Working Papers on The Nature of Evidence:
How Well Do 'Facts' Travel?
No. 18/07

Accurate Measurement and Design Standards: Consistency of Design and the Travel of 'Facts' Between Heterogeneous Groups

Aashish Velkar

Department of Economic History
London School of Economics

June 2007

how well do 'facts' travel?

“The Nature of Evidence: How Well Do ‘Facts’ Travel?” is funded by The Leverhulme Trust and the ESRC at the Department of Economic History, London School of Economics.

For further details about this project and additional copies of this, and other papers in the series, go to:

http://www.lse.ac.uk/collection/economichistory/

<u>Series Editor:</u>

Dr. Jonathan Adams
Department of Economic History
London School of Economics
Houghton Street
London, WC2A 2AE

Tel: +44 (0) 20 7955 6727
Fax: +44 (0) 20 7955 7730

Accurate Measurements and Design Standards: Consistency of Design and the Travel of 'Facts' Between Heterogeneous Groups[1]

Aashish Velkar

Abstract

Design standards are carriers and creators of facts, enabling facts about product value to travel between groups, and assisting in the creation of product value by establishing a reference or comparison against which product attributes are compared. However, when design standards are not consistent, facts about product value may not travel well, even when designs can be expressed or measured with a high degree of precision. Examining the evidence from British iron and steel industry in the nineteenth century, this paper demonstrates how inconsistent design standards (wire sizes) inhibited the travel of facts about the 'true value' of wire products. Consistency in wire sizes depended upon the desirability of certain sizes amongst user and producer groups; often they differed both within and between the relevant groups. Convergence on a common system had to be achieved through intense negotiations between the producer and user groups, with the state becoming involved as an arbitrator. Consistency was a negotiated construct; once achieved, it enabled facts about wire products to be transmitted using consistent design standards.

Why do industries converge on uniform standards? 'Uniformity' implies a 'one-size-fits-all' standard that all industry participants are expected to adopt. Standards improve perceptions of quality, expand user base, reduce search costs, and act as carriers of information. However, they also raise anti-trust concerns, potentially inhibit trade, increase cost of compliance, reduce variety and choice, and can exclude those who

[1] This paper is based on a manuscript, which is being considered for publication by a peer-reviewed journal. No part of this manuscript may be quoted or used without the express written permission of the author. Economic History Department, London School of Economics, Houghton Street, London WC2A 2AE email: *A.Velkar@lse.ac.uk*

don't belong to the 'club'.[2] Network effects alone do not ensure standardization. Firm strategies, buyer preferences, technological change (which could be exogenous to the firm), and public policy contribute towards convergence on uniform standards.[3] Standardization is a double-edged sword and firms tend to use it as a strategic choice variable. In industries where entry barriers are weak and network effects are strong, smaller firms prefer to establish compatible standards as this helps to expand user base and make price competition less aggressive. On the other hand, dominant firms tend to resist uniformity and strive to make their standards non-compatible to protect market share.[4] The exception to this observation would be an external 'threat' either as a result of government regulation imposing standards or dominant buyers insisting that the manufacturers use uniform standards which they specify. If a few dominant producers perceive these to be 'wrong' standards, they would cooperate to pre-empt this move and establish a uniform standard of *their* preference.

This paper presents a historical case from the nineteenth century of such a defensive strategy where dominant firms cooperated to set a uniform standard to prevent 'lock-in' on what they perceived to be an inappropriate standard. I argue in the case of the British wire industry that a few dominant manufacturers, facing intense international competition, cooperated to prevent the standardization of the 'wrong' wire sizes proposed by the Board of Trade (BoT). The resultant standards were a compromise negotiated between the dominant producers of metal wires,

---

[2] Swann, Temple and Shurmer, 'Standards and trade'.; Antonelli, 'Standards as institutions'.; Teece and Sherry, 'Standards setting and antitrust'.; Metcalfe and Miles, 'Standards, selection, variety'.; Axelrod, Mitchell, Thomas, Bennett and Bruderer, 'Coalition formation'.;

[3] Koski and Kretschmer, 'Competing in network industries'.; David and Greenstien, 'Compatibility standards'.

[4] Katz and Shapiro, 'Network Externalities, Competition and Compatibility'.; Besen and Farrell, 'Strategies in standardization'.; Cusumano, Mylonadis and Rosenbloom, 'VHS and Beta'.; Koski and Kretschmer, 'Standards and competition'.

BoT, and the various chambers of commerce – albeit those which were largely based on the preferences of the dominant producers. Before discussing the specific case, the paper presents the nature and significance of standardization in the 19th century, and sets the context in which this case is analyzed.

Standardization in the Nineteenth Century

Although standards can be non-rival public goods, they can also be considered as private goods as they can be made excludable.[5] This duality gives rise to the compatibility as well as the competitiveness nature of standards. Producers use standardization as a competitive strategy in deciding whether to make their standards compatible or not. Consider the variety of measurement standards that producers have used historically. In coal mining, for instance, a baffling variety of measurement standards were in use before the nineteenth century: chaldrons, keels, scoops, fothers, cart-loads, horse-loads, and so on, each reflecting the stage of the production process, each specific to a particular geography and often ambiguous in how they related to each other.[6] Similarly, each workshop had its own standard for producing parts such as screws, wires, rivets, bolts, and early forms of tools and machine parts.[7] Such multiplicity tended to mystify the standards used, increasing exchange costs but protecting market share. Nevertheless, by the late nineteenth century there was a definite move towards mass manufacturing and interchangeable parts production that involved 'making things the same'.[8]

[5] Non-rivalry implies use by one does not reduce the amount available to others and so standards are public goods: Kindelberger, 'Standards', 377.; standards can be restricted to a select few and hence excludable to others, making them non-rivalrous but private: Romer, 'Endogenous technological change', S73-S74.,
[6] Pollard, 'Coal measurements'.; Hatcher, *Coal industry*, 557.
[7] Sinclair, 'Standard American screw'.; Whitworth, *Papers on mechanical subjects*.
[8] I borrow the term from Alder, 'Making things same'.

The techniques of interchangeable manufacturing that originated in the state armouries of eighteenth century France were adopted by engineering firms almost a century later in the form that would become the American system of manufacturing.[9] Technological convergence helped in standardizing processes such as cutting metal into precise shapes; the result being that machine types and machine tools became standardized.[10] Some historians challenge the notion that machine precision replaced artisan skills, arguing instead that newer mechanical methods depended both upon the traditional skills as well as newer skills, making this the limiting condition determining the 'progress of new technology'; and consequently the nature and extent of standardization.[11] The objectivity and the form of nineteenth century standards is as much an outcome of social construction as it is of technological convergence.[12] Standardization also implied de-skilling of labour when, for instance, limit gauges began to be used for measuring the grinding of machine parts. Gauging thus became 'a mechanical affair [not requiring] the same skill or the same knowledge on the part of the workman'.[13] Further, British engineering standards must also be placed in the context of increasing competition from other industrializing nations such as Germany and the United States. The degree to which British industry adopted manufacturing of standardized parts was a result of the competitive response by British producers to the rise of German and American engineering industries.[14]

Standardization was an integral part of the overall Victorian landscape. Apart from standardized engineering products (machine tools,

---

[9] Alder, 'Innovation and amnesia'.; Hounshell, *American system to mass production*.
[10] Rosenberg, 'Technological change'.
[11] Gordon, 'Mechanical ideal and reality'.
[12] Alder, 'Making things same'.
[13] Speech by Sir R T Glazebrook at a meeting of the Physical Society of London at Imperial College, London on Mar. 28, 1919
[14] Allen, 'Iron and Steel'; Floud, 'American engineering competition'; Saul, 'Engineering industries, 1860-1914'.; also Landes, 'Watchmaking'.

screws, gauges, etc.), this included scientific and technological standards (the ‘ohm’ and the voltmeter),[15] measurement standards (e.g. accounting, weights and measures),[16] standards used in trade (e.g. commercial contracts, commodity grades),[17] etc. The issue of standardization was important enough for the Board of Trade in the UK to have a Standards Department by the 1860s, and by the early 1900s the British Engineering Standards Association was formed. Standardization in this period must also be placed firmly in the context of the Victorian markets, which were far from being the ‘neutral arena for competitive exchange’.[18] Many Victorians considered the ‘un-trammeled market forces’ to be dangerous unless linked to a source of ‘unquestioned authority’ which adjudicated when ‘morality clashed with market principles’.[19] This view of the market has important implications for any standardization story, as setting standards involves not only solving the technical issues but also overcoming issues of coordination between the various groups involved. The need to solve coordination issues arises due to path-dependency of standards. Industries can get locked into standards at an early stage and so fail to switch to better or more efficient standards.[20]

I situate the case of the wire industry and the emergence of standard wire sizes in the context of the foregoing issues. British wire producers did not manufacture according to standardized wire sizes and ‘consequently purchasers [were] so completely at the mercy of the manufacturers that they [were] driven to all kinds of expedients in order to

[15] Hunt, ‘Electrical standards’; Gooday, ‘The morals of energy metering’.
[16] Brackenborough, Mclean and Oldroyd, ‘DCF in Tyneside coal industry’; Fleischman and Macve, ‘Management accounting in coal mining’.; Connor, *English Measures*.
[17] Forrester, ‘Commodity Exchanges’.; Ferguson, ‘Commercial disputes system’.; Chattaway, ‘Arbitration’.
[18] Johnson, ‘Market Disciplines’.
[19] Searle, *Morality and market*, 256.; cf. Gambles, *Protection and politics*.
[20] David, ‘QWERTY’.; Cowan, ‘Technological lock-in’.; Farrell and Saloner, ‘Standardization, compatibility, and innovation’.; Arthur, ‘Lock-in by historical events’.

protect themselves'.[21] In the 1870s, telegraph engineers complained that wire sizes varied with every manufacturer.[22] Each group of buyers and sellers of wire wanted their own standard to be adopted as the industry standard. Standardizing the size of wire depended upon standardizing the wire gauge used in its manufacture. This was easier said than done, as different gauges had emerged by the early nineteenth century, varying by geography (Birmingham, Lancashire, etc.), by different metals used in making wire (iron, steel, brass, etc.), according to end-use (e.g. needle wire, music wire), or by manufacturer (Stubs, Rylands, etc.). The multiplicity of wire gauges implied multiplicity of sizes. This paper traces the events that brought about the standardization of wire sizes. The argument is that standard sizes (and the uniform gauge) were the negotiated outcome between producers and buyers. The specific form of the standard was influenced by the efforts of the producers to prevent lock-in into a 'wrong' standard.

The rest of the paper is structured as follows. The next section reviews the metal wire industry in Britain, which is followed by a section on the technology and process of wire making and the importance of gauges in the production process. The aim of that section is to demonstrate the interrelatedness that existed between the gauges and the production process and to review the economics of wire making in the late nineteenth century. The following section examines some of the early attempts at standardizing wire sizes followed by a discussion on the emergence of the legal standard in 1883. The next section looks at the role of competition and coordination and lock-in effects to understand why the dominant wire manufacturers cooperated to resist the standards proposed by the buyers and the Board of Trade and why they proposed

[21] *Ironmonger and Metal Trades Advertiser* (hereafter *Ironmonger*), Nov. 27, 1880, p. 621, editorial note
[22] Mallock and Preece, 'Wire gauge'.

their own preferred industry standard. The following section briefly reviews the state of the industry following the standardization of the wire gauge in 1883 and makes some observations regarding the extent of its adoption. The final section puts these events into perspective and draws general conclusions regarding competition, coordination and standardization.

Wire Manufacturing in England

Standardization of wire sizes is best understood in the context of the economic geography of wire manufacturing in the late nineteenth century. The origins of metal wire manufacturing in England can be traced back to the fourteenth century with wire drawing technology introduced from Germany. By the early nineteenth century, Lancashire had become an important centre for wire making activity, encouraged by engineering workshops located in this region. Peter Stubs, the Warrington tool maker, became involved in the wire trade initially as a large buyer of pinion wire, but eventually the firm he founded became one of the most important wire producers in the country.[23] By the 1870s, Yorkshire, the West Midlands and Lancashire had emerged as the major wire manufacturing centres. The ten-largest wire manufacturing firms were located in and around Birmingham, Warrington, Manchester and Halifax claiming to produce nearly 80 to 90 percent of the wire manufactured in Britain.[24] These firms included Richard Johnson & Nephew (Manchester), Whitecross Wire and Iron Co. (Warrington), Nettlefolds (Birmingham), Ryland Brothers & Co. (Warrington), Shropshire Iron Co. (Shropshire/Birmingham), Longford Iron and Wire Co. (Cheshire/Warrington), Frederick Smith & Co.

