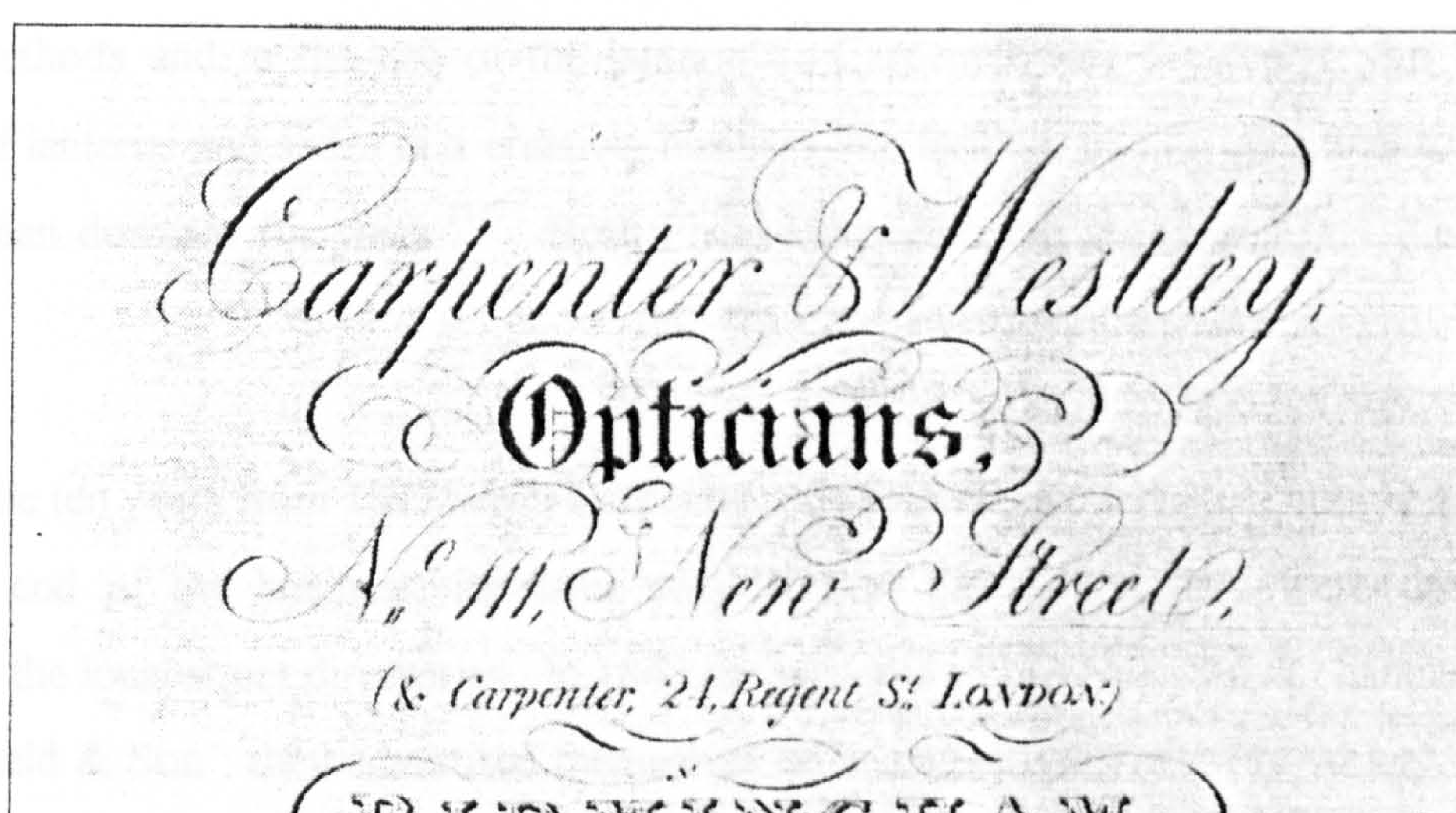


Fig. 5:7 Philip Carpenter's 1833 advertisement and Carpenter & Westley's trade card for 1826-1833. Birmingham Public Library; Science Museum.

This exhibition was named the 'Microcosm', and visitors to it were encouraged to buy Carpenter's wares. It is perhaps worth noting that apart from examples of Brewster's kaleidoscopes, all the surviving instruments with Philip Carpenter's signature appear to come from the London end of his business. This must have been a marketing device, given the current understanding that only the best quality goods were manufactured in the metropolis, and that - as Henry Mayhew's 'experienced tradesman' claimed - 'made in Birmingham' had a pejorative ring to it.

Philip Carpenter's other popular line in instrumentation besides the microscope, and the shorter-lived kaleidoscope boom, was in optical projection, which developed from the success of the 'Microcosm'. Solar microscopes and subsequently magic lanterns had been used as teaching aids since the late seventeenth century, as outlined recently by Thomas L. Hankins and Robert J. Silverman.[116] Indeed, Carpenter produced his own 'improved magic lantern' which he described and offered for sale in his 1823 *Elements of Zoology*, described by Hermann Hecht as 'a well-designed and fairly cheap lantern and - for the first time - mass-produced, well-painted slides with an educational subject matter, based on "scientific" principles [which] proved a turning point in projection methods and in the use of the lantern. ... Carpenter was the first to go about the production of lanterns and slides in a creative, business-like fashion, finding solutions to problems which had been dormant for years.'[117] Both Philip Carpenter and his sister Mary died wealthy people.[118]

For the ten years from 1837 when Carpenter's ex-foreman Robert Field bought and ran the Birmingham end of the business, its name was 'Robert Field', and they were described as 'opticians' in the local street directories. In 1845 the business at 113 New Street changed its name to 'Robert Field & Son': they advertised themselves as 'manufacturers of every variety of optical, philosophical and mathematical instruments'.[119] As we have seen, the firm exhibited microscopes and photographic optics at the Great Exhibition in 1851, where the Juries dismissed these as 'not

[116]. Hankins and Silverman (1995), chapter 3 'The Magic Lantern and the Art of Demonstration', 37-71.
[117]. Hecht (1993), 77.
[118]. Public Record Office, Death Duty Registers, IR 26/1316 Reg. 2 No 229 Philip Carpenter, died 30 April 1833. Total £4000.
[119]. In Birmingham directories, 1837-1845.

such as demand especial notice'.[120] That year, on 14 September, at the age of 64, Robert Field senior died.[121] His son (also named Robert) continued to run the business, and it was under his aegis in 1855 the firm put in for and won the Society of Arts Prize for two cheap microscopes.[122]

The Birmingham instrument trade - like its neighbouring industry, the small arms manufacturers - was made up of a number of small capitalists, who were flexible enough to manufacture in increasingly large quantities parts or entire instruments, and had the ability to alter these to suit changing markets by changing the product or taking on more skilled hands, or laying them off. Field himself wrote for the British Association in 1866 that 'Few trades have advanced as rapidly during the last thirty years, and although the workmen do not earn very high wages, their labour is light and well-paid, and many of them set up as "small masters", and carry on their business at their own homes... machinery, although used wherever necessary, is not employed to any great extent; the chief requisites being careful finish and delicate skill...'.[123] However, even as early as November 1855, when the Society of Arts Microscope Committee met to examine the first batch of the promised one hundred compound microscopes (only fifty had been delivered) they found that:

> the workmanship is generally not so good as it might be & is not equal to the original Instruments furnished, & that in common with respect to the original Instruments furnished [?the Committee had passed...] over certain aspects of workmanship on the understanding that they had been finished in a hurry & that subsequent instruments were to be of superior workmanship. That Mr Field also be informed with respect to the smaller microscope the Committee have examined the final twelve & do not find any one properly fitted & they therefore require that Messrs. Field have them all duly examined & fitted before they can recommend the Society to accept them.[124]

Clues to what had happened are to be found in the letters written by Robert Field junior to the Society of Arts: for instance, apologising for the delay in completing the order in July 1855 he wrote: 'We ... are sorry they are so long in hand, but some fresh hands are not yet accustomed to our ways of work & do not progress as they should do';[125] small batches were sent with further apologies in August and October, and again in early November:

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120. *Catalogue* ... (1852), 435; *Reports* ... (1852), 267.
121. *Aris's Gazette*, 15 September 1851.
122. 'Premiums' (1855).
123. [Robert Field], 'Optical and Mathematical Instruments' in Timmins (1866), 533-5.
124. R.S.A. MS Minutes of Committees 1853-1855, p.483.
125. A/RSA/13/F/28: Letter dated 19 July 1855 to the Society from R. Field & Son.

> We forwarded the remainder of Microscopes on Saturday ... the number sent is 51 large & 101 small as one of each were sent to Mr Barker our Marker the rec^t of which we enclose. You do not say if any have been examined & approved. We find the price is very close but still with good demand may pay.[126]

This doubt may be reflected in the 'poor workmanship' which the Committee found. So many short cuts were being taken in the search for economy that the instruments suffered in quality.

Despite this, Field & Son had gained enough self-confidence to advertise the instruments in the 1856 second edition of Jabez Hogg's *The Microscope: its History, Construction and Applications*, in which the author mentioned in his preface that the interest in the subject was such that the first edition of five thousand copies had sold out in twelve months flat.[127] Field & Son also produced a *Condensed Catalogue of Optical & Philosophical Instruments*, which was bound in the back of a little booklet with a preface written by H. Woodward, of the Geological Department of the British Museum, entitled *The Prize Microscopes of the Society of Arts...*, in at least two editions, one dated 1859, the second 1863.[128] The 1859 edition lists twenty-one agents throughout the United Kingdom from whom Field's instruments might be procured.[129] The impression given is that in 1859 cheap microscopes with the Society of Arts' stamp of approval were selling rapidly; but the 1863 edition no longer carried the information about the agents, implying that by this date they had stopped retailing Field's microscopes.

By April 1858 at least one London microscope manufacturer, presumably feeling the competitive pinch, was advertising in the endpapers of the *Quarterly Journal of Microscopical Science* that:

> ... C. Baker of 243 and 244 High Holborn from the introduction of improved machinery is now able to supply the pattern microscope so much esteemed by the Society of Arts and finished in a very superior manner with three achromatic powers, and apparatus in mahogany case, complete, at the very low price of £3-3-0.[130]

Baker was matching Field's price rather than undercutting him, and evidently using the design

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126. A/RSA/13/F/23: Letter dated 6 November 1855 to the Society from R. Field & Son.
127. Hogg (1856), endpapers and preface.
128. Field (1859) and (1863).
129. *Ibid.* (1859), 75.
130. *Quarterly Journal of Microscopical Science*, endpapers, April 1858: my thanks to Dr R.H. Nuttall for this reference.

devised by Field. Hogg's third edition of 1858 promoted Baker's Society of Arts Prize microscope, with an illustration of it on the title page and Baker's trade catalogue bound in the back, having dropped the advertisement for Field, although continuing to mention his instruments in the text, where it was more difficult and expensive to alter standing print.[131] The following year, the President of the Microscopical Society, Edwin Lankester (another member of the Committee which had chosen Field's instruments as winners) said in his Presidential Address for 1859:

> I am glad to inform you that the sale of cheaper microscopes of powers decidedly available for scientific microscopes has greatly increased. ... The makers of the microscope which obtained the medal have sent out 1393 of these instruments, and I find, on enquiry amongst various makers, that, since the appearance of this microscope [presumably the compound instrument], the sale of microscopes at a cost of ten guineas and under has greatly increased. Much is thus evidently done towards making the microscope an instrument of popular use and instruction.[132]

William Carpenter's third edition of his text on *The Microscope* of 1862 noted 'with great satisfaction, that no fewer than 1800 of these Microscopes have been sold up to the end of the year 1861'.[133] These text books evidently sold in huge numbers and were extremely influential in guiding the newcomer to microscopy into his or her first instrument. Indeed, in a small university town in Scotland, the young William Carmichael McIntosh, later to become Professor of Natural History at St. Andrews between 1882 and 1916, recalled that:

> hitherto I had depended on the use of Charles Howie's microscope ['a good Nachet's microscope'] but my father resolved to get one for me, & accordingly after an examination of those available in St. Andrews a Field's student's microscope was chosen. This instrument had gained a prize for efficiency & cheapness (£3.3/-), the St. Andrews watchmaker however adding another guinea for expenses. It had 2 eyepieces & 2 objectives x250 & 60 respectively. It filled the gap & was useful for some years until a better was obtained.[134]

By the second half of the nineteenth century, there was a large supporting literature for the new markets for microscopy: these audiences now included women, and the industrious mechanic who spent his few leisure hours improving himself.[135] Another was the new and growing market of

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131. Hogg (1858), 67.
132. Lankester (1859).
133. Carpenter (1862), 70.
134. University of St. Andrews Library: William Carmichael McIntosh Papers, Ms 37113/1, p115.
135. For women, see Phillips (1990), esp. Part III; the case of the amateur naturalist and coastguard, Charles Peach (1800-86), who was presented with a microscope by W.B. Carpenter,

medical students, for whom a number of textbooks were produced. Carpenter's volume, as already stated, ran to eight editions between 1856 and 1901; although Jabez Hogg had died in 1899, the fifteenth edition of his *The Microscope* appeared in 1911; Lionel S. Beale produced a variety of texts, *How to Work with the Microscope*, in five editions between 1857 and 1880; *The Microscope and Clinical* [later] *Practical Medicine*, in four editions between 1854 and 1878. In particular, Beale championed the cheap instruments produced by the London makers 'Mr Matthews of Lincoln's Inn', William Salmon, and Samuel Highley (Salmon and Highley had both failed to win the 1855 prize); Highley also published some editions of Beale's books. John Quekett's *Treatise on the Microscope* only went to three editions, probably because of his early death in 1861.

Other influential authors included the Edinburgh university professor of what was to become physiology, John Hughes Bennett. He was the first to introduce practical microscopy into the curriculum of any British university, although his first course given in 1841 was to extra-mural classes at Edinburgh, and made use of microscopes made by the Parisian optician Chevalier. Bennett, who had done some years of postgraduate work in Paris, promoted Continental instruments (especially, latterly, those of Georges Oberhaeuser), and was critical of the brassy splendour and expense of the best London-made instruments. His *Clinical Lectures on the Principles and Practice of Medicine* ran to five editions in Britain between 1856 and 1868, six in the United States, and was also translated into French, Russian and Hindi.[136] Between 1831 and 1859, a period of twenty-eight years, Oberhaeuser's workshop supplied some three thousand microscopes at the rate of about one hundred a year. Bennett's influential advocacy of the Oberhaeuser microscope probably helped the Parisian instrument maker to sell more student 'drum' models than he might otherwise have done: one observer noted that Oberhaeuser exported more of his microscopes to Britain than to any other country.[137]

Field numbered his Society of Arts Prize microscopes. The reasons why a manufacturer would want to do this is not clear, but it may have been a straightforward counting procedure. Other instances of this exist, such as those by the London makers James Short, and Nairne & Blunt,

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retailed by Carpenter & Westley, is discussed in Smiles (1878), 238-81; the microscope is now in the National Museums of Scotland, inv. no. NMS.T.1999.40.