[23] Dane, *Peter Stubs*.
[24] The National Archives (hereafter TNA), BT 101/116, Letter from the Iron and Steel Wire Manufacturers Association (ISWMA); also, *Ironmonger*, Feb 25, 1882, p. 281

(Halifax/Yorkshire), and Ramsden Camm & Co. (West Yorkshire) among others.[25] However, a majority of the firms involved in wire drawing were numerous small workshops located in and around these major centres. In Birmingham alone there were about 70 wire manufacturers and about 40 wire weavers[26] in 1875, which had increased from 5 in 1800 and 35 in 1866.[27]

In terms of size and output, some of the larger wire makers had multiple manufacturing locations, specialized in many different kinds of wire, employed large numbers of wire drawers and manufactured other products based upon wire. Richard Johnson & Nephew had works at Manchester and Ambergate, employed about 1000 workers and specialized in telegraph and fencing wire, wire rope, tinned mattress wire, fencing wire etc. Rylands produced about 700 to 800 tons of wire and wire products per week, employed about 700 workers, and specialized in telegraph and fencing wire, galvanized, tinned and coppered wire, and roping and netting wire. Similarly, Whitecross Company Ltd, employed between 800 to 1000 workers, made puddled bars, iron and steel billets, wire rods, plain and coated telegraph and telephone wires, plain and galvanized fencing wire, rope wire, tinned and copper wire, and was perhaps the largest and most integrated, diversified enterprise. The annual capacity of this firm was thought to be about 5000 tons of ropes and 5000 miles of netting and 1500 tons of nails.[28] On the other end of the scale were the smaller manufacturers of wire with far less capital and machinery and employing fewer people. According to one estimate, wire drawers making jewellery wires in Birmingham employed less than 150

[25] Stones, *Wire Industry*, 1; Griffiths, *Iron manufacturers*., lists 31 ‘principal’ firms, included those listed here.
[26] White, *Birmingham trades directory*., categorized as wire drawers, wire manufacturers, iron and steel wire manufacturers, wire rope makers or wire weavers
[27] Aitken, ‘Brass manufactures’, 359, those manufacturing of rolled brass and wire
[28] Smith, *Wire, its manufacture and uses*, 93-98.

people.[29] The industry was thus composed of both large and small firms. Most firms, irrespective of size produced a variety of wire products.[30] Nevertheless, there was geographical specialization in that Yorkshire wire makers were drawing mainly finer, smaller wire type, whereas the Lancashire and Birmingham makers were drawing both thicker and finer wire.[31]

In terms of its applications, wire was virtually ubiquitous and one contemporary writer listed no less than 25 distinct uses, including electrical conductors (e.g. cable and telegraph wires) and scientific instruments; carding machines for textile purposes; manufacture of ropes employed for marine, mining, agricultural, and engineering uses; fabrication of sieves, screens gauze, and netting; spectacle frames and watch springs; manufacture of pins and needles, nails, rivets, fish hooks and umbrella ribs; musical instruments; gates, railings, hurdles and fencing. The list goes on.[32] About 80-90 percent of persons employed in the manufacture of pins, needles and nails were located in the West Midlands, along with about two thirds of those employed in the manufacture of rivets, bolts and staples – indicating the concentration of industries using wire and wire products.[33] In Birmingham, there were about thirty-five pin manufacturers, seventy spectacle makers, forty screw manufacturers, and twenty musical instrument makers (of which eight were manufacturers of pianofortes).[34] Lancashire watch makers used to purchase pinion wire from wire makers of Warrington and Manchester.[35] Wire-netting and wire-rope were also manufactured around the Midlands and in Birmingham and several pianoforte manufacturers were located in

---

29 Carnevali, 'Crooks, thieves and receivers', 539.
30 Blake-Coleman, *Copper wire*, 209.
31 *Ironmonger*, Feb. 26, 1881, p. 261
32 Smith, *Wire, its manufacture and uses*, 5.
33 Census of England and Wales (1871, 1881 and 1891), London: HMSO
34 White, *Birmingham trades directory*.
35 Dane, *Peter Stubs*.; Landes, 'Watchmaking'.

Leeds and other locations in Yorkshire. Finer sizes of Yorkshire iron wire were also used for wool and cotton cards, and sieves. Warrington manufacturers were known to obtain fine wire from Yorkshire.[36] Fine wire made from gold, silver, nickel, copper and brass was used by jewellers and brass and metal works in and around Birmingham.[37]

Apart from these small and medium sized buyers of wire products, the large wire buyers included the telegraph companies and consortiums that required wire manufactured to fairly high and exacting specifications. Thomas Bolton & Co., Richard Johnson & Nephew and Webster & Horsfall had supplied large amounts of copper wire to the Atlantic Cable Company. One of the initial orders required 119.5 tons of copper to be drawn into 20,500 miles of wire, which had to be laid into a strand 2500 miles long.[38] Other large users were engineering companies involved in the construction of bridges and other civil projects. Richard Johnson & Nephew had tendered for an order of 3,400 tons of wire to form the main cables of the Brooklyn Bridge in the late 1860s.[39] Makers of fencing wire were other large users of wire products, while wire ropes were also used in mining operations.[40]

Unsurprisingly, Yorkshire, Lancashire and West Midland together employed about three-quarters of the wire drawers in England (table 1). The number of persons engaged in wire drawing or wire making increased between 1871 and 1891 indicating growth in wire making activity in these locations. The number of wire workers in Birmingham had increased from 90 to 600 between 1840 and 1860.[41] Wire drawing was a highly skilled activity and drawers were paid a premium wage compared to other occupations. For instance, in the mid-nineteenth century, a wire

[36] Hughes, *Wire Gauge*.
[37] *Ironmonger*, Feb. 26, 1881, p. 261
[38] Cited in Blake-Coleman, *Copper wire*, 157.
[39] Seth-Smith, *Richard Johnson & Nephew*, 75.
[40] Smith, *Wire, its manufacture and uses*.
[41] Lean, ‘Wire drawing’.

drawers weekly wage could be between £3 and £5 in Sheffield, while an engineer could be paid between £1.20 and £1.30; wire workers wages were reportedly higher than those of skilled ironworkers in 1873.[42] Nevertheless, wire drawers normally had to pay for the wire to be cleaned before bringing it into the mills, a cost that must be factored in the 'premium' that wire drawers received.[43] Initially, trade union activity amongst the wire workers was limited as most early workers were self employed or worked in small scale shops. By the 1860s, union activity had increased and in 1868 the 'Thick Iron and Steel Wire Drawers Trade and Benefit Society' was formed. However, union membership decreased during the 1870s, and when the manufacturers began to implement wage reductions after 1878 the union was unable to present an effective resistance. As a result of this, manufacturers were able to negotiate wages down by as much as 25 percent.[44]

[42] Bullen, *Drawn together*, 7-8.; these varied considerably and the average earnings in Birmingham in 1866 were about 35s (£1.50) per week according to other sources, see Lean, 'Wire drawing'.; *Ironmonger*, Jan 11, 1879, p. 51-2
[43] Seth-Smith, *Richard Johnson & Nephew*, 81.
[44] Bullen, *Drawn together*, 14-15.

Table 1: Distribution of Wire Workers in England and Wales

	1871		1881		1891	
Total: England & Wales (Nos.)	7,914		9,243		11,175	
West Midlands	2,138	*27%*	2,366	*26%*	2,524	*23%*
Birmingham	*1,031*		*1,380*		*1,479*	
Northwestern Counties	1,459	*18%*	2,054	*22%*	2,690	*24%*
Warrington[a]					*1,027*	
Manchester	*369*		*333*		*685*	
Yorkshire	2,112	*27%*	2,611	*28%*	3,199	*28%*
Halifax	*408*		*600*		*638*	
Sheffield	*306*		*535*		*698*	

Source: Census of England & Wales (1871, 1881 and 1891). Occupation classified as 'Wire Worker and Drawer' in 1871 and as 'Wire Maker, Worker, Weaver, Drawer' in 1881 and 1891.
[a] No figures were reported separately for Warrington in 1881 and 1871
Figures in parentheses represent proportions to total numbers

Estimates of market size in terms of output are difficult to locate. Sir Lowthian Bell, president of the British Iron Trade Association, declared in 1886 that 'I have no account to make of [output of wire] in Great Britain, but it looks as if half a million tons a year at least is the total annual production of this article'. Another estimate put the domestic production between 40,000 and 80,000 tons, which was reportedly underestimated by half.[45] The 1907 Census of Manufactures report estimates the net domestic production of iron and steel wire to be between 210,000 – 215,000 tons with brass and copper wires contributing an additional 15,500 tons. The number of persons employed in the wire trade is given

[45] Bell, *UK Iron Trade*, 23.; Thomas, *Wire rod production*, 10.

by the Census to be approximately 17,000.[46] Using these figures, per person output in 1907 appears to be about 13 tons per annum. Further, using other estimates for sales of wire products between 1920 and 1922, and the total numbers of wage earners for these years, per person output per annum appears to range between 16 and 20 tons.[47]

It is very likely that per person output varied significantly across wire manufacturers, particularly between the larger and the smaller firms. At worst output could have stagnated between 1880s and the early decades of the twentieth century; but it seems unlikely to have decreased. Given the nature of technological change (discussed later), a broad assumption can be made that 13-15 tons per person per annum is a reasonable estimate for the period between 1870 and 1890. If these estimates are somewhat accurate, domestic production c1881 was very likely to be between 120,000 and 140,000 tons. Thus, the export of wire from the UK formed around 55-60 percent of the annual production around this time, whereas this proportion was lower in 1871 and 1891 (table 2). In value terms, exports of wire (iron and steel as well as telegraph wire) amounted to about £2.9 million and £2.3 million in 1881 and 1882 respectively.[48] In comparison, exports of wire from the UK around 1907 were 55,000 tons or about 25 percent of the total domestic production, consistent with a declining trend in British iron and wire product exports. In order to achieve Bell's estimated output of half a million tons per worker output would have to be around 50 tons per annum, unless this estimate includes the output of other products such as rods and billets used in the manufacture of wire.

---

[46] Final Report on the First Census of Production of the United Kingdom (1907), 1912, pp. 113-117
[47] Stones, *Wire Industry*., see illustrations between p. 12 & 13
[48] *Ironmonger*, Jan 13, 1883 p. 56, Board of Trade Returns

Table 2: Estimates of Domestic Production of Wire in England and Wales

	No. of Wire Drawers	**Annual Output** *Assuming 10 tons per worker*	*Assuming 13 tons per worker*	*Assuming 15 tons per worker*	UK Exports	Exports as % of Prod.
1871	7,914	79,140	102,882	118,710	21,000*	20%
1881	9,243	92,430	120,159	138,645	75,000	62%
1891	11,175	111,750	145,275	167,625	62,000*	43%

Sources: No. of wire drawers from Census of 1871, 1881 & 1891. UK exports as reported in L Thomas, *'The Development of Wire Rod Production'*, 1949, Appendix VIII.
* Export figures are for 1870 and 1890

In comparison, German wire production was estimated to be around 250,000 tons in 1881.[49] Bell estimates the production to have increased from 179,000 tons in 1878 to 378,000 tons in 1882 i.e. more than doubling in four years.[50] The German manufacturers exported around 30 percent of their production in 1878, which increased to about 60 percent by 1881-82. Comparing wire production to other iron and steel products, Britain produced about 519,000 tons of rails in 1879 which increased to more than 1.2 million tons in 1882. At the same time, Germany produced 481,000 tons of rails in 1880 which increased to 564,000 tons in 1882. In fact, the market for commercial iron products, such as wire, was more important for German heavy industry compared to rails, whereas in Britain the reverse was true. During the 1880s, the German firms exported more wire products than rails.[51] The major German firms were also larger and more integrated compared to British firms. Eisen – Industrie zu Menden made 70,000 tons of puddle and

[49] *Ironmonger*, Apr 9, 1881, p. 510. France, Belgium and the United States were also important centres of wire manufacturing internationally.
[50] Bell, *UK Iron Trade*, 23.
[51] Wengenroth, *Enterprise and technology*, 139-141., see tables 15 & 17, also p. 186

rolled bars, wire rods, drawn wire and nails. Westfalische Union, formed from an amalgamation of various older Westphalian firms in 1873, had an output of about 100,000 tons annually, employed about 3,000 workers, and made wire rods, drawn wire, wire strands and roping, nails, rivets, screws, besides large quantities of bar iron, axels, sheet metal, etc.[52]