[136]. For a recent assessment of John Hughes Bennett and his influence on the teaching of microscopy, see Jacyna (1997), and Morrison-Low (1997).

who numbered their reflecting telescopes; the Edinburgh manufacturer Alexander Adie, who produced a patented 'improved air barometer' called the sympiesometer; and, as we have seen, microscopes by the provincial instrument makers J.B. Dancer of Manchester and T.D. King of Bristol.[138] The numbering on Field's microscopes has not received much attention from instrument historians, and not many of his instruments have been recorded or appear to have survived, which in turn begs the question, how many were actually made? It is not clear whether there was one series for both types of instrument, or parallel runs for each sort: and would an instrument-maker begin his numbering with '1'? The highest number recorded (so far) is 1045 for a school microscope, somewhat short of W.B. Carpenter's 1861 figure of 1800; but if added to the highest known for the compound, 706, the total reaches 1751.[139]

In 1862, another international exhibition was held in London, and again, Field exhibited instruments, but the Jurors took a somewhat critical view of his display:

> Very cheap forms of compound microscope are exhibited by Mr Field, who obtained the Society of Arts' prize some years since, but who does not appear to have in any respect improved his model; and others by Mr Parkes, the cheapest of all, but at the same time it must be added, the least efficient optically; whether the quality is as good as can be procured at the price is a question which none but the manufacturer can determine.[140]

Here it is clear that the Jurors regard the 'manufacturer' as a tradesman, no longer as a part of the 'scientific community', a peculiarly British social change from the earlier, more equable status between craftsman and client, noted by J.A. Bennett.[141] Despite this, Parkes obtained an 'Honourable Mention', although Field was ignored. Parkes, another Birmingham manufacturer, who had participated in the Society of Arts competition in 1855, now produced a trade catalogue after the exhibition results had been announced, and used their success to advertise their microscopes, despite the reservations of the Jurors: 'Jury Award Class 13, at International

137. Otto (1970), and Nuttall (1979), 55.

138. Turner (1969); Turner (1979b); a discussion of the numbered Adie sympiesometers is to be found in Clarke et al. (1989), 37.

139. See Nuttall (1979), 50: 102 for the compound, now NMS T.1979.75 and 998 for the school model, now NMS T.1979.76; another example of the 10/6d model is numbered 665 [inventory number: Wellcome Museum A645036]; while two others are an incomplete school instrument numbered 1045, and a compound 601 [inventory number: York Castle Museum: 105A/36; no inventory number]; another compound is numbered 706 [inventory number: Wh:3191; described and illustrated in Brown (1986), catalogue no. 223].

140. *Reports...* (1863), 2*.

Exhibition, 1862: "For economy (*combined with quality*) in the Manufacture of Microscopes and Mathematical Instruments"[141]. Their 'Compound School Microscope' was available for 11s 6d; their 'Improved School Microscope' (a compound achromatic model) for £1 1s; and their 'Student's Model microscope, - recommended by the Society of Arts' for £3 3s, with the qualification 'N.B. Upwards of One Thousand of these Microscopes have been sold since their introduction.'[142] However, it is not clear whether these figures included those previously sold by Field , or by other makers.

By 1867, a preface to Parkes's *Wholesale Catalogue of Optical, Mathematical and Philosophical Instruments* explained their marketing strategy in a 'mission statement':

> A notion has very generally prevailed (one which formerly had too frequent foundation in fact) that certain articles could only be produced, of first-rate quality, IN CERTAIN LOCALITIES. This, it need scarcely be said, is now very far from the truth.
>
> The improvements which have been made in modern machinery, (especially in the Midland Counties of England,) and the facilities which are afforded by extensive railway intercommunication, have done much to break down such local peculiarities. Manufacturers, therefore, instead of depending on a mere name, or old reputation, have now to study how they may skilfully *combine* the special advantages peculiar to some localities, with those of others; so that, by the aid of machinery improvements, they may obtain a superior total result...
>
> In some cases, where we have considered our Continental neighbours to excel us in certain *specialities*, (either as to quality or price,) we have combined such portions of their work, with other of our own Manufacture, and have, by such combination obtained advantageous results. Skilled London workmen are also employed by us on certain parts of Instruments used for Optical and Mathematical purposes; so that, with the additional aid of our own special machinery improvements, we have been enabled to produce a really superior article at a far more moderate cost...

Parkes then illustrated and described two items within their range of stock as 'The Student's Model Microscope, recommended by the Society of Arts ... £3 3s' and the 'Simple Microscope for general use and for dissecting ... 10s 6d. N.B. This instrument is recommended by the Society of Arts.'[143] It would appear that Parkes had taken over producing this cheap but successful model of microscope, while Field withdrew from this particular market.

Correspondence in the Royal Society of Arts' archives reveals that the main reason Parkes

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141. Bennett (1985).
142. Parkes (1862), 6-7.
143. Parkes (1867), 43-44.

had done badly in the 1855 competition was because the firm had found out about it and the 1 May deadline only in early April; unlike Field, their letters reveal that they continued to develop both microscope models after this deadline. It is perhaps a mark of the proprietor Samuel Hickling Parkes's ability as a businessman that by 1857 the Parkes' catalogue advertised their appointment as 'Instrument makers to the Board of Trade, and Government Schools of Design'; by 1886, they were boasting in their 'Introductory Remarks' that their medical and educational microscopes were being used in all the universities, and in many London and provincial hospitals. The firm of Field & Son appears to have bowed out of the microscope market soon after winning the prestigious Society of Arts competition; possibly because they found it impossible to produce instruments of reasonable quality at such a low retail price. They went on to make larger inroads into the optical projection market, with Robert Field taking out a number of patents before his death in the 1890s.[144] Society of Arts pattern microscopes continued to be advertised by various makers until the end of the nineteenth century: an example dating from 1894 was offered by John J. Griffin & Sons Ltd. for £2-16s.[145]

Conclusions

Provincial instrument manufacturers appear to have grasped a number of the marketing opportunities outlined by McKendrick in attracting would-be consumers at the dilettante end of the market. These included more attractive shops, with carefully-dressed windows to tempt the passer-by; canny use of advertisement through trade literature in the form of trade cards, press announcements and lists of goods, whether bound in the back of books, or issued separately. However, Pat Hudson has warned that the theory of a 'consumer revolution' of the late eighteenth century has perhaps been over-emphasised: 'the evidence of change in real incomes for the masses, of poverty levels in the later eighteenth century and of the redistribution of income in society in favour of rent and profit receivers makes it likely that the mass of the population remained below the level at which they could participate in revolutionary fashion-orientated consumption of either domestic manufactures or imported commodities in the period of the industrial revolution itself.'[146] She also feels that the use of Wedgwood as an example of creative salesmanship is 'perhaps

[144]. Hecht (1993), 253 and 296.
[145]. Griffin (1894), 302-3.
[146]. Hudson (1992), 176.

overused: he was not a typical entrepreneur and not even the leading manufacturer in pottery.'[147]

The late example of the Society of Arts microscope, chosen to demonstrate the encouragement of a new market, also shows that the top London microscope makers simply did not, in that instance, bother to compete. Why should this be so? It may show that by 1855, there was already market demarcation, and that specialist, top-quality makers in any field did not need to compete, as they already knew what their market parameters were, and were comfortable with remaining within them. Of the three pre-eminent London makers, only Smith & Beck produced a 'student microscope' in the latter years of the nineteenth century, priced higher that of the Society of Arts three guineas, and clearly did not feel the need to move further downmarket. After mid-century, some firms were able to survive by specialising in a particular line: most provincial firms continued to offer products suitable for needs across a spectrum of potential customers.

Instruments of all sorts - practical, scientific, educational - were supplied by manufacturers based in the new centres of industry outside London, and taken to the marketplace. In 1851, eight provincial English firms displayed goods in Class X at the Crystal Palace, showing that they at least entertained a new-found confidence in selling their wares directly to their customers.[148] The survival of material culture from this period far exceeds that of the preceding century. Even if the majority of the population was unable to participate in a 'consumer culture' the growing middle classes bought their way into 'lifestyles embodying consensus polite culture'.[149] Instruments, representing their owners' intellectual attainments, formed a part of this.

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[147]. *Ibid.*, 179.

[148]. Turner (1983), 309-10; these were: Abraham Abraham & Co., Liverpool; John Braham, Bristol; Chadburn Brothers, Sheffield and Liverpool; Robert Field & Son, Birmingham; J.N. Hearder, Plymouth; Thomas D. King, Bristol; James Parkes & Son, Birmingham; William Wilton, St. Day, Truro.

[149]. Glennie (1995), 169.

Chapter 6: Demand

Introduction

'Demand' in eighteenth century England was described by Neil McKendrick in 1982 as 'a consumer boom'. For McKendrick, 'the consumer revolution was the necessary analogue to the industrial revolution, the necessary convulsion on the demand side of the equation to match the convulsion on the supply side.'[1] Subsequently, other economic historians have criticised his arguments on two grounds. First, their limited empirical basis - clothing, pottery, and shaving accessories - and secondly, that as an instigator of the Industrial Revolution, setting 'demand' on an equal footing with 'supply' is at odds with 'the more common theoretical approach which places it in a subordinate position to supply, abetting or constraining it through pressures of overheated, insufficient or fragmented markets. The institution of demand-led growth, let alone revolution seems to follow from the informal extrapolation to the economy as a whole from a particular sector from within it.'[2] Yet, although Joel Mokyr and Deirdre McCloskey convincingly demonstrate that supply conditions are paramount throughout the economy as a whole, there remains a 'demand' side which needs to be explained.[3] In the case of scientific instruments, which range from necessary tools to luxury toys, there would appear to have been a steady and growing demand throughout this period, which led to the establishment and continuing growth of the trade outside London well into the late nineteenth century. How large and how significant was this?

The evidence does not point to the generation of great local provincial demand, rather towards a growth of the domestic market and of that abroad. Physically, these markets were located either in London itself, or (reached through the gateway of London) overseas. The metal industries in general, Ralph Davis has commented, had increased in value almost to match the output of the woollen industries by the 1770s: 'it was growing demand derived largely from the American colonies that pulled the metal industries forward during the first three-quarters of the eighteenth century; and an increasing output made it possible to secure considerable economies

1. McKendrick (1982), 9.
2. Fine and Leopold (1993), 73.
3. Mokyr (1977); McCloskey (1981).

from division of labour, and this lowering of costs was able to stimulate demand further.'[4] The successful business of instrument production outside London, as shown in previous chapters, had more to do with the integration of regional specialised economies – the metal trades of Birmingham or the Sheffield cutlery industry – or an industrialising hinterland providing a ready pool of skilled labour, as in the areas surrounding Liverpool and Manchester. In the capital, as Gareth Stedman Jones summarised:

> The economic importance of London depended upon three closely-related factors: firstly, it was the major port of the English import and trans-shipment trade; secondly, it was by far the largest single consumer market in England; and thirdly, as a centre of government and the royal court, it was the focal point of conspicuous consumption and its attendant luxury trades.[5]

He went on to show that in the case of 'finished consumer goods', such as instrument production, 'proximity to the market could still be a decisive advantage' for the London producer over the provincial manufacturer until well into the 1860s.[6] Although 'some of these trades underwent a gentle decline in the second half of the nineteenth century' – beyond the scope of this thesis – but as long as there was sufficient demand, and as long as 'technological innovators demanded superior handmade, and often new or experimental precision instruments ... there was little chance of real competition from Lancashire, the West Riding, or the Midlands.'[7] I would argue that Stedman Jones has looked only at the small 'precision instrument' fraction of the entire instrument market, and suggest that he has underestimated the diversity of the products of this trade and thus the range of its customers. This chapter will address these problems: what were the instruments, who bought them, and whether demand grew during this period for particular sections of the market.

Even if the instrument trade was not entirely demand-led, the demands upon it during the Industrial Revolution stimulated its growth, and require further discussion. Maxine Berg comments that historians of consumption have failed to look at the production of luxury products as industries and, conversely, that economic historians have failed to collect output data for industries producing such new consumer wares. In an article demonstrating that product innovation promoted consumerism, Berg has argued that, 'scientific instruments were ornaments of consumption as

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4. Davis (1973), 303.
5. Stedman Jones (1976), 19.
6. *Ibid.*, 20.
7. *Ibid.*, 22.

much as they were tools of engineering'.[8] Because of the absence of any meaningful data, especially output figures or profits, this chapter outlines the main types of customer for different sorts of instrument in order to show where and how growth occurred, stimulating new and viable centres for production outside the metropolis. Even without quantitative data an analysis of demand shows that neither 'ornaments of demand' nor 'tools of engineering' fully describes the products aimed at the various categories within the market.

Consumer demand: the customers

Who were the customers for scientific instruments? The market, whether at home or overseas, as was discussed in the introduction to this thesis, was defined as long ago as 1964 by Silvio Bedini, and was seen as having mainly 'teaching' and 'practical' customers, subdivided into 'scientific', 'professional' and 'dilettante' categories.[9] More recently, Richard Sorrenson, having sketched the supply side of the eighteenth century trade, sums up the demand side as

> domestic, colonial and European consumers purchasing marine, surveying, and household instruments; natural philosophers in Britain and abroad ordering experimental and observational instruments; popular lecturers and schoolteachers buying a whole range of demonstration instruments to explicate the new natural philosophy; and finally ... the British state itself, buying gauging instruments for the customs and excise, marine instruments for the navy, astronomical instruments for the Royal Greenwich Observatory, and surveying instruments for the Board of ordnance, as well as offering prizes for navigational instruments through the Board of Longitude.[10]

Sorrenson has four market categories, merging the 'scientific' with a 'Special Market' which he sees appearing in the eighteenth century, the British state. His contention is that different markets for different types of instruments emerged over time: a 'Natural Philosophical' market appeared in the seventeenth century, absorbing newly-invented instruments such as pendulum clocks, telescopes, air pumps and microscopes as well as older mathematical instruments, such as quadrants and magnetic compasses, used in this new context of demonstration. Two entirely new markets, the 'Natural Philosophical Lecturing' and the 'Household', were created in the late seventeenth and early eighteenth centuries, as applied science moved down the social scale 'into the newly burgeoning commercial market-place of consumers.'[11] Only his somewhat cumbersome

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8. Berg (1998), 154.
9. Bedini (1964), 3-13.
10. Sorrenson (1995), 264.
11. *Ibid.*, 265.

category of 'Marine, Astronomical, Surveying, Weights and Measures' he dates as existing from before the scientific revolution, and into it he places most practical instruments (which Bedini characterised as 'practical' or 'professional'), but adds the rider that 'the most important newcomers in the eighteenth century were chronometers, dividing engines, large theodolites, and achromatic lenses, all of which became commonly available only after they had been first developed in response to the demands of the British state.' There are distinct problems with Sorrenson's analysis of the market, especially where he has put scientific demand together with state demand; however, he appears to be one of the first to articulate in print the role of state demand and intervention.[12]

By building on the analyses offered by Bedini and Sorrenson, and incorporating evidence from the provincial trade, we can create a new characterisation of the trade [see Table 6:1]. This will show how demand changed over time and reveal how new markets came into existence. Clearly, the products across all these markets changed with time. Those aimed at the first category, for instance, the dilettante market, were generally demand-led luxuries, and in the mid-eighteenth century probably formed a larger proportion of the entire instruments market than in 1851. Their design might include a certain amount of cultural involution, or change for change's sake, but served the purpose of increasing the skills of the maker and delighting the fashion sense of the owner. There was not yet an 'industrial' category, as the instruments eventually designed of product control on the factory floor at this period would either have been the 'practical' instruments used in measurement or engineering, or have fallen into the 'State's' market, where standard instruments were required by legislation, from which those in use in the market place were derived. Not until the late nineteenth century, when university-designed equipment was marketed successfully to industry - examples being the highly-successful business of the Cambridge Scientific Instrument Company, or James White of Glasgow[13] - could an 'industrial' category said to have come into existence. Driving it were dramatic changes in the applications of science, in particular the genesis of the electrical industry and its eventual application to the domestic scene. The greatest growth area during the Industrial Revolution was surely in the 'teaching' market, which led to new emerging audiences for science and customers for instruments; especially women, younger people

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12. See also, Wess (1998).

13. For CSI, see Cattermole and Wolfe (19870); for White, see Clarke et al., (1989), 252-75.

Market	Contents	Examples	Size and character
1. Dilettante	Any bespoke item used to demonstrate its owner's virtuosity, cleverness and wealth	Clockwork automata , items constructed in precious metals	Small, metropolitan
2. Practical	Surveying instruments: exploration, mapping, engineering. Navigation instruments: foreign and coastal trade	Compasses, chronometers, tables, telescopes, gunnery and fortification devices, levels, slide rules	Growing with the empire, peripatetic
3. Teaching	Lecture-demonstration material	Orreries, electrical machines, magic lanterns, airpumps, chemical apparatus, magnets, mechanical models	Large growth in late 18th century with the Literary and Philosophical movement, subsequently further down the social scale with the Mechanics Institutes; metropolitan and provincial
4. Domestic	Items that became 'everday'	Clocks, spectacles, telescopes, microscopes, opera glasses, cameras obscura, thermometers, barometers, 'toys'	Small, but spreading with the rise of a consumer culture
5. Scientific	Precision pieces, used for specific experiments, or as national standards	Physics apparatus made for J. P. Joule by Manchester instrument maker J.B. Dancer to measure calorific heat. More usually commissioned from London instrument trade than the provinces. Astronomical transit instrument at Greewich, defining the prime meridian (accepted internationally 1884)	Small, but sometimes expensive; usually London-based or generated, but extremely influential nationally and internationally
6. State	Precision pieces, sometimes made to match legislation	Standard yard for the Royal Society; chronometers and dividing engines for the Board of Longitude; pendulum clocks, quadrants, sectors, telescopes for the Royal Greenwich Observatory; theodolites for the Ordnance Survey; hydrometers and saccharometers for Customs and Excise; navigation instruments for the Royal Navy; surveying instruments for the empire	Extremely large

Table 6:1 Table illustrating markets for scientific instruments made in England, 1760 to 1851

and children. These also created a small, but growing 'domestic' market, mostly confined to the upper and middle classes, which would not become widespread throughout society until the late twentieth century. This chapter will look at each of these six broad market categories in turn, and try to assess where the demand for instruments grew during this period, even if, as Hudson has remarked, the effects of the consumer revolution have been over-emphasised.[14] One of the great problems has been the lack of any consistent data concerning the size of particular markets. Such statistics as survive relate to different instruments, and these to different years. These are presented in Table 6:2 to give an idea of broad orders of magnitude of sales. They should not be interpreted as an internally-consistent time series.

The dilettante market

Often scientific instruments were bought for unscientific reasons.[15] Wealthy customers enjoyed star-gazing, or exploring pond-life through a microscope, without necessarily adding to knowledge through their use of these devices, nor understanding fully how the instrument worked. Late twentieth-century equivalents might be the camera, or the personal computer. As far as the maker was concerned, this did not matter: he had made a sale. This trend can be discerned much earlier on the Continent, where collections of contemporary instruments, often constructed in valuable materials, would be presented to royalty and preserved in cabinets. These were often given to show respect for the recipient's understanding of the knowledge represented by the object, even if this understanding was absent; for instance, the gilt astrolabe which may have been presented to Henry Stuart, Prince of Wales (1594-1612).[16] The astrolabe requires an understanding of basic geometry and astronomy in order to be used as either a time-telling or positional-fixing or surveying instrument, and there is no evidence that this example was ever used for the purpose for which it was made. Highly-decorated, and usually highly complex instruments - designed to demonstrate the virtuosity of the maker as well as flatter the intellect of the customer or the recipient of his gift - have survived, particularly in princely collections from the Renaissance onwards.

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[14]. Hudson (1982), 176.

[15]. Bryden (1972), 15.

[16]. Made by the first native-born English instrument maker, Humphrey Cole: Ackermann (1998), 32.

Instrument	Output	Year recorded
Chronometer (1 per ocean going ship)	Royal Navy had 750 (not all new that year)	1859
Kaleidoscope	200,000	1817 (three month period)
Spectacles	Necessary for the population aged 40+	-
Hydrometer	3700 in Excise use 17,000 in traders' hands	1837 1837
Sets of verified standard weights and measures	324 full sets and 149 part sets	1824 – 1834
Various instruments to HM Ordnance	'over 1500 [various] instruments…', (but there was material also supplied by other makers)	1748 to 1772
Survey of India	'[surveying] instruments…20,158'	By 1880

Table 6:2 Table illustrating some known data concerning sales of instruments. For sources on individual items, see the text of chapter 6 and references.

This market required luxury goods, and during the seventeenth century a number of London instrument makers were able to cater for this particular demand, but this luxury end of the market remained tiny, in England as elsewhere. Recent research has shown that instruments have been collected as curiosities or antiquities only in the past two hundred years. This means that instruments which found their way into cabinets of curiosities were usually contemporary, for by the eighteenth century it was human curiosity in the natural world which was the driving impetus to forming such a cabinet.[17] These instruments were usually at the forefront of design, and acquired to impress the owner's acquaintances as much as to undertake an occasional scientific programme. Often, the owner would be a member of the Royal Society - based in London - but might undertake his 'research' in the country. More often than not, his instrument would have been made and purchased in London.

During this period, the aristocracy was growing more wealthy, as land-prices rose. A growing genuine interest in scientific principles led upper-class Englishmen to gather collections in their country houses of natural history, rocks and minerals alongside their paintings and antiquities brought back from the Grand Tour. John Stuart, third Earl of Bute (1713-1792), had large collections of natural history material, but also a substantial collection of instruments.[18] He had clearly been influenced by the intellectual pursuits and collections formed by his uncle, Archibald Campbell, third Duke of Argyll (1682-1761). Items of conspicuous consumption ordered by the Duke included a grand orrery and a large mechanical equinoctial ring sundial which incorporated his coat-of-arms.[19] Bute had enormous political power, and was very close to the widowed Augusta, Princess of Wales, and thus in a position to influence her son, who became king in 1760. Bute arranged for the young George to attend lectures on natural philosophy, and it has been suggested that the king wished to emulate Bute's example in acquiring an even larger and more complete suite of apparatus: within three months of his accession he had appointed George Adams as his Mathematical Instrument Maker, and commissioned him to make pneumatic and mechanics apparatus.[20] Part of the theory of the rise of a consumer society is the 'trickle-down' aspect of emulation through society. This model appears to work for England, where society was more open,

[17]. Turner (1987), 275.
[18]. Turner (1967), 213-42; Bute's other collections are discussed in Schweizer (1988).
[19]. Morrison-Low (1995a).
[20]. Morton and Wess (1993), 17-18.

and there was comparatively more social mobility than in, for instance, France. There appears to be more evidence in England of the successful emulation of one's betters in the hierarchy, or of the possibilities of moving upwards through advantageous marriage.[21] It has, however, been dismissed by Fine and Leopold as 'wishful thinking', in that most contemporary observations deploring emulation of one's superiors were written by upper class observers jealous of their own position.[22] Yet the spread of this sort of collection of instruments during the late eighteenth century amongst the British upper classes must have been given some stamp of approval by the existence and knowledge of the Royal collection, and as we have already seen in chapter 5, instrument retailers frequently mentioned the patronage of royal or noble customers in their trade literature.

These collections were not just demonstrations of conspicuous consumption. Both Bute and Argyll were actively interested in the subject-matter. Bute apparently designed a microscope, albeit one subsequently made in extremely limited numbers by George Adams, which sold for £21 [Fig. 6:3]; and Argyll's patronage of the youthful watchmaker Alexander Cumming, first at his substantial new house at Inveraray (where he repaired some of the Duke's instruments), and subsequently in London, allowed Cumming access to the wealthiest of customers.[23] Such patrons had estates all around the country, hence the survival today of instrument collections at Burton Constable, Chatsworth, Kedleston, Longleat and Petworth. However, apart from a pyrometer made by the precision clockmaker Joseph Finney of Liverpool at Burton Constable, none now contain items made outside London: the dilettante market was almost exclusively supplied by the London trade.[24] By the late nineteenth century, royal patronage of scientific instrument manufacture had declined, partly because of the lack of interest by the reigning monarch.

The significance of wealthy, dilettante collectors, amongst whom the King was the most extreme example, is that in order to keep this market supplied with novelties, the instrument makers

[21]. Perkin (1969), 17-62.

[22]. Fine and Leopold (1993), 138.

[23]. The microscope was first illustrated in Hill (1770), whose patron was Bute, and subsequently described by Adams (1771), 1: 'We owe the construction of the variable microscope to the ingenuity and generosity of a noble person...'; for Cumming, see Cosh (1969).

[24]. Holbrook et al. (1992), 18-19, 105, 113-114, 140-141, 148-149, and 195-196. The George III collection also has pieces made by Finney.

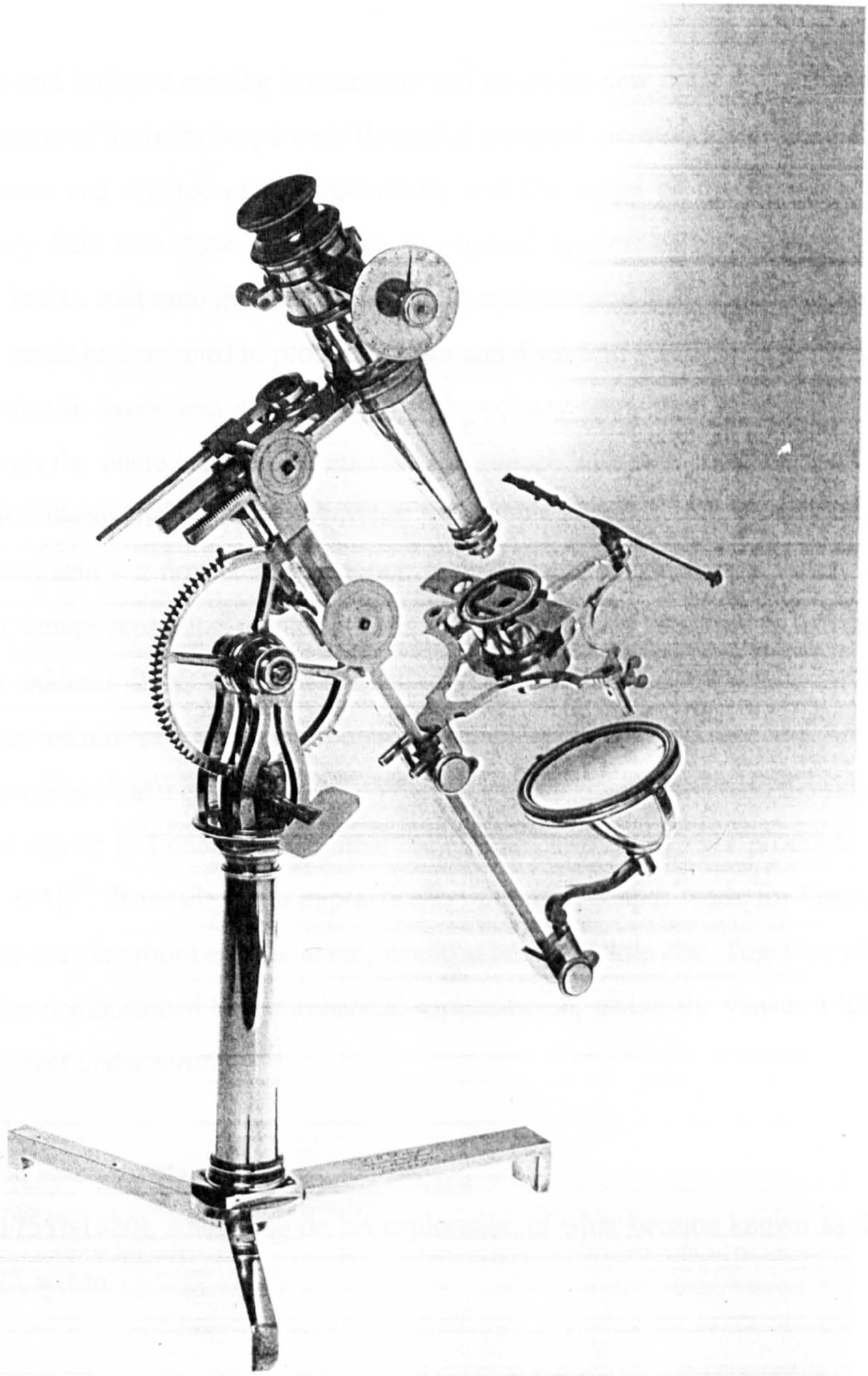

Fig. 6:3 George Adams's 'Variable' microscope, designed by the 3rd Earl of Bute, c.1780; this example is made in silver.
National Museums of Scotland.

were forced to re-design and improve existing instruments and to create new ones. For instance, although the mechanical parts of the microscope went through a thousand permutations during this period – to the adjustment and control of the instrument, and the range of manipulation of microscopic objects – very little was done to improve the optical system of the microscope. Significant improvement had to wait until the early 1830s when mathematical analysis first showed how optical components could be combined to produce colour and distortion-free images with high resolution. Little real scientific work was accomplished with ordinary compound instruments of this period, and it was with the single lens 'simple microscope', which with skill could be used at higher magnifications, that discoveries such as Brownian motion were made.[25] Even as late as 1862, J. Parkes of Birmingham - a firm clearly in touch with demand, by offering a variety of 'educational' models for newly-expanding markets - was willing to offer a particularly baroque compound instrument in oxidised silver, 'designed specially for the International Exhibition ... this magnificent drawing-room instrument is the first successful attempt to combine Science and Art in the construction of a Microscope', at a cost of £150.[26] Whether more were ordered than the single example constructed and shown in London - 'the most magnificent instrument ever produced' - remains to be seen [Fig. 6:4].[27] It recalls, in its impracticality, the microscopes made for George III, which, although fit for drawing room entertainment, would accomplish little else. Together with the Bute instrument, these demonstrated little mechanical sophistication, giving the viewer a less-than-steady view of the object under scrutiny.[28]

The market for practical instruments

Alexander Mackenzie (1755?-1820), embarking on his exploration of what became known as the Mackenzie River, in 1792, wrote:

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[25]. For the successful introduction of the achromatic microscope, see Nuttall (1979). Ford (1985) discusses the single-lens instruments used in serious work done by Carl Linneaeus (fungal spores), William Withering (botany), Joseph Hooker (botany), Robert Brown (botany) and Charles Darwin (natural history). Brownian motion is 'the erratic random movement of microscopic particles in suspension, for instance in a liquid or smoke particles in air: caused by the continuous irregular bombardment of the particles by the molecules of the surrounding medium. Named after Robert Brown (1773-1858)': Uvarov et al. (1971), 55.