Wire Drawing: Process, Sizes, and Gauges

Wire was produced from wire rods, which were approximately ¼ inch in diameter. To make wire, the rods were drawn or pulled through a series of perforated plates called drawplates. The perforations on the drawplate corresponded with sizes that ranged from Nos. 1 through to 20 for thicker wires, and from Nos. 20 through to 40 for finer wires, with increasing numbers signifying smaller diameters.[53] Many of these sizes were further divided into half and quarter sizes. The cost of making wire increased with each successive draw so that finer wire was costlier to manufacture as compared to wire of thicker sizes. A price list from 1884 offered size 1 to 6 for 2¼d per *cwt* (112 pounds), whereas a No. 12 wire was available for 4d. Similarly, a No. 15 wire in the same price list was available for 6¼d and a No. 20 for 1s 5½d.[54] The primary reason for this was that the wire-drawer's remuneration and other costs such as annealing depended directly upon the number of draws that were made to manufacture wire of a required diameter.[55] Although a skilled wire drawer knew what intermediate holes could be avoided, this form of remuneration and the fact that wire reduced more than two sizes in one draw was not of good quality discouraged the practice of 'jumping holes'. For example, if

[52] Smith, *Wire, its manufacture and uses*, 97.
[53] Sizes greater then No. 1 were used to specify wire rods and sizes smaller than No. 40 referred to very fine wire usually not drawn through the drawplate.
[54] Stones, *Wire Industry*., see illustration between p. 12 & 13
[55] Annealing meant 'softening' the metal to make it easier to draw it through the drawplates

No. 4 iron wire was required

> the drawer [took] annealed wire of No. 1, [gave] it a hole to No. 3 [and another] hole to No. 4. If he had reduced it from size 1 to 4 in one draw, [it] would be found irregular in thickness, ellipse here, fluted there, and flat further on, instead of being smooth and equal diameter throughout.[56]

There also existed a 'relationship' between a skilled wire-drawer and the wire sizes. For example, a skilled worker could take six feet of No. 22 soft *brass* wire, fasten one end to a post and pull at the other and thus obtain eight feet long No. 24 wire. Or he could take six feet of No. 22 soft *copper* wire and stretch it to seven feet No. 22¾ wire. The wire-drawer knew these metal properties and also that if he got to the 'limits of cohesion' he either 'sucked' or broke the wire; he used the wire sizes as his guide to do this.[57]

These examples highlight interesting issues concerning the method of manufacturing wire. There was a particular sequence of holes through which wire had to be drawn in order to make wire of a desired size as well as acceptable quality. Such sequences were established empirically through long usage. The skill of the wire drawer was to know such sequences so that the wire that is drawn is smooth, regular and as equal in diameter throughout as possible. Also, the wire drawer was required to know the wire sizes and not the actual diameter of the wire being pulled. In other words, it was unimportant for the drawer to know that a No. 7 was 3/16th of inch thick, or that a No. 10 was 0.14 inches (or 9/64^{ths} of an inch) thick. As long as he was familiar with the sizes and the sequences of holes through which the wire had to pass to reach that size, he could produce wire of almost any diameter that was required.

[56] Smith, *Wire, its manufacture and uses*, 55-56.; *Ironmonger*, Feb 26, 1881, p. 259-61
[57] *Ironmonger*, Feb 26, 1881, p. 259-61

Throughout the nineteenth century, wire making technology kept pace with developments in wire applications. The move towards machine made wire meshes and netting in early nineteenth century led to the shift away from hand-drawn wire to wire drawn by mechanical means. Drawing longer pieces of wire using steam power was being carried out in the 1840.[58] George Bedson, of Richard Johnson & Nephew, introduced a continuous rod rolling mill in 1862, which effectively enabled longer coils of wire rods to be produced.[59] Around the same time, the Germans were also making improvements to rod rolling technology. In 1878 one observer reported that by making some changes to the manner in which rods were rolled in the rolling mill, the German wire makers could cut capital and labour costs.[60]

Nevertheless, the speed with which wire was drawn and the efficiency of drawing machines improved slowly and insignificantly throughout the nineteenth century. In fact the techniques for drawing wire in the late nineteenth century had changed little from those used in the late eighteenth century. In contrast, the output of rod rolling mills increased by a factor of almost fifty.[61] Increasing efficiency of wire drawing by combining several blocks of wire drawing machines was introduced in the late nineteenth century. In 1871, the Woods brothers from Manchester patented a continuous wire-drawing machine, which made it possible to pass wire through four drawplates at the same time.[62] Nevertheless, in 1880 it was reported that

> an ingenious machine has lately been introduced here for expediting the work, the wire passing through a succession of

[58] Thomas, *Wire rod production*, 15.
[59] Seth-Smith, *Richard Johnson & Nephew*.
[60] Thomas Morris, '*Four days in the Iron Wire Manufacturing District of Westphalia, Germany*', Warrington Literary and Philosophical Society, as cited in Thomas, *Wire rod production*, 23-4.
[61] Blake-Coleman, *Copper wire*, 83.; Laman, 'Wire-drawing', 268.
[62] Thomas, *Wire rod production*, 15.; Laman, 'Wire-drawing', 269.

> plates pierced by holes of diminishing gauges, [and] the wire is drawn down three sizes at once, at a great saving of time, labour and cost[63]

Continuous wire drawing technology was relatively new and not generally adopted within the British industry in the 1880s. The exception to this was the Ambergate works of Richard Johnson & Nephew, where in the early 1870s engineers from Washburn Co., an American wire manufacturer with whom the Johnsons had had long ties, were brought in to introduce a system that used unskilled labour supervised by craftsmen. This system used cast iron dies in series, similar to Bedson's continuous rod production methods.[64] It was in the late 1880s, after further improvements that continuous wire could be drawn from say No. 34 to 48 in one operation.[65] This illustrates that wire drawing through drawplates remained the contemporary method of wire drawing in the late 1870s and early 1880s and continuous wire drawing was likely an exception, a technique adopted by a few large wire manufacturers.

The perforations on the drawplate corresponded with the sizes of wire as measured by the gauge. The No. 1 hole on the drawplate corresponded with No. 1 size on the wire gauge used in a workshop and No. 23 hole on the drawplate corresponded with No. 23 size on the same gauge. The wire gauges in use before c1880 were empirically derived, i.e. based upon long experience of wire drawing and on the physical properties of the metal being drawn through the drawplate. Some engineers, however, claimed that there was a definite mathematical relationship between the breaking strength of each wire and the opposition provided by the drawplate.[66] This created a degree of interrelatedness between the drawplates and the gauges. The original

[63] *Ironmonger*, Apr 10, 1880, p. 494
[64] Bullen, *Drawn together*, 12.
[65] Smith, *Wire, its manufacture and uses*, 84-89.
[66] Clark, 'Birmingham gauge, 1869', 338.

gauges were based upon the holes on the drawplates, which were themselves empirically derived. In turn, the gauge was used both as a verification tool, to ensure that the wire drawn was of the correct size, as well as a template, to replicate new drawplates once the older ones became worn out due to repeated use.[67] Each workshop had its own wire gauge, which was arrived at empirically and 'guarded with great care [and] transmitted almost as heirlooms from father to son'.[68]

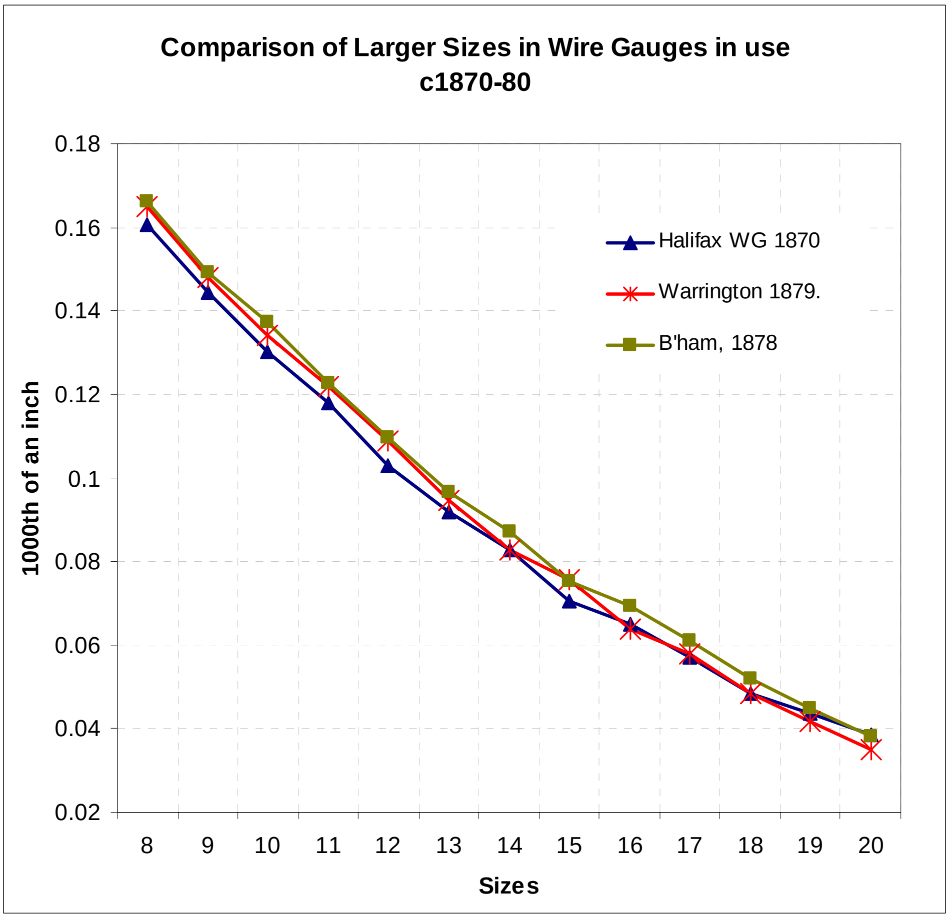
The origin of the wire gauges in the form they were used in nineteenth century Britain, i.e. slot gauges, is uncertain. Thomas Hughes thought that they were brought into England from Germany in the sixteenth century. The sizes were divided initially into vulgar fractions of the English inch but as the number of sizes increased and became cumbersome to express in terms of fractions they were collected into a series of numbers sometime in the eighteenth century.[69] According to Latimer Clark the number system developed by calling the 'largest wire [drawn] as No. 1, the next smallest [as] No. 2, the next smallest drawable wire, No. 3, and so on'. As a result of this, minor variations in the sizes of wire using ostensibly the same method of manufacturing, and with it in the gauges, inevitably crept into the system of wire sizes.[70] This method continued to be used in the nineteenth century to manufacture wire gauges. Hughes narrates the following experience: 'Some years ago I saw a set of [some] standard patterns [consisting] of small pieces of iron wire, all sizes from No. 1 to 40; each size was kept in a box for preservation. The owner had had them for about 50 years and made gauges for sale with them.'[71] Very likely, this method of standardizing sizes resulted in the profusion of wire gauges as each workshop or region

[67] Smith, *Wire, its manufacture and uses*, 55.; drawplates were heated, hammered and partially repunched with the diameters ascertained by the gauge punches
[68] Dickinson and Rogers, 'Origin of gauges', 88.
[69] Hughes, *Wire Gauge*.
[70] Clark, 'Birmingham gauge, 1869', 337 & 341.
[71] Hughes, *Wire Gauge*.

developed their own gauge based upon their own experience of wire drawing, on the metals being used, and the intended use of the wire. In other words, the industry developed multiple technical standards based on the production technologies in use at the time. Many of these different gauges varied marginally in terms of actual dimensions. The difference was apparent only when the measurements were expressed using decimal units rather than fractional units of the inch. Charles Holtzapffel, in 1847, had remonstrated the artisans for expressing sizes in 'three-eights of an inch full or bare [which] sets all attempts at exactness at defiance'.[72] Nevertheless, there were several gauges where the dimensions differed significantly for them to be considered as separate gauges.

Consider two different wire gauges used in Warrington and Birmingham around 1879.[73] Comparing two sizes on these gauges, Nos. 30 and 34, we discover that No. 30 on the Warrington gauge was 0.0108 inches in diameter, whereas it was 0.014 inches on the Birmingham gauge. Similarly, No. 34 was 0.00575 inches on the Warrington gauge as opposed to 0.0106 inches on the Birmingham one. Thus, wire drawn to No. 30 hole on the Warrington gauge would be approximately one-third smaller in diameter to that drawn on the No. 30 hole on the Birmingham gauge and wire drawn on No. 34 hole to the Warrington gauge would be almost half as thick as that drawn to the same hole on the Birmingham scale. The Birmingham No. 34 was actually closer to the Warrington No. 30 than the No. 34 on that gauge. Admittedly, such differences were more apparent in the finer sizes than in the larger ones (figure 1).