[26]. Parkes (1862), 12-13.

[27]. *Catalogue...* (1862), 27.

[28]. The single exception was the work of Hill (1770), carried out using an Adams 'Variable' microscope: Bradbury (1967), 152.

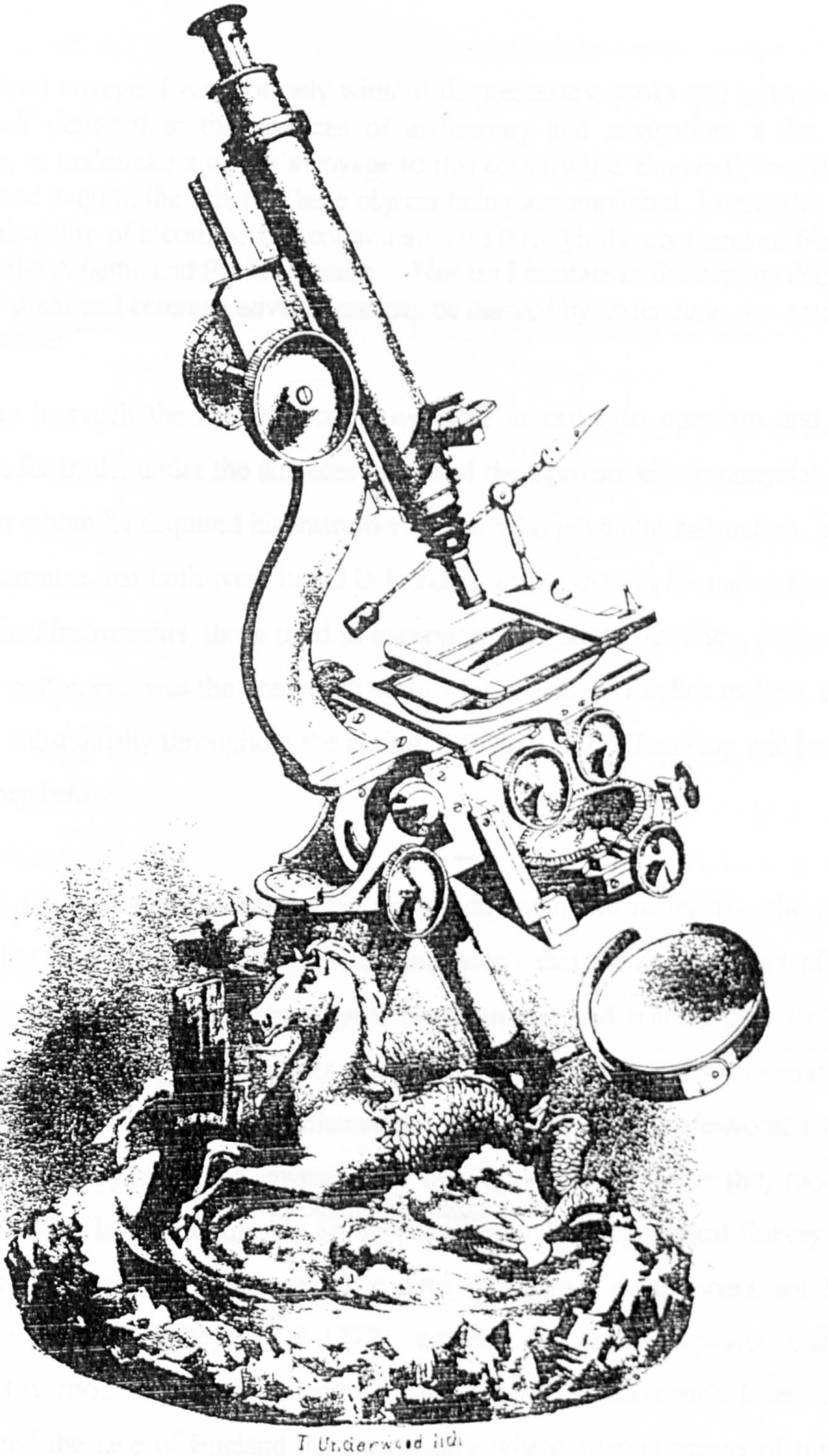

Fig. 6:4 James Parkes & Son's 'Fine Art Exhibition Microscope', offered in 1862. Birmingham Reference Library.

> In this [first] voyage, I was not only without the necessary books and instruments, but also felt myself deficient in the sciences of astronomy and navigation: I did not hesitate, therefore, to undertake a winter's voyage to this country [i.e. England], in order to procure the one and acquire the other. These objects being accomplished, I returned, to determine the practicability of a commercial communication through the continent of North America, between the Atlantic and Pacific Oceans ... Nor do I hesitate to declare my decided opinion, that very great and essential advantages may be derived by extending our trade from one sea to another.[29]

His purpose was to reach the Pacific Ocean overland, in order to open up and exploit new territories for the fur trade, under the auspices of one of the aggressively commercial Canadian fur companies. From whom he acquired his instruments, and who gave him instruction, is not known; but it is safe to surmise that both were based in London, rather than in his native Stornaway. The market for practical instruments, those used in surveying, navigation, teaching, defined by Bryden as 'professional' customers, was the one which grew - for provincial English makers, as well as for the Scots - most substantially throughout the period 1760 to 1850.[30] Teaching will be discussed as a separate category below.

It was in the hands of the large group of practising mathematicians - the surveyor, the navigator and what was to become the precision engineer - that the development of the trade in scientific instruments lay, through technological breakthrough and market growth. Before the Industrial Revolution, the use of instruments was a skill, performed by a few numerate specialists. During the Industrial Revolution, the mathematical practitioner was professionalised: surveyors were no longer exclusively local men, owning their own instruments. Either they moved in under those great state umbrellas, the Ordnance Survey, the Great Trigonometrical Survey of India, or they combined into businesses of their own. The state, or imperial, practitioners, will be looked at below. Men like James Brindley (1716-1772), architect of the Bridgwater Canal between Manchester and Liverpool, who had his portrait painted with his surveyor's level conspicuously visible, transformed the face of England from a country where internal means of transport were slow, dangerous and expensive, first by providing the routes of the canals; latterly, the railways and finally the roads, while the coastal trade continued to ply between ports, whose harbours were significantly improved during this period. Transport improvements, especially those which involved

[29]. Mackenzie (1801), Preface, v.

engineering alterations to the landscape, clearly generated an extra demand for surveying instruments. With the rise of the empire, and Britain's growing maritime trade every ship had to have navigation instruments for a safe passage. Usually these were bought in London, although during this period, as we have seen, it became possible to acquire them elsewhere, particularly in the larger ports of Bristol and Liverpool, and subsequently in others such as Kingston-upon-Hull, Newcastle-upon-Tyne and Portsmouth.[31]

In her work on early consumerism, Lorna Weatherill listed the probate inventory of William Cartwright of Muxton in Shropshire, who died in 1718, and who was described as a 'mathematician'. Although his possessions were not especially valuable, his eight-roomed house was comfortable furnished. Amongst his belongings were 'one hundred books, [a] three leg staffe, one plaine table, one wood Quadrant, one small brass Quadrant, one brass seal, one Brass sights, one pair Brass Compasses, One pensell ... one pair Globes and box'. Cartwright was known to have made estate maps, and surveying would appear to have been his means of making a living. This source does not reveal whether his instruments were made locally or in London; but despite living in a somewhat remote part of England, he had access to the tools of his trade, which he had acquired.[32] By the early nineteenth century, Harold Perkin has demonstrated how, as a by-product of the social upheaval caused by industrialisation, the action between the contending aristocratic, entrepreneurial and working class ideals, a fourth emerged, which he identifies as the professional class, 'characterized by expert, esoteric service demanding integrity in the purveyor and trust in the client and community, and by non-competitive reward in the form of a fixed salary or standard and unquestioned fee.'[33] Gaining respectability and self-respect, he noted that 'at the same time the new professions proliferated, and organized themselves to demand the same kind of status as the old [doctors, lawyers, clergy]: the civil engineers in 1818, the architects in 1837, the pharmacists in 1841, the mechanical engineers in 1847, and so on.'[34] It was not until 1868 that the surveyors formed their institution.

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[30]. Bryden (1972), 10-15.
[31]. The Royal Navy was involved in the almost continual wars with France during the latter part of the eighteenth century, and together with the merchant navy, the numbers of ships rose during this period: see Mitchell (1988), 535-6.
[32]. Weatherill (1988), 181.
[33]. Perkin (1969), 254.
[34]. *Ibid.*, 255.

F.M.L. Thompson shows how the surveyor emerged through the troublesome times in the aftermath of the Restoration: 'from a more secure and reliable mastery over the craft of measuring and plotting, the land surveyor was diversifying into essential supporting roles in matters of valuing, letting, buying, selling, and improving land ... but in all spheres, the commanding heights remained in other hands, in those of attorneys, stewards, scriveners, or architects.'[35] The growing desire for estate improvement on the part of landowners assisted the professionalisation of the surveyor in the mid-eighteenth century, shown through the appearance of textbooks about surveying, often describing the instrumentation and its use. Thompson notes the advent of the improved theodolite of Jonathon Sisson of the Strand, which included a telescopic sight and spirit level grafted on to the original instrument. Other improvements in the tripod stand, the compass needle mounting, and the accuracy of the division of the scale 'converted an interesting gadget into a serviceable and portable field instrument'.[36] Over the next century, a proliferation of designs and 'improvements' in instrumentation appeared: 'the maker', observes J.A. Bennett, 'could not leave the surveyor in peace'.[37]

Most of these design improvements appear to have taken place in the influential London workshops, although the market for their use came from all over England as improving landowners mapped their increasingly valuable estates: nevertheless, Thompson warns that 'enclosure... [was not] the be-all and end-all of eighteenth-century surveying.'[38] He quotes an analysis of eighteenth century manuscript maps in the Bedfordshire Record Office, showing that only 35 per cent were enclosure maps, 46 per cent were made for the owner's purposes, such as inheritance, for sale or ordinary estate management. However, from 1790 to 1815, the picture is different: 'this was the age of busy, almost feverish, enclosing; in this period 60 per cent of the maps were enclosure maps, and only 34 per cent were estate maps.'[39] Were provincial instrument makers responding to this demand? Certainly, in Scotland, the surviving output of the Edinburgh firm run by John Miller and his nephew Alexander Adie appears to have been one responding to the surveying market, and there is great variety in the design of their surveying instrumentation.[40] In Ireland and America, the

[35]. Thompson (1968), 26.
[36]. *Ibid.*, 28.
[37]. Bennett (1987), 150.
[38]. Thompson (1968), 33.
[39]. *Ibid.*
[40]. Clarke et al. (1989), 25-31.

demand was for a different type of instrument, based around the compass, to suit the lower, wooded landscapes; in England, as with the rest of Europe, where buildings and church spires often formed local landmarks, the demand grew for the altazimuth theodolite.[41] In some areas of England, makers of specialist surveying instruments adapted their wares for their customers: in Cornwall, from about 1825, William Wilton of St. Day produced special equipment for the tin mines.[42] Also catering for the mining industry was a firm which had its origins in Leeds with a family of immigrant Jewish instrument makers who settled in Derby in 1830.[43] John Davis, nephew to Gabriel and brother of Gabriel's partner Edward, worked for the company, travelling to Liverpool, Cheltenham and Derby with their wares. With the growth of the railway system, Derby came into closer contact with the capital, but it also came into direct contact with the expanding industrial areas of the West Riding, and the Derbyshire, Nottinghamshire and Leicestershire coalfields. Davis manufactured and marketed two extremely popular mining instruments: Benjamin Biram's anemometer, patented in 1842, a device which measured ventilation air-flow in mines, and John Hedley's improvement of an altitude sight to the standard miner's dial, for surveying inclined underground passages, dating from about 1850.[44] Both these designers worked as mining engineers, with practical experience of particular circumstances, and their local adaptations to instruments were carried out by local instrument makers. This is a reflection of real change within provincial England, as the London instrument makers do not appear to have been suppliers for the mining industry. Elsewhere in England, there were compass makers to be found in Birmingham, from the date of the first street directory in 1767 (and thus probably before), and specialist surveyors' measuring tape manufacturers both there and in Sheffield.

A similar pattern is to be found with marine instruments. Although figures of merchant and coastal shipping is frequently given in tons rather than in numbers of vessels, it is clear that there was substantial growth in the amount of merchant shipping afloat. The rise in numbers has been assessed by Mitchell, and according to McCloskey, rates of tonnage growth per year ran at about 2.3 per cent per year, rising to 3.3 per cent per year between 1814-60. This had a large cumulative

[41]. Burnett and Morrison-Low (1989), 24-27; Bennett (1987), 149.

[42]. Wilton died in 1869 and his eldest son William Henry acquired the business, which he sold in 1874, emigrating to the United States: see Wilton (1989), 71.

[43]. The first advertisement for 'G. Davis & Co., Working Opticians' appeared in the *Leeds Intelligencer*, 7 May 1821.

[44]. Anon. (1979).

effect over time, allowing freight and passenger fares to fall.[45] One of the great technical problems of the age was that of finding a ship's position at sea when out of sight from the land, but after 1707 this became a state-sponsored affair, which will be discussed below, along with state-sponsored surveys. Meanwhile, even ships hugging the coastline required direction-finding aids, and it appears that these were occasionally produced and sold in the provinces. We have seen in chapter 3 that the ports of Bristol and Liverpool produced navigation instruments, apparently in some quantity; manufacturers in Birmingham and Sheffield did so too, although by 1866 'in consequence of the inland situation of Birmingham, nautical instruments are not produced to any great extent.'[46] Despite this statement, it is worth pointing out that the Birmingham firm James Parkes & Son's 1848 trade catalogue offered six unpriced 'ship compasses', and a further half-dozen 'best ship compasses, in square oak box, brass cup, agate cap needle', between six and eleven inches in diameter. Smaller 'miners' and mariners' compasses', from 1s 9d to 8s 6d each were also available.[47] The street directories describe a number of 'manufacturers of mathematical instruments, and mariners' and miners' compasses' during this period, and presumably the 1866 comment reflects that octants and sextants were not made there. In Sheffield, the largest of the early nineteenth century producers, Chadburns, described themselves as 'opticians and manufacturers of nautical instruments' from 1833, but the precise type of these instruments was unspecified.

A ship would require at least one instrument (an octant or sextant) for measuring the Sun's altitude at midday, and from this, and from a knowledge of the Sun's position related to the stars, the ship's latitude could be determined. Longitude is much more difficult to determine, but the problem was greatly simplified with the commercial availability of the first precision chronometer in the 1760s.[48] After that, what Alun Davies characterised as 'the very high demand - from ships' officers, from the Admiralty, and from the trading companies - [which] attracted a number of watchmaking firms to concentrate on, or specialize in, the production of the instrument.'[49] Because these were high-value items, and numbered, Davies was able to trace the economic development and decline of the chronometer trade. With one, later two or three, chronometers per vessel (five

45. Mitchell (1988), 535-6; McCloskey (1981), 251.
46. Timmins (1866), 534.
47. Parkes (1848), 18 and 22.
48. See Andrewes (1996).

on a flagship), one with Greenwich time, another adjusted daily after local noon was determined, Davies reckoned that supply matched demand by about 1840, and in the longer term because of the instrument's static technology and extreme durability this meant that replacement was minimal, so new demand declined.[50] There does appear to have been a considerable market in secondhand instruments, not solely chronometers, and this is apparent from advertisements. Partly because the maritime market was conservative in its purchases, but also because the only real improvement in sighting instruments during this period was the ever-increasing accuracy of scale division, many octants and sextants were overhauled and re-sold. Repairing and maintaining must have been the bread-and-butter business for most 'nautical instrument makers' in provincial ports around Britain. This is shown, for example, by an 1808 advertisement by R.& C. Beilby of Bristol:

> R.& C. BEILBY (Successors to *Mr Springer*) respectfully inform the PROPRIETORS and CAPTAINS of SHIPS, that they have a large and well assorted Stock of COMPASSES, QUADRANTS, TELESCOPES, and other Musical [sic] Instruments, which may be depended upon as correct and good.
> N.B. Any of the above instruments REPAIRED with accuracy.[51]

Another method for finding the longitude at sea was by the 'lunar distance method' - measuring the distance of certain stars from the ever-changing position of the Moon - and this required more accuracy than was generally obtainable from the octant. The sextant, which has a longer scale, was developed around 1770, and was accurately divided by the most eminent London instrument makers: Bird, Ramsden and Troughton. Although octants appear to have been made outside London, sextants do not seem to have been. This was presumably because of reasons of construction: octants were normally made of wood, whereas the wider frame of the sextant had to be cast or fabricated in brass, and this provided the basis for an instrument from which greater accuracy in division, and sophistication in construction was expected. Often, wealthier naval officers, or members of the East India Company bought their own instruments: sextants in particular being 'in great request in the naval service'.[52] It does not seem to be possible to gauge the numbers which were required, and although the design did not change much over the next one hundred years, supply does not appear to have outstripped demand.

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[49]. Davies (1978), 511.
[50]. *Ibid.*
[51]. *Bristol Weekly Intelligencer*, 20 August 1808.

Better navigation instruments allowed for longer and safer voyages, and once the problem of 'finding the longitude' was solved, was arguably one of the factors which allowed Britannia to rule the waves, in the peace that followed Waterloo. As the amount of shipping grew to cater for the demands of Empire, both governmental and mercantile, so demand for instrumentation to afford it a safe passage kept pace with it.

The growth of natural philosophy and other lecturing

The effect of the cultural and social diffusion of a scientific culture during the period of the Industrial Revolution has received considerable attention from historians of science during the last thirty years. Although difficult to quantify, the understanding of scientific principles, it has been argued, may have been associated with industrial advance.[53] The audience for science grew enormously during the eighteenth century. The early itinerant lecturers, spreading the Newtonian gospel found eager listeners first in London, subsequently in the provinces. 'The community of experimenters, the instrument makers, and self-styled engineers with their varying degrees of dependence on Newton's principles, and the devotees of the public lectures, constructed a broad bottom for natural philosophy', Larry Stewart has written.[54] These first London-based lecturers, at the start of the eighteenth century, usually involved the collaboration of a university-educated lecturer with an instrument maker: examples cited by Morton and Wess are James Hodgson with Francis Hauksbee the younger, and Benjamin Worster with William Vream.[55] A later generation, which included Benjamin Martin and James Ferguson, would combine these roles in the same person. At first, only the syllabuses of the lecture courses were published, but in due course the lecture text, together with illustrations of the demonstration apparatus - much of which had evolved specifically for lecturing purposes - was published in 'textbooks which often gave details that would help someone wanting to replicate the equipment'.[56] Morton and Wess link the increased mid-century activity of natural philosophy lecturing with the successful establishment of the press, and the ability of the lecturers to attract their audience through newspaper advertisement; however, this fell away as the audience was diverted by other attractions, including the foundation of the Society

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52. Pearson (1828), 576.
53. Inkster (1973), 99.
54. Stewart (1992), 386.
55. Morton and Wess (1993), 52.
56. *Ibid.*, 56.

of Arts and other institutions which offered a more stable environment with extensive facilities.[57] The nucleus of George III's collection of instruments was formed by his tutor, Stephen Demainbray, who had previously been an itinerant lecturer, but whose career had ended when his audience evaporated, and he obtained his royal appointment in 1769 through the patronage of the Earl of Bute. As Morton and Wess comment, the collection contains 'items acquired on his travels ... several in Edinburgh ... a number in France ... Henry Hindley of York also made a pyrometer for Demainbray, possibly to the latter's design.'[58]

Clearly the market demand here was not large, although it was challenged by the younger generation. The later eighteenth century lecture-demonstrators, of whom Benjamin Martin and James Ferguson are the most frequently cited, encouraged the continuing interest in natural philosophy through the spread of literacy by publishing their own populist works, and in Martin's case, as we have seen, by advertising the apparatus in trade catalogues bound with each volume.[59] We have also seen how Martin (together with other London makers and suppliers) was able to equip Harvard College with a suite of instruments after the fire of 1764.[60] Millburn commented in his 1986 critique that 'it is not even known with any certainty precisely who, or what class of person, attended the scientific lectures which are thought to have played an important part in developing the market for the instrument makers' products.'[61] However, much of this has been remedied, in part by the work of Ian Inkster, whose work on the growth of provincial science included the study of just such audiences in relation to their class-consciousness, political and religious affiliations: in particular such audiences in Sheffield, Liverpool and Derby.[62]

In the provinces, Inkster has shown that 'the activities of the itinerant lecturers in Sheffield were fundamental in the formation of an intellectual community', but that the restructuring of that culture, through the formation of various scientific societies, in particular the mechanics' institutes and literary and philosophical societies meant that eventually the itinerants' independence became

[57]. *Ibid.*, 72-87.
[58]. *Ibid.*, 123.
[59]. Millburn (1976), (1986a), (1986b), and (1988b).
[60]. Wheatland (1968).
[61]. Millburn (1986c), 84.
[62]. Inkster (1973), (1976), (1977) and (1980).

unviable.[63] In Sheffield by the early nineteenth century, 'opticians and instrument makers were particularly active members of the [scientific] community ... such men provided the apparatus around which science in the institutions revolved.'[64] In another essay, Inkster charts the success of these itinerants, with their apparatus, moving out from London to provincial England and beyond, from the mid-century onwards, becoming common in 'the growing industrial centres of Manchester, Birmingham, Sheffield, Leeds, Glasgow, Dublin and elsewhere.'[65] Subsequently, they were unable to compete as science itself was reorganised: indeed, Inkster agrees with Taylor, that 'between the 1820s and the 1840s ... the older style of practitioners "disappeared"'.[66] Although this led to the setting up of a variety of institutions which were dependent on the members of the local scientific community, often the apparatus was not acquired locally. Dr Thomas S. Traill went to London in 1823 to purchase apparatus for the Liverpool Royal Institution, where he 'went to [John] Newmans [Instrument Maker to The Royal Institution] and purchased upwards of £130 worth of Voltaic and chemical apparatus including what I had before ordered...'.[67] Other London makers were visited, and orders placed with them by Dr Traill, which suggests that by this date the firm of A. Abraham, which had made its first appearance in the 1818 Liverpool directory, did not yet stock the teaching apparatus which it clearly produced by 1851.

In fact, as Inkster sums up, 'the educative public science lecture gave way to specialized educational instruments designed to service the needs of the middle class, both industrial and professional.'[68] It exposed a wide variety of provincial audiences, including women and children, to ideas which they would not otherwise have encountered, through lecture demonstrations by societies which were formed with the intention of putting together libraries, museum collections, and demonstration apparatus, such as the Literary and Philosophical Society at Hull. By 1835, the Sheffield Literary and Philosophical Society had a collection of electrical apparatus, an air pump and associated pneumatic accessories, and other instruments for demonstration or study (including a microscope and a balance).[69] In contrast, the Bristol Institution was 'notably short of instruments

63. Inkster (1976), 225.
64. Inkster, (1973), 113.
65. Inkster (1980), 85.
66. *Ibid.*, 95, quoting Taylor (1966), 95-107.
67. National Library of Scotland, MS 19353, Diary of Thomas S. Traill.
68. Inkster (1980), 106.
69. Brears (1984), 3 and 19.

... containing only a lucernal microscope, an air pump, some meteorological instruments' and an Atwood fall machine (a piece of apparatus devised in 1784 by the mathematician George Atwood to demonstrate the laws of motion).[70] As we have seen, these societies fostered local exhibitions, which were well attended, and often displayed locally-made or designed instruments. As the structure for scientific teaching became more formalised, the apparatus of the itinerant lecturer was firstly owned by the individual, subsequently by societies which invited the lecturers to be tied to them in a more formal way, and then owned by schools and colleges. It was this final phase, which came into its own after late nineteenth century legislation made education compulsory, which led to tremendous growth in this area, as more people were educated for longer. Even by the time of the Great Exhibition, instrument makers were able to supply increasing amounts of educational apparatus to a public thirsty for knowledge.

The domestic market

Lorna Weatherill has shown that the ownership of domestic goods increased between 1675 and 1725. Using probate inventories for a range of English counties, and looking at the luxury end of the market, she demonstrated that in London (among other indicators) clocks were to be found three times more frequently by 1715 than they had been in 1685.[71] By 1715 clocks were considerably less expensive to make and their technology had improved radically, but the trend is there to be marked; they were on their way to becoming an everyday item in the home, as the purchasing power of families grew. Unfortunately, her study cannot be extended further in time into the period under discussion here, because the nature of the records alter significantly.

A small domestic demand for restricted types of instruments such as the barometer appears to have grown out of the teaching category: by being exposed to new scientific ideas through public lectures, or by reading about them in the proliferating local press, people came to desire these objects for the home. These items came to be considered as 'everyday', in the same sense that domestic clocks and pocket watches had been previously. The demand grew for domestic barometers, which Nicholas Goodison links with the furniture trade (rather than specifically with the instrument trade). With distribution of wealth 'the growing middle classes took an interest in furnishing their houses comfortably. The expansion of the furniture trade was therefore assured:

[70]. Neve (1983), 188-9.

and the vast majority of domestic mercurial barometers which survive date from this period [1660-1860].'[72] It is the housing of these scientific instruments which is the important fashion element here, so that in the case of barometer construction, the cabinet-maker clearly had to be aware of trends in furniture design (and incidentally illustrates the division of labour in the construction of this type of instrument). Similarly, other types of equipment can be considered as fashion accessories: telescopes, globes and microscopes as accoutrements for libraries and studies, or longcase clocks in hallways. Yet in spite of this domestication of the scientific instrument, it was the instrument maker who continued to refine, manufacture and adapt the instrument to market demand, besides producing more obviously 'scientific' or accurate versions. By the late nineteenth century, the largest barometer makers had adapted to producing the item in large numbers from factories in Birmingham and central London: 'Birmingham', stated an account of the trade in 1866, 'produces more barometers and thermometers than any place except London.'[73]

Domestic thermometers were produced in huge numbers. The most successful version of this was the clinical thermometer, invented in 1867 (and thus outside the time scale of this thesis), and manufactured to great effect with patent protection and advertising bombast, so that by the time J.J. Hicks of Hatton Garden, London, retired in 1914, he could claim to have sold thirteen million.[74] Unlike the barometer, relatively secure on the wall, the fragility of the mercury-in-glass thermometer allowed a built-in obsolescence and thus further purchases. The rise in interest in natural history, particularly botany and gardening, during the early nineteenth century, especially amongst middle-class women, meant that increasing numbers of thermometers and barometers were kept in the house, conservatory, or in special shelters outside, to record and forecast weather conditions. Other equipment for these new, widespread and socially-acceptable hobbies included microscopes and killing bottles for entomologists, aquaria and dredge-nets for marine biologists, and binoculars and guns for ornithologists: the camera had to develop the faster gelatine-emulsion films of the late nineteenth century before it, too, could be used as an investigative tool.[75]

Items which became 'everyday' included those constructed for amusement, perhaps first

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[71]. Weatherill (1988), 25.
[72]. Goodison (1977), 83.
[73]. Timmins (1866), 534.
[74]. McConnell (1998).

encountered through education but which could be used for fun. Gerard Turner explains that books which encouraged improving parlour games became extremely popular from the early eighteenth century onwards, and that three of the most ancient 'toys' known to mankind - the whip-top, the hoop and the yo-yo - demonstrate the principle of angular momentum.[76] One of the most popular optical toys of the period of the Industrial Revolution was the kaleidoscope, which, as we have already seen in chapter 5, was manufactured, retailed and sold widely throughout provincial England, and indeed elsewhere: David Brewster estimated that over two hundred thousand pirated instruments sold in London and Paris during a three-month period in 1817, none under his patent. Demand had outstripped supply, in an unprecedented way, and Brewster tried to unscramble the muddle by visiting his licensed manufacturers, writing to his wife from Sheffield:

> We have ... spent our day very agreeably in visiting the principal manufactories, with which we were much delighted and entertained. We were introduced to most of them by Mr Cutt, the partner in the house of Cam and Cutt [of Sheffield], who have undertaken to manufacture the kaleidoscope for Mr Ruthven [Brewster's Edinburgh agent]. They have agreed to make and sell the instrument under my patent on the same terms as Mr Carpenter [of Birmingham], provided I get his permission to allow them to be employed. This I must do, as he cannot possibly supply the demand. On my arrival at the Tontine Hotel here, the first sight that displayed itself was a pair of kaleidoscopes in two tubes (most deplorable instruments) lying on the chimney-piece. The waiter told us that they were invented by a doctor in London, who had got a patent for them, - that, by some variations, the tinmen had invaded [sic] the patent, and that the said doctor was trying to find them out and prosecute them! The Sheffield newspaper lying on the table contained a flattering paragraph about the same instrument; and when I called on Mr Cam, I saw lying on his table a kaleidoscope, most beautiful on the outside, but deplorable within.[77]

Clearly, there was little quality control here, even for those manufacturing under the patentee's eye.