[72] Holtzapffel, *Turning (Vol. 2)*.
[73] Hughes, *Wire Gauge*.



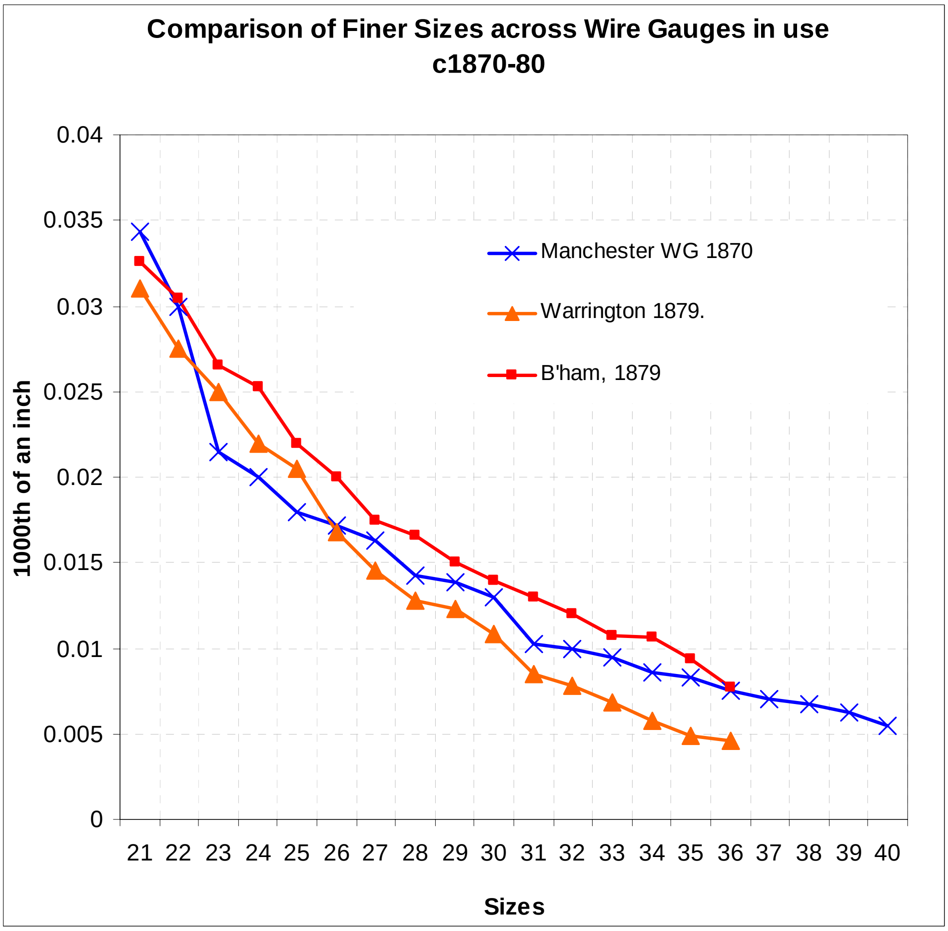


Figure 1: ***Source***: Thomas Hughes, The English Wire Gauge. London, 1879

As the number of applications in which wire products were used increased, it led to the increase in the number of sizes included on the wire gauges. Eighteenth century wire gauges appeared to have used between twelve and sixteen sizes, whereas by 1842 the number of sizes had increased to at least twenty-six.[74] This indicates that the wire gauges in the mid-nineteenth century were a collection of various sizes, which got combined into one gauge.[75] The increasing complexity of sizes also emphasized the need for workmen to remember only the wire numbers rather than the measurements in inches; the gauge numbers functioned as a convenient mnemonic.

The most widely known and used of the several gauges was the Birmingham Wire Gauge (BWG), although no single gauge can be traced which could be termed as *the* BWG. It was most likely a loosely termed collection of gauges that originated and were used in and around Birmingham. The BWG was also used in other locations apart from Birmingham, such as Manchester and Sheffield. Internationally, the BWG was known in Germany and parts of the United States.[76] The Stubs Lancashire gauge was originally defined by Peter Stubs and was preferred in Warrington, Sheffield, Manchester and Canada. Apart from these, other gauges included the Rylands gauge, the Cocker Steel gauge, the South Staffordshire gauge, etc. The size and dimensions of wire defined by some of these gauges is compared in table 3 below. Such slot-wire gauges were not the only type used by wire makers, although they were very widely used in Britain, Germany and the US, more than any other kind. A micrometer gauge used by some manufacturers in the US was described in 1877. This movable type of gauge was reported to be very precise and in trials 'gauge boys [could] very easily be taught to

[74] Dickinson and Rogers, 'Origin of gauges'.; Hughes, *Wire Gauge*.
[75] Hughes, *Wire Gauge*.
[76] Clark, 'Birmingham gauge, 1867', 332.; *Ironmonger*, Feb 14, 1880, editorial note

read the thousandth of an inch'.[77] However, the micrometer gauge was not generally used in Britain as its use was considered to be 'slower and more complicated [and] in the hands of workmen [was] liable to errors of unobserved movement'.[78]

[77] 'Report on a standard wire gauge', paper read before the American Institute of Mining Engineers at Amenia, October, 1877, reprinted in the *Journal of the Society of Telegraph Engineers*, Vol. 7, 1879, pp. 344-50; other forms included the old French bent wire gauge, the step gauge used in the eighteenth century, the V gauge used in the US, etc., see Dickinson and Rogers, 'Origin of gauges'.
[78] Smith, *Wire, its manufacture and uses*, 117.; Hughes, *Wire Gauge*.; the micrometer gauge was used in the metal sheet and strips trade, see Dickinson and Rogers, 'Origin of gauges'.; also, *Ironmonger*, Nov. 27, 1880, p. 621

Table 3: Comparison of Sizes of Various Wire Gauges *(1000th of an inch)*

Sizes	Stubs Gauge[1]	BWG[1]	Rylands Gauge[1]	Cocker Steel Gauge[2]	South Stafford-shire Gauge[2]	Variation as compared to the Stubs gauge (%)			
						BWG	Rylands Gauge	Cocker Steel Gauge	South Stafford-shire Gauge
1	300	312.5	300		302.5	-4	-		-1
2	284	281	274		275.5	1	4		3
3	259	265	250		256.5	-2	3		1
4	238	234	229	246	236	2	4	-3	1
5	220	218	209	226	217	1	5	-3	1
6	203	203	191	198	207.5	-	6	2	-2
7	180	187	174	183	184.5	-4	3	-2	-3
8	165	171	159	175	167.5	-4	4	-6	-2
9	148	156.25	146	160	153	-6	1	32	-3
10	134	140	133	136	134	-4	1	-1	-
11	120	125	117	128	116.5	-4	2	-7	3
12	109	109	100	107	106.5	-	8	2	2
13	95	93	90	100	96.5	2	5	-5	-2
14	83	78.125	79	92	89	6	5	-11	-7
15	72	70	69	79	73	3	4	-10	-1
16	65	62	62	70	60.5	5	5	-8	7
17	58	54	53	63	54	7	9	-9	7
18	49	46	47	57	49.5	6	4	-16	-1
19	42	42	41	47	41.5	-	2	-12	1
20	35	38	36	42	39	-9	-3	-20	-11
21	32	34	31		34	-6	3		-6
22	28	31.25	28		28.5	-12	-		-2
23	25	28			26	-12			-4
24	22	25			23	-14			-5
25	20	22			19.5	-10			3
26	18	19			16.5	-6			8
27	16	17			15.5	-6			3
28	14	15.625			14.5	-12			-4
29	13	14.5			11	-12			15
30	12	13.5			10.5	-13			13
31	10	12.5			10	-25			-
32	9	11.5			9.5	-28			-6
33	8	10.5				-31			
34	7	9.5				-36			
35	5	8.5				-70			
36	4	7.5				-88			

[1] Extract from John Watkins, '*A Comparison of numbers and sizes of the new legal standard wire gauge…'* (1888) British library MS 1881.c.3 fo.10; BWG: Birmingham Wire Gauge
[2] *Ironmonger* 'The Birmingham Wire Gauge: Being a collection of better know versions…', (1905) British Library 1882.d.2 fo. 126

The foregoing discussion about wire sizes, numbers and gauges is significant in that we can identify various sources of transaction costs arising as a result of the different gauges in use. It is shown above how different wire numbers on two different gauges could refer to the same diameter of wire (in terms of length units). Or, to put it differently, the same wire number as measured by two different gauges could refer to different diameters of wire. Latimer Clark claimed that he was personally involved in a contract where the use of one gauge instead of another would have made a difference of £8,000 to the contract value. The solution was to specify both the gauge number as well as the diameter of the wire, which according to him proved the 'uselessness of the present system'.[79] Hughes writes of an order from New York for a No. 36 Birmingham gauge wire, but

> the [British manufacturers] rightly concluded the gauge intended was Stub's, or Warrington Wire Gauge, that being the "Birmingham Wire Gauge" commonly [referred to] in the United States [had] this order been executed to the Birmingham gauge [the] difference in price of metal on this order [would have been] £28 per ton'[80]

By the 1880s, foreign buyers had become wary of these differences in gauge sizes. Muller, Uhlich & Co. wrote to the *Iron Age*, New York, that 'the diversity in the gauges of wire, sheet iron etc, is the cause of much trouble, especially when orders are sent from the United States.'[81]

But it was not only foreign buyers who faced this situation. Some wire manufacturers secured orders through supposed underselling; however, this was the effect of supplying a thicker wire for the same gauge number, which cost less to produce. For example, a No. 22 copper wire according to the gauge used in Birmingham could be invoiced as No.

---

[79] Clark, 'Birmingham gauge, 1867', 226.
[80] Hughes, *Wire Gauge*.
[81] Reprinted in *Ironmonger*, Mar. 12, 1881, p. 345

21½ in Warrington, Liverpool, or Staffordshire, making it cheaper outside Birmingham by £4 13s 4d per ton. Consumers also took advantage of this asymmetric information to gain a price advantage. Some buyers sought to obtain finer sizes of wire for the lower price of thicker wire by claiming that they could obtain, say, No.36 brass wire at the price of No.33, potentially saving as much as £84 per ton.[82] Hughes narrates the following anecdote.

> when a customer used certain sizes largely, the gauge made for him had those sizes made smaller than they should be, to enable him to purchase wire cheaper. [This] customer used No. 25 wire largely; notch 24 on his gauge was the same size as No. 25 on ordinary gauge; he thereby obtained wire No. 25 at the price of No. 24, saving £4 10s per ton[83]

In contrast, German wire was reputedly being drawn to standard sizes by the 1880s. Although the BWG was 'extensively adopted' in Germany, Westphalian wire was measured by the millimetre gauge.[84] These wire-drawers had earlier used a gauge known as the 'Bergish' with its own unique system of sizes that were expressed in terms of letters such as 'K', 'GR', 'FR' 'GM', 'MM', etc. Hughes describes one such gauge dated 1877 which he calls 'Westphalian Common Wire Gauge'. [85] A report from 1881 claimed

> A few years ago the French adopted a modification of their old gauge. To facilitate its acceptance they retained the old numbers on one side, and the new numbers indicating the diameters in millimetres, on the reverse. The Germans long discussed a standard wire gauge, ultimately deciding upon one similar to the French'[86]

Large buyers purchasing wire from multiple manufacturers, overseas buyers acquiring wire from British manufacturers, buyers whose

---

[82] *Ironmonger*, Jan 1, 1881, pp. 18-20
[83] Hughes, *Wire Gauge*.
[84] *Ironmonger*, Feb 14, 1880, editorial notes, p. 209
[85] Hughes, *Wire Gauge*.
[86] *Ironmonger*, Feb 12, 1881, pp. 206-211

gauge did not match the manufacturers gauge and vice-versa, etc., faced transaction costs arising from non-standardized wire sizes. On one hand, there were distinct advantages in making standard sizes uniform. Equally, there were advantages in maintaining ambiguity between wire sizes and gauge numbers. Transaction costs theoretically could be reduced by specifying the exact dimension of wire required (in length units) for each contract. The alternative was standardizing the gauge numbers to signify uniform measurements. By the late 1870s, orders for wires had begun to specify diameters in decimal length units in addition to gauge numbers. Wire manufacturers had begun printing lists of wire sizes specifying the diameters (in decimal parts of an inch) for each gauge number.[87] Nevertheless, between 1878 and 1883, the industry attempted to define a uniform industry standard – a standard wire gauge – which they hoped would overcome the problems of multiple standards.

Standardizing Wire Sizes

In 1847, Charles Holtzapffel made one of the earliest attempts at standardizing the system of gauges used by the industry, notwithstanding an earlier attempt reported in 1824.[88] He proposed an 'easy and exact system' of wire sizes to remove the existing 'arbitrary incongruous system' by using the decimal divisions of the inch so that they are made to 'systematic and defined measures'.[89] Joseph Whitworth too proposed a decimal scale of sizes for the wire gauges in 1856 as 'different wire and other gauges [differed] so considerably that the [customer had] to send a sample of what he [wanted], there being no means of correctly expressing

[87] Hughes, *Wire Gauge*.; see also TNA, BT 101/40, copy of advertisement of W & C Wynn & Co.'s gauge, compared to the Stubs gauge, and with diameters in decimal inches.
[88] Dickinson and Rogers, 'Origin of gauges'.
[89] Holtzapffel, *Turning (Vol. 2)*.

its size'.[90] Between 1867 and 1869, Latimer Clark presented two papers to the British Association wherein he stressed the 'necessity for having a recognized standard gauge' and proposed a scale, based on decimal divisions of the inch, where the size of the wire diameters increased by a constant rate of about 11 percent from the smallest size, or the weight of the wire by about 25 percent.[91] He acknowledged, however, that the new standard gauge should closely resemble the existing wire-gauges and retain the numbering system in use.

These proposals involved replacing existing methods to yield the desired wire sizes, either in terms of using decimal measurements or altering the relationship between the numbers and diameters that were established through long practice and experience. For instance, Whitworth's proposal involved completely altering the existing system of gauge numbers by reversing their order. Clark's proposed sizes involved a uniform decrement in sizes, meaning that some of his thicker sizes were larger than those actually in use. We lack any clear evidence regarding the industry's reaction to these proposals. The fundamental issue, however, is that these proposals were not adopted by the trade and the numerous wire gauges – by location, wire metal, application, or manufacturer – continued to be used into the 1880s.

In contrast to the rather lukewarm response from the industry to the early standardization attempts, the decade 1872-1882 witnessed a flurry of activity within the trade particularly after 1878. During this period, the buyers of wire products made several attempts to establish a standard wire gauge. Telegraph cable companies, by the mid-nineteenth century, had become large and sophisticated purchasers of wire products, particularly of copper wire. For example, one contract for a submarine

[90] Whitworth, *Papers on mechanical subjects*., Paper to the Institution of Mechanical Engineers, 1856

[91] Clark, 'Birmingham gauge, 1867', 153.

cable specified the core to be made of seven No. 22 BWG copper wire with a total diameter equal to No. 14 BWG weighing 107 pounds per nautical mile.[92] Other buyers, such as pin manufacturers, demanded greater consistency in wire diameters. The introduction of automatic pin-making machines in the middle of the nineteenth century meant that there was now a greater demand for ‘exactitude’ in wire diameters. Pin making was a large volume business where about 50 million pins were being manufactured in Birmingham alone by the late 1880s. These required the equivalent of £100,000 worth of wire per annum. Wire used in fine woven gauzes also had to be made to fairly exacting standards: some gauzes contained nearly 40,000 meshes per square inch.[93] Hughes wrote that

> Much wire is in these days ordered quarter sizes, [and] is worked up by self-acting machines. Unless the wire is accurately drawn, the machine either makes an imperfect article or spoils it.[94]

Clark, echoing this, argued that ‘pin makers and others have really to resort to small divisions [and] it is most desirable [that the gauge be defined] so that it can be measured on a machine’.[95] In fact wire makers had to manufacture wire not only to a specified diameter but also to a specified weight per gauge and length with diameters expressed in ten-thousandth parts of an inch, and in hundredths of a millimetre.[96] The users and retailers of wire were urged to demand an industry standard with one journal writing that ‘it is from these classes that the pressure for a standard uniform gauge must come’.[97]

In 1872, two telegraph engineers proposed a uniform wire gauge based upon a mass-length standard. They argued that, as copper wire

---

[92] Blake-Coleman, *Copper wire*, 157.
[93] Smith, *Wire, its manufacture and uses*, 6-26.; Dutton and Jones, ‘British pin industry’, 190.; *Ironmonger*, Jan. 1, 1881 p. 18
[94] Hughes, *Wire Gauge*.
[95] TNA, BT 101/124, notes on conference dated Dec 27, 1882
[96] *Ironmonger*, Jan 1, 1881, pp. 18-21
[97] *Ironmonger*, Dec 18, 1990, editorial

was increasingly being purchased either by weight or with diameter specified in thousandths of an inch, this same system could be extended to the purchase of iron wire.[98] Nothing further seems to have occurred on this issue until May 1878 when the Society of Telegraph Engineers (STE) appointed a committee to further consider the issue of the wire gauge. Carl Siemens, brother of Werner and William Siemens and who was involved in the first major transatlantic submarine cable expedition aboard the ‘Faraday’, was a prime mover in getting the STE committee appointed in May 1878.[99] It consisted mainly of engineers (Latimer Clark, H Mallock, W H Preece, C V Walker, etc.), but also had J Thewlis Johnson of Richard Johnson and Nephew on the committee. The committee proposed a British Standard Gauge (BSG) which was basically Latimer Clark's geometric gauge as proposed in 1867. Although the BSG was to conform closely to the existing gauges, the report acknowledged that due to the principle of its construction (geometrically decreasing sizes) it would differ from the existing gauges, sometimes as much as whole sizes. However, it felt that ‘the workmen and dealers would gradually become acquainted with it, and would soon begin to prefer it on account of its precision and uniformity, and its authority as a gauge of last appeal.’[100]

In October of the same year, the Birmingham Chamber of Commerce (BCC) canvassed the opinions of the principal dealers in metals and wire, and jewellers to seek their opinion as to the desirability of a uniform gauge. After corresponding with the other chambers of commerce, the BCC council decided to write to Joseph Whitworth asking

[98] Mallock and Preece, ‘Wire gauge’, 81.
[99] Society of Telegraph Engineers, Minutes of Council Meetings, Council Papers, IET Archives, London, IET/ORG/2/1/2, entry for May 23, 1878
[100] Report on the BWG, STE Journal, 1879, p. 493

for assistance in developing a standard wire gauge.[101] In March 1879, at the annual general meeting of the Associated Chambers of Commerce (ACC), the BCC representatives got a resolution adopted to establish ‘one uniform standard gauge’ and that its use should be made ‘if necessary compulsory by law’. An ACC committee on wire gauges, which met in October 1879, was chaired by T R Harding (a pin-maker from Leeds) and both Clark and Whitworth attended it.[102] The committee was unable to report until 1882 due to the multiplicity of gauges proposed by ‘individual members, [each] determined to have his own [accepted as the standard gauge]’.[103] In fact, there were deep divisions within the ACC committee on this issue. The committee itself was composed of both wire makers as well as buyers of wire products and each group had its own distinct opinion on what constituted an appropriate standard. Apparently, ‘certain members of the committee [were] pushing their own ideas, some of the chambers [were] in favour of a metrical gauge...Birmingham [was] inclined to fight for its own hand, and Warrington evidently [held] to the gauge in general use amongst its manufacturers’.[104]

In February 1882, several wire manufacturers - Edelsten, Williams & Co., Rylands, Richard Johnson & Nephew, Nettlefolds, Whitecross, etc. - met in Birmingham along with W F Haydon and T R Harding from the BCC. The ACC had recently considered adopting Harding's proposal as its recommended standard gauge. Virtually all the large manufacturers - claiming 70-80% share of wire production - were opposed to Harding's proposal accusing it to be a compromise and ‘theoretically imperfect’.[105]

---

[101] TNA, BT 101/114, Report of the Associated Chambers of Commerce (hereafter ACC) on Wire Gauge; Birmingham Chamber of Commerce, Council Minutes Books, Council Papers, Birmingham City Archives, Birmingham, MS 2299 Acc2000/127 Box 4, entries for Oct. 23, Nov 20 and Dec 18, 1878

[102] Association of Chambers of Commerce, Executive Council Minutes: Vol 3, Council Papers, Guildhall Library, London, Ms 14476/3., entries for Mar 6 & Oct 29, 1878

[103] *Ironmonger*, Jan. 29, 1881, p. 134-6

[104] *Ironmonger*, Feb 25, 1882, p. 268-9

[105] *Ironmonger*, Feb. 25, 1881, p. 281

Nevertheless, in March 1882, the ACC adopted Harding's proposal as the basis for their standard wire gauge.[106]

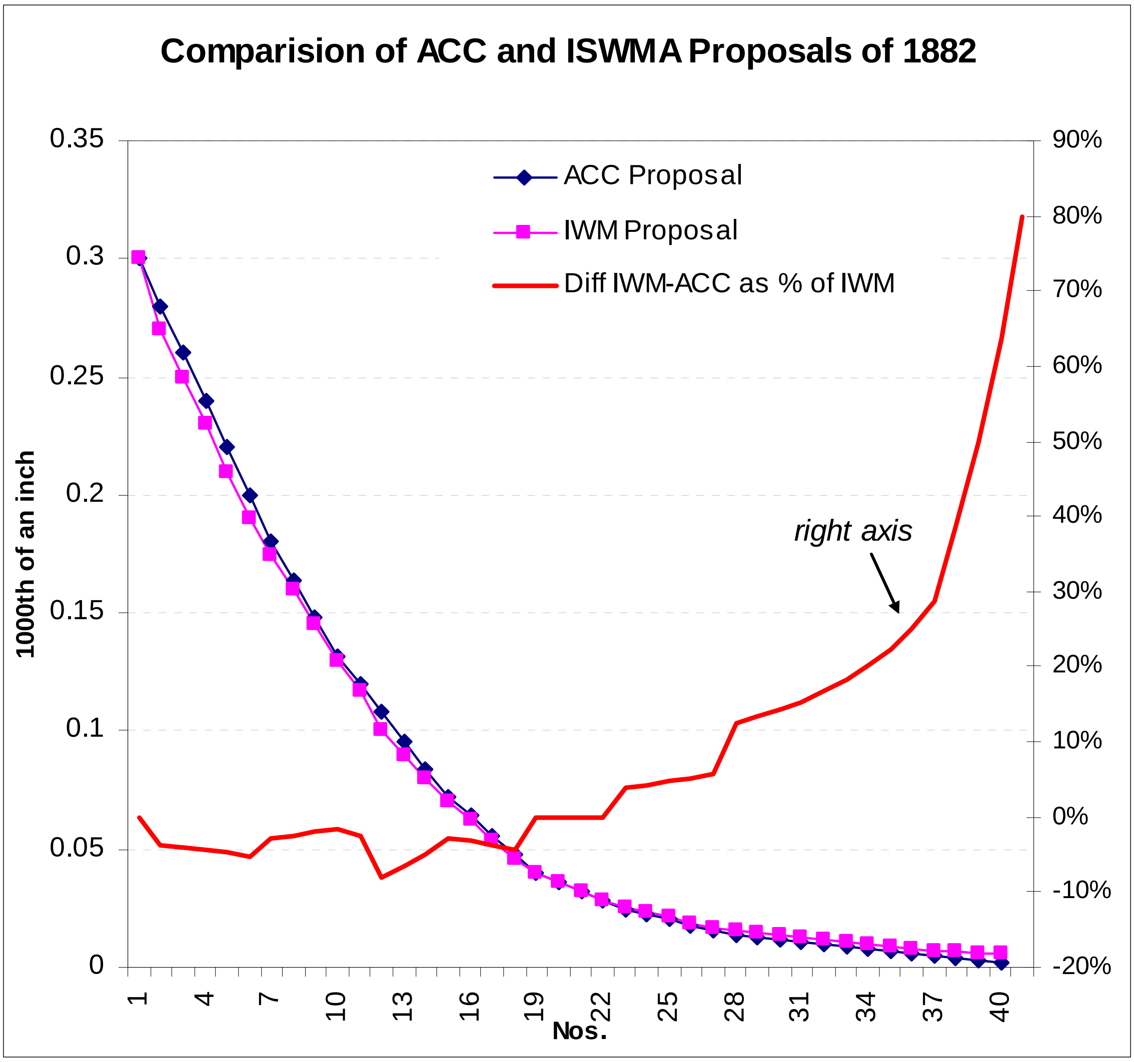
In March 1882, the ACC sent a memorial to the Board of Trade (BoT) presenting a case for the adoption of a uniform standard based on the Harding gauge. The memorial strongly urged the Board to consider their proposal ‘for the purpose of its being legalized [as] the British Standard Wire Gauge’.[107] Immediately thereafter, in April 1882, the BoT circulated this proposed wire gauge to the rest of the industry, with some modifications, asking for their reactions and opinions on the proposal.[108] The industry response to this was fairly mixed. The proposal was approved by the large users of wire products, especially cable wire users such as the General Post Office and the telegraph companies. Several chambers of commerce also approved the BoT proposal, including the London, Birmingham, Leeds and Wolverhampton chambers. Also, many Birmingham engineering and metal working firms approved the proposal.[109]

However, the large wire makers, who were opposed to the ACC proposal from the beginning, objected to the BoT proposal forming the only legal and uniform gauge. In May 1882, the Iron and Steel Wire Manufacturers Association (ISWMA) was formed ‘to decide upon the course to be taken [in] the matter of a standard wire gauge’.[110] The ISWMA wrote to the President of the Board of Trade stating that the sizes proposed were arbitrary, ‘drawn without regard to the method of production’, and were different from the sizes ‘most generally known to

[106] Association of Chambers of Commerce, Executive Council Minutes: Vol 3, Council Papers, Guildhall Library, London, Ms 14476/3., entry dated Mar. 1, 1882; TNA, BT 101/114
[107] TNA, BT 101/114, Letter from the ACC dated Mar 15, 1882
[108] TNA, BT 101/119, Circular from BoT dated Apr 15, 1882
[109] TNA, BT 101/115; BT 101/116; BT 101/119
[110] Stones, *Wire Industry*, 1, 12.

consumers'.[111] The association came up with its proposed list of sizes – the Lancashire wire makers proposing the sizes for Nos. up to 20 and the Yorkshire manufacturers proposing the finer sizes from Nos. 21 to 50.[112] Although the wire sizes between the ACC and ISWMA proposals appear to be virtually identical, the difference between the sizes seemed to be of material importance at least to the wire manufacturers (figure 2 and table 4).