Other optical devices which grew in popularity were those which assisted drawing, one of the sought-after middle-class female accomplishments. These included the camera obscura, a device known since the sixteenth century, and the camera lucida, patented in 1807 and developed through a series of improvements. Both had a profound effect on the early development of photography, although this could not have been foreseen.[78] Similarly, various kinetic toys, including the magic

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75. Allen (1976); Barber (1980).
76. Turner (1983a), 293-5.
77. Quoted in Gordon (1869), 96.
78. See Morrison-Low and Simpson (1995).

lantern, were to influence greatly the genesis of the cinema at the end of the nineteenth century.[79] With growth of culture and leisure, demand for opera glasses and small telescopes or field glasses also grew, assisted by canny advertisements by the retailers, as we have seen in chapter 5.

The greatest domestic demand remained, however, with the one 'instrument' which most people require with age: spectacles. By the mid-nineteenth century, the word 'optician' no longer meant 'optical instrument maker', and instrument makers were no longer making spectacles for their bread-and-butter: spectacle making became a separate enterprise. This development can be seen in Birmingham, where, for instance in 1815, Thomas Askey was described in local directories as an optician, by 1830 as 'optician and spectacle maker' and by 1850 as a 'spectacle maker':

> The manufacture of spectacles appears among the Birmingham trades as early as 1784, and was doubtless carried on some years earlier. The "goggle spectacles" of our grandfathers were made here in large quantities, and the patterns remained unchanged till about fifty years ago. Even as late as 1820, hampers of spectacles were sent away from Dudley Street, like packages of nails or chains, to be distributed throughout the country. The frames were large, thick, and clumsy, mostly of some sort of white metal, varying according to price. Mr Lancaster and Mr Godfrey were the first improvers, and as soon as steel wire became adapted for spectacles, a lighter and more elegant article was produced. At present [in 1866] there are at least ten manufacturers engaged in making spectacles, and about 200 hands are employed, Birmingham being the chief seat for the trade.[80]

Yet these necessities have always been subject to fashion, as shown by a York advertisement of 1754: '... Spectacles of all Sorts, set in Gold and Silver, Tortoiseshell, Horn, and Leather; also Reading-Glasses, Burning Glasses and Concaves for Persons near-sighted...'.[81] If there was a demand, the instrument maker could supply it, and offer permutations often undreamed-of by his would-be customer. More importantly, as pointed out by David Landes, most people require spectacles for close work after the age of about forty, because of physical changes within the structure of the eye. This necessity remained a constant demand, and clearly rises as the population expands. It remained a staple product of instrument houses in London and the provinces throughout the period. Using spectacles prolonged the working life of a craftsman by twenty years, and moreover, qualitatively, these were his best years; thus investment in an experienced workforce was encouraged. '[Corrective lenses] doubled the skilled workforce, and more than doubled it if

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79. Turner (1983a), 301-306; Hecht (1993).
80. Birmingham directories, *passim.*; Timmins (1866), 533-4.
81. *Yorkshire Courant*, 12 February 1754.

one takes into account the value of experience'.[82] Only in the late nineteenth century did the word 'optician' come to mean 'oculist', and 'spectaclemaker' become a specialist activity.

The 'scientist' and the state

The 'scientific' demand for instruments was always a small one, and remained particularly so for makers based in the provinces. Apart from a very few examples - James Prescott Joule of Manchester ordered instruments from J.B. Dancer for his work on the mechanical equivalent of heat; John Dalton was supplied by a microscope by the same maker; Richard Adie of Liverpool constructed a cometarium for Sir James South; Thomas Cooke's order book contains such eminent scientific customers as Charles Piazzi Smyth, David Gill and James Nasmyth[83] - most men of science went to London to order their special equipment. Conversely, aspiring instrument makers in eighteenth-century provincial England moved to London to find their markets: as we have seen in chapter 2, most of the makers of the 'heroic age' of instrument-making were born outside the metropolis. Once established there, their customers would come to them with their diverse demands. The London makers who ventured out into the provinces from the 1780s onwards appear to have been less specialist, and supported by diverse supplies from the metropolis. The term 'scientist' was not coined until 1833, and implies an element of professionalism. For much of the Industrial Revolution, experimental science demanding special custom-made apparatus was undertaken by wealthy amateurs, and not - as in the late nineteenth century - in the two English universities.

One of the largest customers during this period was the state itself. Clearly, weights and measures had been enshrined in English legislation since at least medieval times and appear to have been generally accepted as standard throughout the kingdom, with the occasional legal clarification, such as that of 1824.[84] With the expansion in trade from local to regional, and from national to international, the need to standardise was essential. The state had to define the market standards in order to ensure its share. By the eighteenth century there was a demand by the state for increasing exactitude in measurement, essential for the correct regulation of markets, for taxation purposes

[82]. Landes (1998), 46-47.

[83]. For Dancer, see Wetton (1990-1), 43, 61-2; for Adie, see Clarke et al. (1989), 50-51; for Cooke, see McConnell (1993c).

[84]. Connor (1987), 255-261.

and for finding the way across the oceans. Money was put aside by Parliament at various dates to fund a national observatory, to find the longitude, to pay for instruments used by various government departments, including Customs and Excise, the Board of Longitude and the Admiralty. Their efficacy was tested by another quasi-government institution, the Royal Society.

In chapter 2 we have seen how setting up a national observatory with precision equipment proved expensive, but impressed foreign visitors sufficiently to generate orders from abroad from the London specialist makers. Similarly, J.A. Bennett has explained the career paths of the London makers of 'heroic age' were bound up around the Royal Observatory, the Board of Longitude and the Royal Society.[85] Others, including the bestselling Dava Sobel, have looked at the *raison d'être* for the Board of Longitude, for, of the work that depended on precision timekeeping, as David Landes has written, 'the most important of these, politically as well as economically [was] finding the longitude at sea.'[86] Here is evidence of direct government intervention, where prizes were awarded for chronometers,[87] lathes and dividing engines which broke through technological frontiers, as we have seen in chapter 4. In exchange for the prize, the information had to be published and lessons given to other craftsmen.[88] Above all, the work had to be replicable, because it was for national advancement.

The Board of Longitude was run by a group of government and Royal Society appointees, together with university professors and admirals; here, the Royal Society acted in an advisory capacity. The Royal Society could also act as arbiter, as it did in the case of new hydrometers authorised by Act of Parliament in 1802, after which the Excise Board advertised, requesting that instrument makers offer accurate and reliable instruments for adoption as standard.[89] As Anita McConnell recounts, nineteen instruments were submitted, of which nine were selected for further examination by a committee formed of Fellows of the Royal Society and Excise representatives: a number of makers from outside London sent instruments, including, as we have seen in chapter 4,

85. Bennett (1985).
86. Landes (1998), 212.
87. Anthony G. Randall, 'The Timekeeper that Won the Longitude Prize', in Andrewes (1996), pp.236-254.
88. The history of the tasks of the Board of Longitude, 1714-1828, is discussed by Stimson (1985).
89. 42 George III c.37. For an account of this, see McConnell (1993a), 9-18.

Mary Dicas of Liverpool. Other instrument makers from outside London who sent up instruments were Thomas Saunders of Dublin and Alexander Allan of Edinburgh.[90] The competition was won by a design devised by Bartholomew Sikes, who had worked in the Excise Department for almost fifty years. He also produced a set of specialised excise tables, which greatly impressed the committee. Unfortunately, he died, aged 73, in October 1803. His widow petitioned for the approval of her late husband's hydrometer in May 1805, and in December 1806 suggested £3000 for the rights to the instrument. The Revenue thought this over-valued, and in January 1807, Mary Sikes (now remarried) reduced the sum to £2000, but proposed that Robert Brettell Bate, her nephew and son-in-law, should be granted the sole right to manufacture the instruments. Although the Act did not come into force until 1818, R.B. Bate nevertheless won the contract, and subsequently managed to win other Government contracts, presumably on the strength of this, such as being appointed the sole distributor of the standardised Imperial weights and measures introduced by the Act of 1824, and subsequently obtaining a chart agency from the Hydrographic Office.[91]

As McConnell has shown, between 1824 and 1831 Bate was paid a total of £18,131 18s 2d for the supply and repair of hydrometers and saccharometers to the Excise. He was also 'supplying brewers and distillers who needed to provide themselves with the instruments specified [in the legislation] ... £2½ million [tax] came in annually from this source and the allowance of even a small error in the distillers' favour amounted to a sizeable loss of revenue.'[92] Bate also won the contract to verify all the weights and measures supplied under the 1824 legislation: each set cost £105 5s 0d, or about £160 if cased and engraved with the coat-of-arms of the purchasing authority. By 1834, 324 full and 149 part sets had been delivered to local authorities all over the United Kingdom.[93] Clearly winning a government contract could prove to be immensely lucrative for the successful bidder.

Earlier, during the wars with France, both the Admiralty and the Board of Ordnance were being supplied by contractors. John Millburn has done extensive work on the papers of the Board

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90. *Ibid.*
91. McConnell (1993a); Connor (1987), 256-7.
92. McConnell (1993a), 17-18.
93. *Ibid.*, 28.

of Ordnance, examining invoices of instrument suppliers.[94] He found that: 'the number and value of orders were ... extremely small in comparison with orders for (say) weapons and ammunition.'[95] He shows that the London maker William Deane supplied the Ordnance between 1723 and 1747 (a twenty-four year period), with a total of 102 invoices for a total of almost £1200. With the outbreak of war in Europe, Millburn dryly remarks, 'the outlook brightened', and for the first five years of the 1740s 'Deane received a total of 34 orders worth in all £453.'[96]

Millburn's work for the mid-eighteenth century investigated the years 1748 to 1772, when George Adams senior was Instrument Maker to the Board of Ordnance: 'during this period Adams supplied over 1500 instruments, ranging from drawing pens to theodolites, detailed in 148 bills amounting to a total value of £2425.'[97] He found that there was little change in the design of the instruments supplied during this particular quarter-century, although more would have been found by comparing the beginning and end of the eighteenth century. An analysis of Adams's bills 'shows a marked correlation with the state of activity of Britain's armed forces, particularly in the early stages of the Seven Years War.'[98] However, Millburn concludes with a warning: the lack of complete business records makes it impossible to estimate what 'proportion of Adams' total turnover the Ordnance orders represented, nor what profit margin was made on them.'[99] He goes on to conclude that:

> the principal conclusion to be drawn from this exercise is therefore that even a long sequence of records of a major customer, such as a Government Department ... provides only a small contribution to understanding the nature and extent of the trade of an individual business. Bearing in mind the number of scientific instrument makers who were operating simultaneously in London in the mid-eighteenth century, this serves to underline how little is really known at present about the overall manufacturing capacity of the instrument-making trade at this time.[100]

Indeed, Millburn does not touch on the subcontracting issue, possibly because it does not appear in the records he used. A later state enterprise, the Survey of India, reveals a little of the

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94. Millburn (1988a), (1992a), (1992b), (1992c) and (1995).
95. Millburn (1992b), 1.
96. Millburn (1995), 17-18.
97. Millburn (1988a), 221.
98. *Ibid.*, 290.
99. *Ibid.*, 292.
100. *Ibid.*

underpinning substructure of the trade. From fairly slow beginnings, but using large and expensive London-made instruments for the primary survey, the Great Trigonometrical Survey is probably identified mostly with the man who galvanised it into becoming a professional body in 1829, George Everest. The Survey spent £5000 on new instruments, and paid for Henry Barrow to go to Madras as full-time instrument maker and repairer.[101] By 1880:

> the stock of instruments in the depot was increased ... about 7,540 instruments ... were obtained from England; 500 were purchased locally ... nearly 9,950 were manufactured in the workshop ...; nearly 5,970 instruments were received by inter-departmental exchange ... The number of instruments issued from stock amounted to 20,158.[102]

Clearly the instruments discussed here were not those used in primary triangulations. Indeed, at an earlier date, the order book of Thomas Cooke demonstrates supply to other contractors, including Newman of Calcutta; but as Anita McConnell has shown, Cooke's display at the 1862 Exhibition attracted the attention of officials for the Survey of India, and a first order was placed in June 1864 for sixteen variously-sized theodolites for a total of £368.[103] Previously, major instruments had been commissioned for the Survey from the London makers, Troughton & Simms, but Cooke's new factory and willingness to introduce new designs persuaded the Survey to place orders outside London.

To obtain state patronage, until the mid-nineteenth century, the instrument contractor had to be located in London. This, manifestly, was the centre of communications: it was the port from which instruments would be sent - to the battlefront, to naval establishments, to the Empire overseas. It was also the centre of the instrument-contracting network, and from where organisers such as George Adams or R.B. Bate were able to subcontract either within London or without, to obtain instruments or their parts to fulfil those lucrative government contracts. Provincial instrument makers were unable to break into this market, except as subcontractors, until well after the Great Exhibition.

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[101]. There is a substantial literature, most recently encompassed by Edney (1997); for Barrow, see Insley (1995).

[102]. Walker (1880), 52, quoted by Clarke et al. (1989), 81 n.26, in support of the subcontracting nature of the workshop of the London instrument maker Patrick Adie.

Conclusions

Although the London trade has been examined in this thesis from the point-of-view of how it supported and interacted with provincial activities, it is not self-evident that the instrument trade followed a similar pattern to the closely-allied and better-documented watch-making trade. As described by F.A. Bailey and T.C. Barker, watch-making was developed in the Prescot area of Lancashire from the late seventeenth century, and the many intricate parts were separately manufactured by a highly-skilled workforce using specially-developed precision machinery.[104] The parts were sent to London for finishing and assembling, as David Landes has shown, and put into cases signed with a London watchmaker's name.[105] As L.D. Schwarz has written, 'the relationship of the Clerkenwell watch makers to those of Lancashire and, subsequently, Coventry is unclear. They all seem to have achieved a tolerable *modus vivendi*, with a rapidly expanding market at home and abroad, though London workers seem to have concentrated more on the finishing and assembly end of the process ... in retrospect, it is clear that many London trades were vulnerable to provincial competition', but, writes Schwarz, this 'would not become obvious until the 1860s.'[106] The demands on the instrument trade, as we have seen, were considerably more varied than that on the watch-trade – which had a single product, applicable to a number of somewhat limited markets. The instrument trade, as we have seen, may have in some of its elements resembled the watch trade, but it covered a significantly wider variety of products which would appeal to customers from a much broader range of categories, as suggested by Table 6:1.