Figure 2.



Source: The National Archives, BT 101/114 (ACC proposal); BT 101/116 (IWM proposal)

[111] TNA, BT 101/116, Letter from the ACC to the BoT dated July 7, 1882
[112] Stones, *Wire Industry*, 1.

The ISWMA did not represent the opinion of all wire makers. One irate correspondent, presumably a wire maker from Birmingham, wrote:

> because the major quantity is supposed to be drawn in Warrington all the others must submit to the Warrington wire gauge. Do we not see in the fact [that] iron wire can be drawn to the BWG and if it can in Birmingham, Yorkshire, Wales, etc., why not in Warrington?[113]

Even within the ISWMA there were differences in opinion regarding the response to the BoT's April 1882 proposal. The Yorkshire manufacturers, Frederick Smith & Company and Ramsden Camm & Company were in favour of the BoT proposal, but decided to go along with the majority view of opposing it and proposing an alternate standard gauge.[114]

Despite the fact that a majority of the replies received by the Board had approved the proposal, the BoT felt its proposal needed to be modified 'to meet the views of the Warrington district where most of the iron and steel wire [was] made'. Consequently, the BoT circulated a modified proposal in November 1882. The wire makers once again objected to the Board's proposal, and a further modified scale was proposed in February 1883.[115] The wire makers this time accepted the Board's February 1883 scale down to sizes 22, but recommended changes to sizes 23 to 39.[116] The rivalry between the ACC and the ISWMA up to that point was cogently summarized by Claude Morris of Rylands, and the chairman of the ISWMA:

> On the one hand, [we have] a large & important trade petitioning the BoT *against* a proposed legislation, and on the other hand, [we have] the ACC [who is] supposed to be representing the trade [but is] actually endeavouring to force the government to

[113] *Ironmonger*, May 20, 1882, Letters to the Editor, pp. 686-7
[114] Stones, *Wire Industry*, 1.
[115] TNA, BT 101/119, memo dated Jul 28, 1882; BT 101/123, letter dated Jan 5, 1883; BT 101/124
[116] Stones, *Wire Industry*, 4.

establish as legal the sizes which the trade say will be ruin to them![117]

Nevertheless, BoT's February 1883 proposal appears to have met the views both of the Lancashire and Yorkshire wire drawers, and eventually, in August 1883, an Order in Council was passed which introduced the Standard Wire Gauge (SWG) making it the only legally recognized wire gauge in Britain.[118] The ISWMA felt that they could 'congratulate themselves upon having impressed the Board of Trade [with] the weight of their representations [and which] considerably modified the proposal of the Board in favour of the wire trade generally'.[119]

In comparing the various proposals made by the different groups between March 1882 and February 1883 the following picture emerges. The first BoT scale in April 1882 was virtually identical to the ACC March 1882 proposal, excepting the sizes finer than No. 35. The ISWMA's proposal of July 1882 was considerably different from the BoT's April 1882 proposal, particularly for the finer sizes (below No. 27), where the difference in diameters was of the order of two or three numbers on the respective gauges. The BoT's November 1882 proposal incorporated some of the ISWMA's proposed sizes for the larger numbers, but kept the finer sizes unchanged. Although the ISWMA responded to this by modifying their proposal in January 1883, the modifications were very slight and the diameters remained largely unchanged. The BoT's final proposal in February 1883, which would become the SWG, made significant changes over their 1882 proposals. The size differences between the BoT and ISWMA proposals were decreased considerably by this scale, however, the differences in the finer sizes – especially between

[117] *Ironmonger*, Feb 24, 1883, letters to the editor, p. 249-50 (emphasis in the original)
[118] *Ironmonger*, Mar 17, 1883, editorial p. 386; Letter by Thomas Hughes p. 392
[119] Stones, *Wire Industry*, 4.

No. 27 & 34 – remained. Table 4 shows the differences between the SWG and the ACC and ISWMA proposals.

(See Table 4, below) [120]

The events narrated above suggest that there was vociferous, often acrimonious, debate on the issue and that the various groups could not coordinate between themselves to agree on a single industry standard.[121] With the industry unable to resolve the issue by itself both groups sought an arbitrator. The state, through the Board of Trade, acted as the arbitrator between the rival groups and attempted to solve the coordination problem.

[120] *Notes & Sources to Table 4:* The measurements above, including the differences, are reported in 1000th of an inch. The SWG gauge of Aug 1833 is taken from BT 101/133, the ACC gauge of Mar 1882 from BT 101/114 and the ISWMA gauge of Jul 1882 from BT 101/116

[121] Numerous letters, articles and editorials in *Ironmonger* between 1880 and 1883

Table 4: Comparison of the Standard Wire Gauge (SWG) to the ACC and ISWMA proposals

Gauge Nos.	SWG *(1000th of an inch)*	Differences across gauges *(1000th of an inch)*		
		SWG & ACC	SWG & ISWMA	ACC & ISWMA
1	300	-	-	-
2	276	-0.4	0.6	10
3	252	-0.8	0.2	10
4	232	-0.8	0.2	10
5	212	-0.8	0.2	10
6	192	-0.8	0.2	10
7	176	-0.4	0.1	5
8	160	-0.4	-	4
9	144	-0.4	-0.1	3
10	128	-0.4	-0.2	2
11	116	-0.4	-0.1	3
12	104	-0.4	0.4	8
13	92	-0.4	0.2	6
14	80	-0.4	-	4
15	72	-	0.2	2
16	64	-	0.2	2
17	56	-	0.2	2
18	48	-	0.2	2
19	40	-	-	-
20	36	-	-	-
21	32	-	-	-
22	28	-	-	-
23	24	-	-0.10	-1
24	22	-	-0.10	-1
25	20	-	-0.10	-1
26	18	-	-0.10	-1
27	16.4	0.04	-0.06	-1
28	14.8	0.08	-0.12	-2
29	13.6	0.06	-0.14	-2
30	12.4	0.04	-0.16	-2
31	11.6	0.06	-0.14	-2
32	10.8	0.08	-0.12	-2
33	10	0.10	-0.10	-2
34	9.2	0.12	-0.08	-2
35	8.4	0.14	-0.06	-2
36	7.6	0.16	-0.04	-2
37	6.8	0.18	-0.02	-2
38	6.0	0.20	-0.05	-2.5
39	5.2	0.22	-0.08	-3
40	4.8	0.28	-0.07	-3.5

Competition, Coordination, and Negotiation

The initiative to establish a standard wire gauge in the 1870s came from the telegraph engineers. Subsequently, there were several different proposals for a uniform gauge that were under consideration. The STE had their own proposal by 1879, which the BoT was aware of, although the 'subject [was] not referred to [them]'.[122] The ACC committee itself considered numerous proposals, including several made by Harding, Hughes and others, before deciding upon Harding's scheme as its preferred wire gauge.[123] It is only after ACC's decision to recommend the Harding gauge to the BoT as the legal standard and BoT's subsequent actions to follow through this recommendation that the large wire makers cooperated to suggest their own standard gauge in 1882. Why did ISWMA oppose the ACC proposal? Why did the large manufacturers cooperate in the first place to form the ISWMA?

Towards the end of the 1870s, British wire industry was experiencing stagnation and stiff competition from foreign manufacturers, both in its domestic as well as overseas markets. German wire production nearly doubled between 1878 and 1882 and its exports of wire increased sevenfold during the same period. In contrast growth in British production and exports was quite modest (table 5). By the 1880s, German wire was outselling British wire in the international markets by a factor of two. English firms were losing market share in the North American, Russian, European and Australian markets. US manufacturers, such as Washburn & Moen and others, were able to meet domestic demand, whereas German and Belgian firms were outselling British wire in the other markets.[124] German wire was also being imported into Britain during this time and in one instance the British government placed an order for 1,000

[122] TNA, BT 101/76
[123] *Ironmonger*, Feb 25, 1882, p. 281
[124] *Ironmonger*, Jan 28, 1882 & Sep 7, 1878. US duties on British iron wire increased between 1860 and 1880; also Blake-Coleman, *Copper wire*, 212.

tons of 'strand' wire with a German firm 'due to its cheapness'.[125] Some British wire makers imported German iron rod to turn it into wire or purchased German wire to make wire products such as screws, needles, and piano wire. Rylands was forced to purchase German rods when firms such as Pearson & Knowles found it difficult to compete with German steel, rods and billets. At least five other wire-rods mills were reported to have been closed due to excessive German competition. German wire was also purchased by pin makers, netting weavers, rope makers, etc. sometimes in preference over English wire of the same price. [126]

Table 5: Relative growth of wire exports

Year	Germany (tons)*	UK (tons)
1877	32,398	51,092
1878	56,644	43,480
1879	76,710	37,259
1880	104,775	59,180
1881	159,416	75,129
1882	227,000	86,686

Source: Ironmonger, May 5, 1883
* The figures for Germany also include the export of wire rods

German heavy industry, protected by tariffs, was dumping iron and steel products, such as wire and rails, in international markets.[127] German rail prices in their domestic markets exceeded costs by 24 percent, but export prices were only 92 percent of costs. Low price of raw materials in Germany (and America) contributed to low steel prices. Also, German efficiency in iron and steel manufacturing increased relative to Britain

[125] *Ironmonger*, Jan 3, 1880, p. 28; Sep 7, 1878, p. 929-30
[126] Janes, *Rylands of Warrington: 1805-1955*, 63.; *Ironmonger*, Oct 23, 1880, p. 489; Nov 3, 1883, p. 651; , June 7, 1879, p. 763
[127] See Wengenroth, *Enterprise and technology*.

during the latter part of the nineteenth century. The resultant lower steel price in Germany vis-à-vis Britain meant that German firms found this policy of dumping steel and wire products overseas to be sustainable.[128] Transportation costs were comparatively lower in Germany (and Belgium and Holland). Railway freight rates in Britain were more than twice those of Germany, Holland and Belgium. Cost of Belgian wire in London was lower than wire from the Midlands.[129]

German firms were operating at or near full capacity compared to English firms whose domestic capacity had enlarged faster than demand.[130] In addition, labour productivity was also considered to be higher in Germany compared to Britain. The cost of producing a No. 20 iron wire from a No. 4 rod was 70 shillings per ton in Germany compared to more than 130 shillings per ton in England: lower wages, longer working hours and cheaper raw material were proposed as the primary reasons for the cost differential.[131] When Thewlis Johnson and George Bedson (of Richard Johnson and Nephew) visited the wire works of Felten and Guilleaume's wire works in Germany in 1878, Johnson was 'perturbed when he compared the financial structure of Guilleaume's wire production with his own at Bradford'. A similar report was made when another British manufacturer visited several Westphalian wire works and reported that labour costs were about 40 to 50 percent lower in Germany.[132] The overall picture of the British wire trade that emerges is one of 'slackening demand and increasing competition [with the wire trade in a] state of depression'.[133]