As we saw earlier, the instrument trade was subject to division of labour, as recounted in John Holland's eyewitness description of a Sheffield shop-floor in about 1800. This was not, however, along the same lines as the Prescot watch trade at a similar date. Holland's description details a 'systematic distribution of work throughout the establishment, one man being mostly employed in a special class of articles, in the making of which he acquired great dexterity',[107] rather than individual elements being manufactured on an interchangeable basis. Neither is there any discussion by Holland of the sending of unfinished items to London for finishing, although as we have seen elsewhere, the retailer's name could be added there. Jesper Bidstrup's account of the

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103. McConnell (1992), 54-56; McConnell (1993c), 437.
104. Bailey and Barker (1969).
105. Landes (1983), 230-234.
106. Schwarz (1992), 38-39.

London shop-floor varies from that of Holland: either parts were subcontracted out, or, as in the special and remarkable case of Jesse Ramsden, everything was made *in situ* but with strict division of labour according to specific skills of individuals.[108] It remains an open question as to whether parts may have been manufactured elsewhere in the provinces for assembly in London.

The relationship between supply and demand is of course an interdependent one, and supply of instruments during the Industrial Revolution appears to have remained reasonably elastic, so that the workforce of skilled labour grew in the provinces, as craftsmen moved out of London for a variety of reasons. There is little evidence of any technological bottlenecks in supply (as can be found in, for instance, textiles) during this period. As prices appear to have been relatively stable, and there were no supply blockages suddenly overcome creating an immediate demand, the slow growth of a gradually-enlarging pool of skilled labour must have meant that supply and demand did not outstrip each other.

How large were the market categories as outlined in Table 6:1? The dilettante market, however serious in its intentions, remained a small and London-based demand sector throughout this period. Its significance lay in keeping up the momentum of novelty in design, thus keeping the skills of the maker in constant use: if these were not practised, they would be lost, as horological skills are under threat today. Not all wealthy patrons were interested in science: others put their efforts towards conspicuous consumption into art, furniture, acquisitions on the Grand Tour, architecture, landscape gardening and other expensive pastimes. Only an influential handful of dilettantes could ever have been interested in instrumentation and its development. A much larger – if not the largest component of demand – came from the practical instrumentation used in jobs which were becoming professionalised at this period: surveying, navigation, architecture. A recent assessment of surveying practice in Great Britain and Ireland from 1530 to 1850 has demonstrated 'how the number of new surveyors, by the date at which they are first documented or the time when they started to practise (taken as the age of 20), grew steadily and especially markedly from the late eighteenth century',[109] and gives the number of new surveyors between 1784 and 1850 as 7886, or 119 a year, compared with the figure between 1725 and 1783 as 3276, or 56 a year. The

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107. Holland (1869).
108. See p.123.
109. Bendall (1997), 10.

inference has to be made that as numbers of surveyors in the field rose, so did their requirement for the instruments of their trade.

As we have seen, both the merchant and Royal navies grew in size, according to the number of UK-registered ships during this period: 12,464 in 1788 compared with 26,043 in 1851, each requiring a suite of instruments to ensure safe and accurate navigation.[110] Both the expanding navigation and architectural trades required drawing instruments for chart-work and plans, which ranged from special writing implements to the engineer's rolling parallel rule. As the population grew, there was an increased demand for more houses with better drainage, indirectly leading to increased demand for the tools of all these occupations.

The size of the lecture-demonstration audience is more difficult to calculate: on the one hand this movement has been characterised, notably by Roy Porter, as an emulation of metropolitan values by the provinces; and on the other, as a growth area demonstrating significant cultural evolution as a concomitant of the rise of industrialisation, for instance by Ian Inkster.[111] Inkster has pointed out that it was through this area of the market that the new audiences of women and children were encouraged; and indeed, this can be seen in the famous paintings of Joseph Wright of Derby. From witnessing a demonstration, it is a logical move to acquire the apparatus to undertake one's own experiments, and by the end of the period the chemical populariser and supplier J.J. Griffin had successfully developed a range of new kits which were being bought in sufficiently-large numbers to ensure the survival of the firm well into the twentieth century.[112]

The growth of a domestic market for an assortment of everyday items rests largely on the thesis of the rise of a consumer society at this time, and the evidence to support it can be found with the increasing amount of surviving artefacts from this period. Although there are not the household inventories to support it, it is very clear from the amount of middle-class survivals which go through the auction houses each year that considerable amounts of household objects were bought new from instrument suppliers and used in a domestic capacity. In particular, clocks, optical instruments and barometers became part of the domestic scene: the largest of these

[110] See p.174.
[111] See p.234.
[112] Gee and Brock (1991).

instrument categories, spectacles, are less likely to have survived, because less intrinsically 'precious'.

The scientific market, bespoke special new items made at an investigator's request, must have remained small, because expensive, and as we have seen hardly impinged upon provincial makers' experience until the very end of the period. And although the state's requirements grew with time and the growth of empire and trade, it was not until the mid-nineteenth century, as we have seen, that provincial makers were able to break into this section of the market in their own right.

From these arguments we may deduce that instrument trade was largely a demand-led industry, where canny makers were able to stimulate demand for new items through careful marketing. During this period, they were assisted by a prevailing intellectual curiosity from the aspiring middling classes, and market growth through new groups of consumers: women, students and younger people generally. A broader-based literacy, demonstrated by the growth of publishing and the spread of newspapers, enabled a much wider audience to understand how instrumentation could extend the senses. Farmers wanted to predict the weather: they were encouraged to buy barometers; medical students needed to examine bodily fluids: specially-inexpensive microscopes were aimed at the student market; women enthusiastically took up botanizing: portable 'field' microscopes were advertised; and children could be indulged with special toys which had underlying scientific principles. The growing purchasing power of women of the middle classes meant that their attention to fashion in the home could be channelled into acquiring quasi-scientific items, such as drawing instruments or globes, along with the pianoforte of the drawing room. The general growth in all market sectors during the Industrial Revolution, in the traditional areas as well as these newer markets, meant that instrument makers in the provinces were creating markets closer to the point of production, rather than merely supplying the main one to be found in London, and through London, abroad. From the 20 firms located in six provincial centres in 1775, the number there had grown to 155 in 1851.[113] From this it can reasonably deduced that both the volume of output for traditional items had expanded, and that the variety of 'new' products had grown to fulfil increasing demand.

[113] See Table 2:4.

Chapter 7: Conclusions

Introduction

Much of the work in this thesis has been descriptive, rather than quantitative, because of the nature of the evidence, and because it is covering new ground. However, some indication of the numbers of businesses outside London which were concerned with the production of scientific instruments, either fully or part time, has been gleaned from the local and national street directories. These numbers rose significantly between about 1760 and 1851, and are borne out by Census information at an individual level, whereas in contrast the material evidence which survives - old instrumentation - has indicated very few items with a provincial signature. This has led unwary instrument historians to conclude that outside London, almost nothing was produced. As Lorna Weatherill has written:

> surviving artefacts are cared for in museums or collected privately, and this influences the works about them, for their main intention is to provide detailed guides, descriptions, attributions. This fact, together with the nature of surviving objects themselves, gives a quite different view of consumption ... [yet] on the other hand, economic and social historians tend to regard the objects as illustrative material for their studies and show a surprising disregard for the physical remains of the past.[1]

Looking at the material evidence alone, she says, gives a picture showing the upper end of the market and not a true cross-section. It can produce as biased a picture as if one had ignored it. With instrumentation, proportionally more later nineteenth-century items originating outside London have survived, but there was no adequate explanation of how manufacturers based there managed to compete with the apparently longer-established London makers, nor how or why some provincial makers were able to break into the international market without acting through a London middleman.

This research has looked to a criticism of instrument history, written by an eminent instrument historian in 1986, as an agenda for conducting research into instrument history in a virtually uncharted area.[2] This concluding chapter will assess how adequately the questions posed by Millburn have been answered, as well as considering whether economic historians have taken the

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1. Weatherill (1988), 21.
2. Millburn (1986c), quoted on pages 16-17.

instrument business seriously enough in their own recent reassessments of the Industrial Revolution.

Millburn's agenda: what has been covered?

The investigative agenda taken in this thesis covered essential business components such as financing, marketing, organisation, employee skills and industrial relations: research uncovered more about some aspects than others. The instrument trade in the provinces appears to have been more extensive, in that there were many more producers, than known about before. The dearth of business (and official) records at this date precludes any detailed discussion about finances, particularly profit or loss, inputs or outputs. There are financial indicators, however, concerning some individual firms: for instance, bankruptcies, although the reasons for particular firms failing are often clouded by lack of evidence. Official papers demonstrate that state contracts were lucrative for the holder, and the case of the hydrometer in particular shows that there was a scramble of competitiveness each time the contract was to be renewed.[3] However, these papers do not show how the provincial trade was involved, and it was not until after the mid-nineteenth century that contracts were made directly with provincial wholesalers, who advertised it in their trade literature.[4] Bearing in mind the range of products covered by the term 'scientific instruments' - from 'ornaments of consumption ... [to] tools of engineering'[5] - there is some evidence of how financing was linked with their marketing. This appears to have been two-tier: bread-and-butter retailing and specialist construction.

There is little information on pricing, particularly outside London, although there is the evidence of trade prices offered by G.& W. Proctor of Sheffield in 1814, which has been compared with London retail prices given by W. & S. Jones at almost the same date.[6] This demonstrates the considerably cheaper rate per item of the Sheffield-made products. Some manuscript annotations in the Proctor pattern book give an indication of piece-work rates for various brass or wooden components. There is no information about pricing, for instance in the form of a price series for a 'standard' instrument between 1760 and 1850 (impossible, given the variety and consumer delight

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3. Tate and Gabb (1930).
4. For example, Parkes (1857): 'Instrument Makers to the Board of Trade, and Government Schools of Design.'
5. Berg (1998), 154.

in novelty, with the maker's corresponding response to accommodate this). However, the retail prices gleaned from a series of London pricelists dating between 1784 and 1855 shows that prices remained relatively stable throughout the period. How can this stability be explained? If productivity was increasing, then the price should have fallen; if demand was elastic - responding to pricing - then the share in the economy should grow with time. Today's contemporary example of the ubiquitous personal computer demonstrates that market growth, responding to demand, should bring the unit price down for the consumer. Yet for instrumentation during the Industrial Revolution, prices remained stable, and although the industry grew - more firms - it was not through rising productivity. Methods of production did not dramatically change, and by and large the instrument industry remained a craft industry.

There was no sudden move into factories, although this was gradually beginning to happen by the mid-nineteenth century: the London firm, Troughton & Simms of Fleet Street, set up purpose-built premises in a green-field site in Woolwich which was in operation by 1866. By 1871 it employed 61 men and 18 boys, increasing to 78 men and 20 boys ten years later.[7] Outside London, as early as 1855, Thomas Cooke of York was the first to erect customised premises, with a loan from a family friend.[8] Elsewhere, the Grubbs in Dublin manufactured a variety of light engineering products - cast-iron billiard tables, engraving machines, glass working machinery, with telescope construction as a sideline - but with the growing international reputation of their reflecting telescopes they became more specialised, and built new premises in the Dublin suburb of Rathmines, in about 1875.[9] In Glasgow, Lord Kelvin's firm James White appears to have moved into factory premises by 1884:

> the growth of the workshop represents the transition from craft-based manufacture to factory-based production, although in the absence of adequate evidence for the period 1849 to 1870 it is difficult to say when this occurred. Certainly the size of the workforce in 1881 suggests that specialisation on separate components of particular instruments within the shop was occurring.[10]

This was clearly an industry which remained in transition until the late nineteenth century. The manufactories uncovered in research for this thesis in Sheffield - Proctors, Cutts and Chadburns -

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6. See Table 3:7, page 142.
7. McConnell (1992), 42.
8. *Ibid.*, 51.
9. Glass (1997), 2-3; 82-84, where a photograph and plan of the new works are shown.

have little supporting evidence as to size, numbers, or date of establishment. That they existed at all, can be inferred from the firms' advertising, and a single contemporary description.

The instrument trade outside London was clearly prepared to expand into new markets, demonstrated by their willingness, for instance, to participate in the 1855 Society of Arts competition to promote a cheap, and newly-designed microscope. Where did the capital come from to invest in this enterprise? As with most investment before limited liability was enforced by statute in 1862, this was undertaken by the family through common law partnerships, who acted as a supporting network, not solely for financial capital, but also for reasons of trust in an uncertain and hazardous business climate. As Mary Rose has shown, these operated in some measure as a self-regulating entity:

> whilst the family represented an internal market of skilled and managerial labour and a source of funds for establishment and expansion, family connections could also be reliable sources of market information. Such involvement of family and connections could be especially helpful in transactions between provincial centres and London or in overseas trade.[11]

Several examples of exactly these sorts of networks occur in the instrument trade, where brothers, for instance, set up in different provincial centres. Three instrument-making sons of Alexander Adie of Edinburgh did just that: John remained in Edinburgh, eventually taking over his father's business; Richard went to Liverpool, where he set up as an 'optician, philosophical and mathematical instrument maker' in 1835, subsequently running the Edinburgh and Liverpool businesses in tandem after both Alexander and John died in the 1850s until his own death in 1881; while the youngest son, Patrick, sailed for London in 1844, where he ran a successful enterprise which continued well after his death in 1886, with useful links into Kew Observatory, which at that time verified the accuracy of certain classes of instrument for the British Association.[12]

In a review of the literature on the financing of business, Pat Hudson explains that the nature of the family firm - the model which prevailed in metalwares, including instrument making - had further ramifications:

> Partnerships were usually family or extended family concerns with partners having close

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10. Clarke et al. (1989), 258.
11. Rose (1994), 63-69.
12. Clarke et al. (1989), 25-84.