[128] Allen, 'Iron and Steel', 920, 928-29 and Table 8.
[129] Bell, *UK Iron Trade*, 108.; *Ironmonger*, June 7, 1879, p763, cost of Belgian wire calculated on the Thames on f.o.b. basis.
[130] *Ironmonger*, Nov 4, 1882, p. 635; May 5, 1883, p. 626
[131] *Ironmonger*, Oct 4, 1878, p. 514
[132] Seth-Smith, *Richard Johnson & Nephew*, 78.; *Ironmonger*, Apr 27, 1878, p. 305
[133] *Ironmonger*, Jul 31, 1880

Technological improvements, such as continuous wire drawing, newer methods of annealing and treating wire, and so on, do not appear to have improved production efficiencies appreciably to the extent of allowing British firms to become competitive vis-à-vis the German firms. The British firms were consequently forced to rationalize production costs. Early in 1878, several large wire makers formed the Steel Wire Manufacturers Association with the objective of setting a standard wage scale for wire workers. This association met with the wire workers union with a proposal of reduced wages. This resulted in industrial action by the wire workers in many firms such as Whitecross, Rylands, and others towards the end of 1878. However, the strikes could not be sustained due to lack of union funds and by early 1879 they were called off, with many of its members returning to work at reduced wages. A strike of wire drawers at the Bradford works of Richard Johnson and Nephew in December 1878 in protest of wage reductions was soon disbanded with virtually all wire drawers indicating their desire to return to work. Not all workers could be reinstated, however, and those that did return had to accept reduced wages.[134] A second round of wage reductions was attempted again in 1883, with the same results: a general strike of wire workers, followed by a return to work in 1884 at substantially reduced wages.[135] Thus, the manufacturers 'were fortunate [in reducing wages] without which they [would have had to close their mills on] account of the severity of Westphalian competition.'[136] Wire makers also sought to reduce input costs by substituting cheaper, sometimes lower quality, German wire rods to make wire and wire products. Even so, underselling

[134] Seth-Smith, *Richard Johnson & Nephew*, 79-80.; also Bullen, *Drawn together*, 13.; various issues of *Ironmonger* between Sep 1878 and April 1879

[135] Ironmonger, May 24, 1884, p. 711; Stones, *Wire Industry*, 5.; Bullen, *Drawn together*, 14-16.

[136] *Ironmonger*, Apr 1880

was reportedly common, creating an intensely competitive domestic market environment.[137]

Apart from cost rationalization, some firms followed the strategy of diversification. The firms of Edelston & Williams and Cornforth, makers of iron wire, began manufacturing steel wire for pianofortes – the traditional domain of firms such as Horsfall – in addition to making steel wire for ropes, cables, picture cords, etc.[138] Other firms such as Nettlefolds began amalgamating or merging with other, smaller firms producing screws in Smethwick (Birmingham), Stourport (West Midlands), Manchester, etc. with a view to eliminating competition. This increased concentration, reduced overcapacity and provided Nettlefolds with an assured market for its wire products as well as an assured supply of inputs for its screw-making business.[139] Apart from individual firm strategies, co-operative action by manufacturers was actually limited. The larger manufacturers - Rylands, Whitecross, Nettlefolds, Edleston Williams, Richard Johnson & Nephew, Hibell & Co., etc. – had formed the Steel Wire Manufacturers in 1878 to establish a common wage list. However, as soon as the wage cuts were made the association is known to have disbanded.[140] The wire industry did not form combinations or cartels to tide over this period of stagnant demand and high competition, such as those seen in the German industry, the US industry in 1894-95 or even those that were formed in related British industries, such as pin manufacturing.[141] There is no evidence of any other industry association during this period until the

[137] *Ironmonger*, Jan 22, 1881, p. 110
[138] *Ironmonger*, June 7, 1879, p. 763
[139] *Ironmonger*, Apr 9, 1881, p. 511; Nov 3, 1883, p. 650-51; May 24, 1884, p. 711
[140] Seth-Smith, *Richard Johnson & Nephew*, 83.; Bullen, *Drawn together*, 14.
[141] Jones, 'Price associations and competition'.; Warner, John Dewitt, *Steel & Wire*, Letters, No. 12, New England Free Trade League. There is mention of an association attempted in the 1860s, Stones, *Wire Industry*, 1.; Bullen, *Drawn together*, 14. mentions an industry organization dealing with export prices around 1867; it is unclear how these operated and the purposes for which they were formed.

ISWMA was formed in 1882, primarily to deal with the issue of the standard wire gauge.

In the context of this competitive environment, we can now evaluate the failure of ACC and ISWMA to agree on a single industry standard. The main objection of ISWMA to the ACC and other proposals was that the difference in the sizes proposed by the various gauges implied that the numbers to which wire was normally drawn would have to be altered. For instance, switching from a Lancashire gauge to the ACC gauge involved changing the numbers in thirteen of the fourteen sizes between Nos. 6 and 18 of the existing gauge. It is this change in numbers rather than the differences in the length of the diameters *per se* which increased the cost of producing wire. Hughes argued that as 75 percent of the thick wire is drawn according to the Lancashire gauge, the result of switching to the ACC gauge would be 'ruination' for the wire trade and would mean 'more serious complications with their workpeople'.[142] This assessment is evident from the cost increases he estimated (for sizes up to No. 18) which were substantial, especially when compared to the price of wire for each size (see table 6). He further argued that iron wire finer than size 20 was not seriously affected by the ACC/Harding gauge as finer iron wire was mostly drawn in Yorkshire to the gauge, which was already in use by Yorkshire firms such as Harding & Sons: implying that there was little difference between the existing Yorkshire gauges and the ACC/Harding gauge. His analysis further concluded that copper and brass wire of finer size would be equally affected, as the cost of production of sizes finer than 30 could increase by as much as £18 to £56 per ton. Considering the price of copper wire around 1880 was a little

[142] *Ironmonger*, Mar 25, 1882, letter by Thomas Hughes

more than 9s per pound or £84 per ton, this was a substantial increase in production cost.[143]

Table 6: Impact of switching from Lancashire wire gauge to Harding's proposed wire gauge[1]

Lancashire Wire Gauge No.	Harding Gauge No.	Increase in cost of production *(shillings per ton)*	Reference Price *(shillings per ton)*[2]
6	*7*	10	4
7	*8*	5	4
8	*9*	10	5
9	*10*	15	5
10	*10*	-	5
11	*12*	10	6
12	*13*	10	7
13	*14*	10	8
14	*15*	15	8
15	*16*	15	10
16	*17*	20	13
17	*18*	25	17
18	*19*	25	18

[1] The table has been reproduced from estimates reported by Thomas Hughes in *Ironmonger*, Mar 25, 1882.
[2] The reference prices mentioned here are from a price list from 1884 which was reproduced in .

The dominant wire manufacturers fiercely objected to the ACC gauge becoming the legal industry standard. The memorial sent by the ISWMA to the BoT in July 1882 stated that switching to that gauge would give 'the foreign manufacturers an additional advantage over the English manufacturers' which they would be unable to either absorb or pass on to

[143] Price of copper wire from Blake-Coleman, *Copper wire*, 230-32; *Ironmonger*, Mar 25, 1882, letter by Thomas Hughes; see also Mar 5, 1881, p. 304-306 for a similar analysis by an anonymous correspondent

buyers.[144] The switching of standards also implied a renegotiation of wages with the wire workers. Sheffield manufacturers complained that the ACC gauge would involve 'arranging new prices with the workmen and warehousemen'.[145] Thus, the switchover was likely to result in both a short as well as a longer term impact on the competitiveness of the British manufacturers. Consequently, the ISWMA proposed their own gauge which was different from the ACC gauge in that the sizes between 1 and 20 in the ISWMA proposal were smaller compared to the ACC proposal (see table 4). The large manufacturers argued that the ACC gauge would require them to draw the wire to a smaller number just to maintain the same diameter of wire. This would increase the number of draws and therefore the cost of wire. They argued that as the thicker sizes constituted the bulk of the iron wire exported from Britain, the result of legalizing the ACC standards would be to 'place the English wire trade at a material disadvantage at a time it is suffering severely from foreign competition'.[146] In effect, the ISWMA proposal was to get the iron and steel wire and brass and copper wire manufacturers to agree to accept Lancashire sizes up to number 20 thick wire and all the Lancashire manufacturers to accept finer sizes from number 21 onwards to be set by the Birmingham and Yorkshire manufacturers of fine wire.[147] The February 1883 gauge, which eventually became the legal standard, considerably reduced the differences between those that ISWMA were demanding and those that BoT (and ACC) had originally proposed (table 4).

The fundamental question is why did the large manufacturers cooperate to form the ISWMA in the first instance? Until 1882, the large manufacturers did not have any reason to set a single or common

---

[144] TNA, BT 101/116, letter to the Board of Trade dated Jul 7, 1882
[145] *Ironmonger*, Dec 2, 1882, p. 749
[146] TNA, BT 101/116, letter to the Board of Trade dated Jul 7, 1882
[147] *Ironmonger*, Mar 25, 1882, letter by Thomas Hughes

industry standard. They dominated the industry and remained competitive, even with increased German exports and imports of cheaper wire, by reducing wages and rationalizing labour. Some, such as Richard Johnson and Nephew, rationalized production techniques to remain competitive. Others, such as Nettlefolds, remained competitive by amalgamating or acquiring smaller firms, eliminating competition and concentrating production facilities. Still others, such as Rylands, decreased input costs by purchasing cheaper German rods to draw wire and wire products. Nor is there any evidence that the German wire makers were able to compete more effectively due to standardized wire sizes. It was their cost structures and the dumping strategy they followed which gave them the edge over the British wire makers.

While individual producers such as Thewlis Johnson and Thomas Rylands were involved in discussions with the telegraph engineers regarding standard wire sizes, until a legal gauge seemed imminent there is no evidence of cooperation between the large wire makers on the issue of setting a single industry wide standard. The timing suggests that it was formed to prevent the industry from being locked into what the large wire makers considered to be the 'wrong wire sizes'. The ISWMA served as a lobby group to oppose the ACC, and to a lesser extent the STE, proposals and to influence the BoT to accept the sizes that most suited those manufacturers represented by the ISWMA. The specific objective with which the ISWMA was formed is testified by the fact that as soon as this 'crisis' was over, it was disbanded on June 21, 1884. It would be 1889 before the large manufacturers cooperated again to form a different association, this time to consider the Railway Act of 1888.[148] Thus, before 1882 it suited the manufacturers to produce wire using their own existing gauges. However, once a legal gauge based on the ACC proposal seemed imminent, the manufacturers considered it better to have the

[148] Stones, *Wire Industry*, 5-6.

single industry standard of their preference rather than the ‘wrong’ sizes proposed by the ACC.