> links through birth, marriage, community or religious affiliation ... High failure rates, coupled with high risk, uncertainty and continuous change in the business environment, encouraged the predominance of family concerns.[13]

This, she explains, meant that there were implications for the financing of such enterprises. The very nature of the family and its networks meant that 'the ownership and finance of most firms tended to be local or regional'; and the family connections which allowed for consolidation, respectability and continuity also meant that provision for offspring could eventually necessitate withdrawal of capital and lead to fragmentation of the operation.[14] François Crouzet, in an illuminating review article on 'Capital formation in Great Britain during the Industrial Revolution' suggests that despite the literature concerning 'takeoff' and recent heated discussions about rates of change, whether slower or more rapid than previously thought:

> many firms ... had quite modest beginnings, and then gradually increased the scale of their operations, enlarging their buildings and buying new machinery ... All in all, during the first stages of the Industrial Revolution, the need for investment in fixed capital was modest, the threshold for entry in industry - factory industry included - was low ... The total sums of money which provided 'the material envelope' for the new technology were thus relatively small.[15]

As Hudson observed, 'urban and rural workshop industries ... flourished during industrialization. These required more overhead finance, but, using mainly hand skills and labour-intensive methods, their fixed capital needs remained modest.'[16] Later, as these workshops tried to establish markets outside their own localities, financial demands grew. This is where it is difficult to know just how, for instance, Abraham of Liverpool (run at this stage by Charles West and George Smart) managed to afford to display a range of apparatus at the Great Exhibition, or how in 1854 the Sheffield firm J.P. Cutts, Sutton & Son managed to retain an agent in New York.[17]

The state had a long-term interest in seeing the instrument industry being developed, for instance, in ensuring that both the merchant marine and the Royal Navy did not encounter disaster of the magnitude of Sir Cloudesley Shovel, but was famously hampered by its inability to allocate

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13. Hudson (1994), 90.
14. *Ibid.*, 91
15. Crouzet (1990), 161.
16. Hudson (1994), 92.
17. *1851. Gore's Directory for Liverpool and its Environs* (Liverpool: J. Mawdsley, n.d.); *Post Office Directory of Sheffield, with the neighbouring Towns and Villages* (London: printed and published by Kelly and Co, 1854).

funds. However, this perception was not entirely correct, and, as we have seen, the government provided substantial capital, for instance, in setting up a national observatory, which subsequently produced increasingly accurate star maps for the safety of its navigators; and also through the Board of Longitude, and other purchasing government departments, with the Royal Society on occasion acting as a neutral arbiter. Yet none of this valuable patronage appears to have gone outside a charmed circle of London makers, who were still known on a personal level by those making the crucial financial decisions. Only with changes in the organisation of science in the early years of the nineteenth century, as described by J.A. Bennett, did this situation alter.[18] Despite this, instrument makers in the provinces appear to have survived, by inference subcontracting - as described by John Holland in 1834 - to those in London who needed to fulfil large contracts.[19] There is no evidence - apart from one or two early examples in Sheffield - that they diversified into other trades, such as pubs, brewing or armaments, all of which metalworkers traditionally took up in hard times, or combined two occupations simultaneously.[20] From the evidence of the local directories, makers of instruments described themselves as making instruments, or other pieces of metalware, or they moved into light engineering.

To fully answer Millburn's questions about the financing of the industry, there remain a number of unanswered questions. How much did it take to set up in business in the provinces? Why would one do so, there, then? Why would one not - to use a twentieth-century political metaphor anachronistically - 'get on one's bike' and find an instrument-making job in London? It may well have been the inhibiting factor of family enterprise and local forms of capital investment which prevented this, but more supportive evidence to confirm this needs to be found.

Millburn suggested that 'marketing techniques' should be investigated, and these appear to have been developed throughout this period, and many were adopted by the instrument industry. At a time when the local press was expanding, in step with rising literacy levels and keeping pace with demand for news from London and overseas, instrument makers who had newly-moved out of London were able to use these as a forum for their range of wares and expertise. As discussed in chapter 5, provincial instrument businesses grasped every new method of promoting their wares as

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[18]. Bennett (1985).
[19]. Holland (1834), 261, quoted on page 180.
[20]. Berg (1994), 54.

soon as they could: attractive shop windows in fashionable spas; literature which drew attention to patronage by the nobility and gentry; advertising the availability of a wide variety of items, whether described in famous textbooks or made to order; selling by lottery; price lists added to the back of textbooks; participation in exhibitions of an educational nature; lecture tours using demonstration apparatus. Even articles in encyclopaedias blatantly advertised instruments made by particular makers: anything to place the objects in front of a public thirsty for new scientific knowledge in the hope of an impulse buy. However, despite all of these ploys - many of which were successful for both London makers and those based outside - it appears that there was little or no export market for the English provincial trade until after the establishment of the international exhibitions. Unlike 1760, by 1850 it was no drawback to be located outside London: transport networks allowed material to be moved much more rapidly into London. But also by 1850, the Industrial Revolution had produced a broader range of activities in the provinces, so that London as a market was less central: the trade had generated its own external economies, and this can be seen particularly in the cases of Sheffield and Birmingham.[21]

Outside London, the growth of instrument-making generally mirrored population growth, but as an industry nowhere is it mentioned in the statistics, as it is too small. N.F.R. Crafts's magisterial work demonstrates that during the Industrial Revolution rates of growth in iron and cotton went down, while everything else went up: however, all measurements at this date are partial. The instrument trade was an area of traditional growth during this period, there were no dramatic price falls or significant changes in techniques, but instead an overall expansion in economic activity. The new methods of marketing were an important component of this. On the supply side, the raw materials - the brass and optical glass industries - experienced growth and some considerable technological change, as outlined in chapter 4. From being fairly localised industries with products of a fairly uneven quality in about 1760, these became with some European knowhow, more than sufficient for the supply of the instrument trade, whether based in the provinces or in London.

'Almost nothing is known for certain about the size of individual instrument makers' workshops', wrote Millburn, 'or how many different specialist workmen were involved in the

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[21]. Berg (1993).

construction of different types of instrument.'[22] Outside London, this thesis has uncovered new evidence in the course of fieldwork, particularly in the case of Sheffield, where there was some discipline in the Proctor workshop, yet still a considerable amount of independence for individual skilled hands. They appeared to be at liberty to engage in the rural aspects of their working life as the seasons demanded, something which was not to be found in the later factory of Thomas Cooke. Although Holland's account gives an unambiguous account of the division of labour within the Proctor workshop, we cannot tell whether his description of individuals being devoted to making particular instruments was peculiar to that particular workshop, or whether others elsewhere were constrained to particular components, or materials.[23] The evidence from Thomas Cooke's orderbook, dating from 1856-68, shows that the scale of incoming orders was increasing. However, the size of the workshop remains a problem: the fieldwork did not reveal any definite figures until the 1861 Census, and from this it can be deduced that most must have remained smallscale craft workshops.

What do we know about the employees? We know that 'foreigners', whether incomers from a different region or from abroad, or of similar dissenting religious persuasion, tended to work together. By 1850 the workforce may have had a greater division of labour than that of 1760, but most of the skills were still learned 'on the job' as there was no other form of educating the younger men than an apprenticeship, formal or otherwise. The work of Inkster and others has demonstrated that in provincial England, instrument makers were prominent amongst those active in the provinces for promoting scientific education through lecturing, the formation of societies, and holding exhibitions.[24] Employees may well have become more numerate than their counterparts in 1760 - thus forming part of the national 'human capital' - on their way to becoming themselves skilled artisans, who may have been able to eventually set up in business themselves in a small way. Outside London, there were no guild restrictions to make this more expensive for an individual. Unlike other industries hit with economic convulsion through rapid industrialisation, employees in the scientific instrument trade did not become deskilled through depressed wages as a consequence of technological change in their industry. There is no direct evidence for actual figures for wages, apart from John Smeaton's brief daily accounts for a six-month period in 1751-52, where the

[22]. Millburn (1986c), 84.
[23]. Holland (1867).
[24]. Inkster (1973), (1976) and (1980).

amount paid varied according to the competence of the workman.[25] We know next to nothing about industrial relations generally, which is unsurprising, given the paucity of evidence about individuals who ran even relatively successful businesses. It can be inferred, though, that in a small, craft-based workshop, where masters and men worked side-by-side throughout this period, that relations remained paternalistic: and in some cases, as we have seen, former apprentices married the boss's daughter, thus extending and reinforcing the family network already discussed.

What was the effect of the Industrial Revolution on instrument production?

The Industrial Revolution produced cheaper and better quality brass and glass, new methods of engineering and machine tools with greater tolerances brought in from allied trades, although the industry had to wait for the implementation of Whitworth standards before being able to move on to interchangeable parts and the possibility of 'mass-production'. The most that was achievable was large batch production, but in this the individual components were fine-tuned by hand and eye to each individual instrument. Was there cheaper power? Although power could be applied to hand tools, especially in areas like Sheffield, where there was readily available waterpower, there does not appear to be much evidence for steam-power being applied to instrument-making machinery, which would have entailed a move into the factory; however, there is evidence that by the end of the period power was being applied to various repetitive tasks in Birmingham works which were not exclusively devoted to instrument production. By 1850 the workforce may have experienced greater division of labour, but all employees appeared to continue to learn by doing: beyond apprenticeship, whether formal or otherwise, there was no other way to obtain the skills, which remained mainly handskills. Even if the workforce had become more numerate - and instrument makers, by the very nature of their job would have to be among the more literate and numerate of the British workforce - their formal education remained what it had been, supplemented by what could be self-taught or learned through experience. The state was not to intervene here until the later nineteenth century.

Unlike workers in other sectors of the economy which experienced dramatic economic upheaval through technological change during the Industrial Revolution, the skilled artisans of the scientific instrument trade did not become deskilled through sudden changes in technology - as did,

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[25]. See page 128.

for instance, the handloom weavers. The instrument trade thus forms part of the 'slow growth' model of industry during the Industrial Revolution. This is unsurprising, as most of the products were hand-produced, so productivity was always going to remain slow. The changes which took place occurred at the margins of the industry, for instance, the introduction of the dividing engine, in London in the late eighteenth century. As we have seen, there is no evidence for the existence of a dividing engine in the provincial trade until Thomas Cooke constructed one from first principles in 1864-66.[26] This is supported by the remark, often quoted, made by Edward Troughton in his article on 'Graduation', written (about 1812) for David Brewster's *Edinburgh Encyclopaedia*, where he states that there are ten or twelve dividing engines in London at that time, implying that these were the only ones available to the trade.[27]

Did the quality of the finished product change during the Industrial Revolution? There is no way of measuring this, in terms of output per man, or costing of a particular instrument, but it would appear that prices remained relatively stable. Instruments did not get cheaper, and although they were produced (apparently) in greater quantities, the customers appeared - mostly - to be satisfied.[28] Was there any increase in the amount of instruments being produced in the provinces at this time? Again, although there is no direct evidence for this in terms of output per annum, this research has demonstrated that numbers of businesses increased during this period, began to produce trade literature, and began to offer a wider variety of items directly to customers who had previously been seen as exclusively metropolitan: the conclusion must be that more instruments were supplied.

What was the effect of instrument production on the Industrial Revolution?

To pose a counter-factual question: what would have been missing if there had been no instruments produced during the Industrial Revolution? Firstly, there would have been no Empire: Britannia would have been unable to rule the waves. Her navies would have remained coastal-hugging, unable to command the oceans with the various (hard-won through war and diplomacy) strategically-important islands used as fuelling stations. She would have been unable to map

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[26]. McConnell (1992), 54-55.

[27]. For instance, in Stimson (1985), 112; Chapman (1995), 134.

[28]. Dissatisfied customers can be found in the letterbooks of government departments; and Bugge (1777), 191.

efficiently - and therefore tax and administer comprehensively - her substantial dominions overseas: India, South Africa, Canada. At home, the transport revolution, a necessary concomitant to the Industrial Revolution, would not have taken place with the same efficiency and productivity gains: canals would have been leaky, hit-and-miss affairs; railway track has to be level to ensure some safety of passage; the new road system, replacing that of the Romans, might have been wasteful, coping with contours in a way that horse-drawn vehicles would be unable to negotiate. In industry, standards could not have been maintained by using thermometers, pyrometers (for measuring heat above temperatures where conventional glass thermometer would melt), saccharometers (for measuring sugar content), microscopic thread-counters, and other instruments which were introduced during this period to keep up the beginnings of quality control, particularly in the chemical industry. The state itself, as we have seen, would have lost out in taxation, in particular in the brewing and distilling industries, without the use of the hydrometer, for measuring the specific gravity of a liquid.

Without an instrument trade, there would have been little investigative science, with all the implications that has for the human understanding the environment, the universe, or the development of preventative medicine. The customers identified in chapter 6 - from the wealthy amateur through to the new markets of women and students would have gone unenlightened and uneducated. Ships would have been lost at sea; people would have been lost on land. Electricity, which developed from an observed phenomenon demonstrated by travelling lecturers, might never have become the force we take for granted today.

The instrument trade was crucial to the Industrial Revolution in this country at a number of levels. Within industry itself, instruments allowed the extension of the senses, if the aging workforce was using spectacles to allow their sight to last for a further decade or so of close work, as David Landes has shown,[29] or where gauging tools were necessary to measure components of any sort of machinery at all, from pithead winding-gear to shoe-maker's lasts. The coal industry developed new instruments to allow mine surveys, and regulate the flow of air; thermometry was required in most production of food and beverages. Subsequent testing for purity might require the knowledge of the government chemist using analytical equipment, but this would have been derived from

[29]. Landes (1998), 46-47.

already-existing instrumentation. As scientific knowledge grew in the second half of the nineteenth century, instrumentation was applied more frequently to industrial processes in a less haphazard way, and came to be seen as part of the process of quality control and standardisation. This practise grew from small beginnings, to be seen in the instrument-maker's response to producing what was asked of him.

To conclude: the growing availability of instruments during this period allowed the development of knowledge, assisted in the growth of empire, and contributed to the transformation of the landscape through the transport revolution; is it too much to identify such an industry as a cutting edge technology?

Conclusions

This thesis has pursued John Millburn's questions, posed in 1986 to focus attention on how little was known about the more prominent London makers at the end of the eighteenth century. His questions, however, have proved fruitful grounds for discussion for the English trade for a wider timespan and for a larger geographical area. The investigations reported here have demonstrated that, as Gloria Clifton suspected, the instrument making trade in the English regions was much more dynamic than previously thought. By the 1850s, the trade there was able to compete with London on many fronts, but the most important unanswered question posed by Millburn remains that of how these enterprises were financed.

It is clear from the surviving papers of Thomas Cooke of York that financing an instrument-making business from scratch, as he did, must have been a hazardous endeavour. Capital investments - plant, shop premises and advertising meant that the initial outlay was large, resulting in an immediate cash-flow problem. The day-to-day expenses - labour and materials - would have been a continued drain before he ever saw even a fraction of return on his initial outlay. It is not entirely clear how this problem was resolved, in this individual case or in general for new entrants to the industry. From the evidence uncovered, it would appear that the only way forward was through good personal contacts, and borrowing from wealthy friends or family. The contents of Cooke's order book seems to suggest that there was a balance between the large and expensive orders which would take time to complete, and the smaller and cheaper items, which could be produced relatively quickly. It is probable (although not provable with the available evidence) that, as he became better established and won a greater international reputation, more effort was put into the larger orders and it was less necessary to fund that side of the business with cheaper items.

Although not all of Millburn's questions have found a ready answer, much of his agenda has provided a framework for how the development of the regional instrument trade came to underpin the British instrument trade between the Great Exhibition and the outbreak of the First World War. In the latter part of the nineteenth century, important firms were to be found - still in London - but also in locations as far apart as Birmingham, Cambridge, Glasgow and York, as well as the other centres described here. This thesis has gone some way towards providing Millburn's 'reliable and comprehensive synthesis of the trade', especially in the areas of marketing, materials and structure. However, more of his 'painstaking [extraction] piece by piece from a variety of sources' will have to be undertaken to add more of the maddeningly elusive information which lies just below the surface of the available historic evidence.[30]

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