Wire Industry and Gauges After 1883

Modern wire sizes are expressed using standardized gauges, such as the American Wire Gauge or the Metric Wire Gauge. Products derived from wire, such as hypodermic needles, also use gauges to express sizes rather than measurements such as inches or millimetres.[149] The legalization of the SWG was intended to remove the confusion surrounding the wire sizes and the industry largely discontinued the use of older gauges such as the BWG. Vestiges of the old gauges remained in the use of the *term* BWG, which was often used interchangeably with the SWG or the Imperial Wire Gauge (as the SWG also became known). One engineering firm from Birmingham advertised the legal SWG sizes as ‘Imperial Standard Wire Gauge, B.W.G.’; signifying that many in the trade continued to associate wire gauges with the old Birmingham Wire Gauge, although they used the new legal gauge sizes.[150] When the BoT revisited the subject of gauges in the early twentieth century, they encountered a variety of *terms* in use: BWG, SWG, IWG (Imperial Wire Gauge), or LSG (Legal Standard Gauge).[151] Notwithstanding this, the legal gauge defined in 1883 was the gauge that was ‘generally used in the wire trade’.[152]

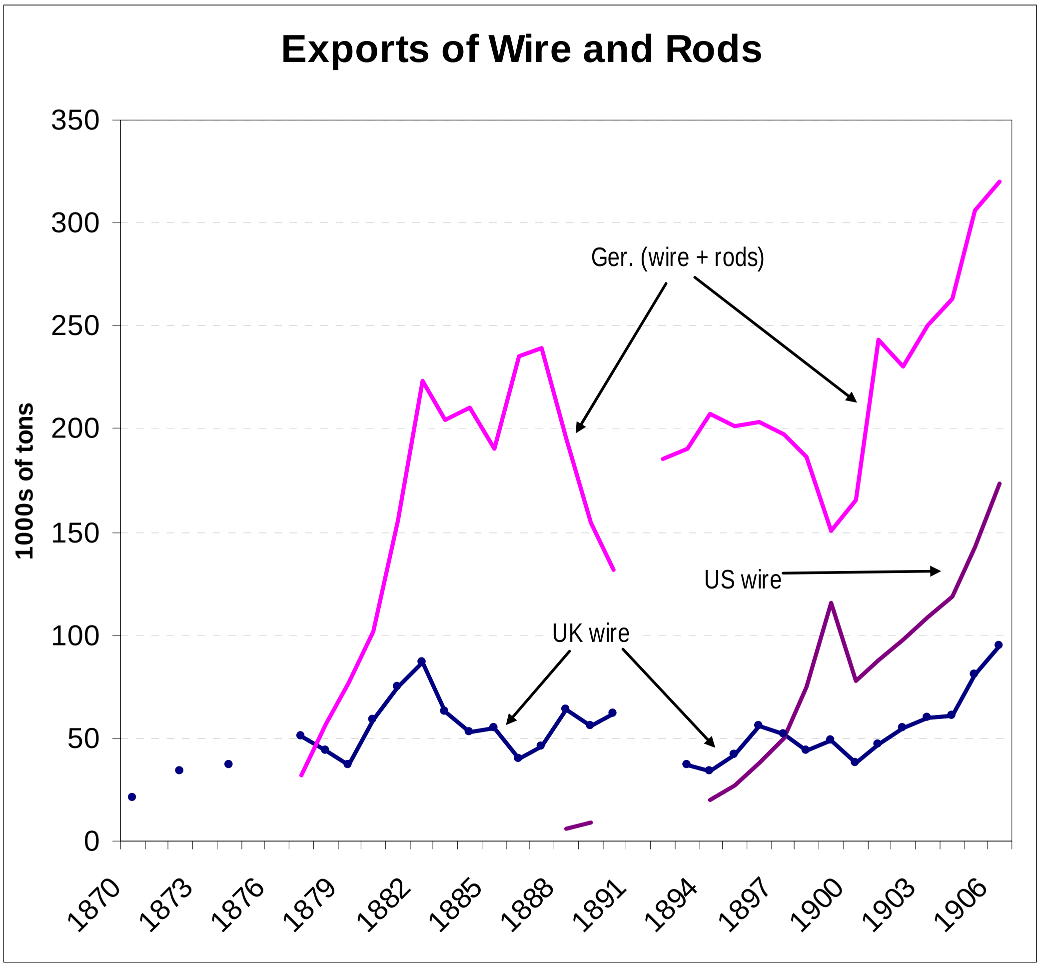
Did standardizing the wire gauge assist the British industry to become more competitive after 1883? Figure 3 shows the trends in the exports of wire products from Britain, Germany and the US between 1870 and 1906. We notice that British exports of wire remain more or less

[149] Pöll, ‘The story of the gauge’.
[150] TNA, BT 101/537 and BT 101/538
[151] TNA, BT 101/943
[152] TNA, BT 101/943, letter from the Deputy Warden of Standards.

stable throughout this period, except for a short increase during 1880-1882 and after 1900. In contrast, exports of German wire after 1880 and that of US wire after 1898 overtook those from Britain. German exports until 1887 comprised primarily of drawn wire, whereas the export of rods comprised a major proportion of their exports after this period. US exports continue to be dominated by drawn wire and have a much smaller proportion of wire rods (not included in the chart). British exports, shown here, are primarily comprised of drawn wire. Thus, standardizing the wire sizes did not make the British manufacturers any more competitive in relation to German manufacturers and the origins of German competitiveness lay in other factors such as cheaper input costs and overall efficiency. A trade report from 1886 stated that ‘the superiority of the Germans, owing to their long hours of work and low wages, is such that English manufacturers have in many cases ceased to compete with them, and find it more to their advantage to buy than to make wire'.[153] Although the British industry declined in competitiveness during this period, many of the large wire manufacturers such as Rylands, Nettlefolds, Richard Johnson, etc. continued to dominate wire manufacturing well into the twentieth century. Either way, standardizing the wire sizes did not appear to have given a strategic edge to the British wire makers to reinstate their previous internationally competitive position.

Figure 3:

Source: Leslie Thomas. *The development of wire rod production*. London, 1949.



[153] *Ironmonger*, Oct 30, 1886, p. 244-45

Conclusion

This paper has shown how, when rival industry groups could not agree on a 'one-size-fits-all' standard, a compromise solution emerged after the state became involved as an arbitrator in the dispute. The solution, in the form of a *de jure* standard, was sought to replace the various *de facto* standards that had emerged over time. The interesting aspect of this case is that the *de jure* standard was not a mandatory one, but an authoritative standard: a standard of last resort, such as that sought by engineers like Holtzapffel and Clark. This has some broad implications with regards to standardization and measurements in industry.

Firstly, the dynamic between the rival industry organizations – the ACC and ISWMA –, and the state brings into focus competitive strategy and lock-in effects. It is worthwhile reflecting upon the possibility that multiple standards can lead to lock-out effects (locking out competition), just as uniform standards can lock-in industries into fewer products or technologies. This may be pertinent in industries with weak entry barriers and high network effects. Incumbent firms – both producer or buyer firms – could actually prefer multiple standards in this scenario. Shifts in buyer preferences could initiate a move towards uniformity and the potential for lock-in effects. If different groups within the industry disagree on the nature of standards this would lead to coordination failure. The manner in which this is resolved will depend upon issues such as the exact nature of lock-in effects, cost of coordination and switch-over, relative bargaining power of the groups involved, the competitive environment and the political economy of industrial policy.

Secondly, the voluntary but authoritative *de jure* standard calls into focus the efficiency (and welfare) effects of uniform standards. A voluntary *de jure* standard implies use of other standards, even if their use is limited to occasional or marginal applications. In our case of the wire industry, a majority of the wire manufacturing after 1883 occurred with the use of the SWG; however, it is likely that other sizes were used for unusual or one-off contracts. The introduction of the SWG did not make the old gauges illegal. In fact, it may have been necessary for the industry to use non-SWG sizes to capture the market for specialized, non-standardized or customized wire products. The issue here is whether this arrangement was more efficient than having a uniform but mandatory standard. What were the efficiency gains (or losses) from voluntary standards versus mandatory standards? Should *de jure* standards be voluntary or mandatory? Are *ex-ante* (*de jure*) standards better than *ex-post* (*de facto*) standards? While these questions still remain open, the history of wire gauges indicates that authoritative but voluntary standards can encourage competition within the legal gauge, and yet retain the flexibility to use other standards for specialized or customized applications.[154]

Finally, the authoritative nature of the *de jure* standard brings into focus questions of the precision and accuracy of wire sizes measured using devices such as gauge. The key issue here is that the legal wire gauges became authoritative not because the wire sizes could be defined and measured with greater precision (i.e. wires drawn to a standard gauge would show smaller errors in repeated measurement), but because a majority of the groups agreed that those sizes were more desirable. This desirability aspect includes many non-technical, economic and social factors; the measurements validated by the gauges are more 'accurate' in that sense. Clearly, there was no true measure that these wires must accurately fit: no natural constants for wire sizes. But there were, in this industry, more desirable sizes and less desirable sizes. The facility to produce wire in desirable sizes was not only a technical issue, but also involved negotiation and agreement about the measurements that wires

[154] Koski and Kretschmer, 'Standards and competition'., p. 93

should fit. This notion of desirable sizes, of accurately producing the sizes that were wanted by both users and producers, was ultimately important in converging towards uniform standards.

References

Adams, C A. "Industrial Standardization." In *The Annals of the American Academy of Political & Social Science: Industries in Readjustment*. Philedelphia, 1919: 289-299.

Aitken, W C. "Brass and brass manufactures." In *The resources, products and industrial history of Birmingham and the Midland hardware district*, edited by Timmins, Samuel. London: Robert Hardwicke, 1866: 225-380.

Alder, Ken. "Innovation and amnesia: Engineering rationality and the fate of interchangeable parts manufacturing in France." *Technology and Culture* 38, no. 2 (1997): 273-311.

---. "Making things the same: Representation, tolerance and the end of the ancien régime in France." *Social Studies of Science* 28, no. 4 (1998): 499-545.

Allen, Robert C. "International Competition in Iron and Steel, 1850-1913." *The Journal of Economic History* 39, no. 4 (1979): 911-937.

Antonelli, Christiano. "Localized technological change and the evolution of standards as economic institutions." *Information Economics and Policy* 6, no. 3-4 (1994).

Arthur, W Brian. "Competing technologies, increasing returns, and lock-in by historical events." *The Economic Journal* 99, no. 394 (1989).

Axelrod, Robert, Will Mitchell, Robert E Thomas, D Scott Bennett and Erhard Bruderer. "Coalition formation in standard-setting alliances." *Management Science* 41, no. 9 (1995): 1493-1508.

Bell, Lowthian. *The iron trade of United Kingdom*. London: British Iron Trade Association, 1886.

Besen, Stanley M. and Joseph Farrell. "Choosing How to Compete: Strategies and Tactics in Standardization." *Journal of Economic Perspectives* 8, no. 2 (1994): 117-131.

Blake-Coleman, B C. *Copper wire and electrical conductors - The shaping of a technology*. Reading: Harwood Academic Publishers, 1992.

Brackenborough, Susie, Tom Mclean and David Oldroyd. "The emergence of discounted cash flow analysis in the Tyneside coal industry c1700-1820." *British Accounting Review* 33 (2001): 137-155.

Bullen, Andrew. *Drawn together: One hundred and fifty years of wire workers' trade unionism*, 1992.

Carnevali, Francesca. "'Crooks, thieves and receivers': transaction costs in nineteenth-century industrial Birmingham." *Economic History Review* 57, no. 3 (2004): 533-550.

Chattaway, C. "Arbitration in the Foreign Corn Trade in London." *The Economic Journal* 17, no. 67 (1907): 428-431.

Clark, Latimer. "On the Birmingham wire gauge (Paper Presented to the British Association in 1867)." *Journal of the Society of Telegraph Engineers* 7 (1878): 332-335.

---. "On the Birmingham wire gauge (Paper presented to the British Association in 1869)." *Journal of the Society of Telegraph Engineers* 7 (1878): 336-344.

Connor, Robert Dickson. *The weights and measures of England*. London: HMSO, 1987.

Cowan, Robin. "Nuclear power reactors: A study in technological lock-in." *The Journal of Economic History* 50, no. 3 (1990).

Cusumano, Michael A, Yiorgos Mylonadis and Richard S Rosenbloom. "Strategic maneuvering and mass-market dynamics: The triumph of VHS over Beta." *Business History Review* 66, no. 1 (1992).

Dane, E Surrey. *Peter Stubs and the Lancashire hand tool industry*: John Sherratt & Son, 1973.

David, Paul A and Shane Greenstien. "The economics of compatibility standards: An introduction to recent research." *Economics of Innovation and New Technology* 1 (1990): 3-41.

David, Paul A. "Clio and the economics of QWERTY." *The American Economic Review* 75, no. 2 (1985): 332-337.

Dickinson, H W and Henry Rogers. "Origin of gauges for wire, sheets and strip." *Transactions of the Newcomen Society* 21 (1943): 87-98.

Dutton, H I and S R H Jones. "Invention and innovation in the British pin industry, 1790-1850." *Business History Review* 57, no. 2 (1983): 175-193.

Farrell, Joseph and Garth Saloner. "Standardization, compatibility, and innovation." *Rand Journal of Economics* 16, no. 1 (1985): 70-83.

Ferguson, Robert B. "The adjudication of commercial disputes and the legal system in modern England." *British Journal of Law and Society* 7, no. 2 (1980): 141-157.

Fleischman, Richard K and Richard H Macve. "Coals from Newcastle: an evaluation of alternative frameworks for interpreting the development of cost and management accounting in Northeast coal mining during the British Industrial Revolution." *Accounting and Business Research* 32, no. 3 (2002): 133-152.

Floud, R C. "The adolescence of American engineering competition, 1860-1900." *The Economic History Review* 27, no. 1 (1974): 57-71.

Forrester, R B. "Commodity Exchanges in England." *Annals of the American Academy of Political and Social Science* 155, no. 1 (1931): 196-207.

Gambles, Anna. *Protection and politics: conservative economic discourse 1815-1852*: The Royal Historical Society, 1999.

Gooday, Graeme J N. "The morals of energy metering: Constructing and deconstructing the precision of the Victorian electrical engineer's ammeter and voltmeter." In *The values of precision*, edited by Wise, M Norton. Princeton, NJ: Princeton University Press, 1995.

Gordon, Robert B. "Who turned the mechanical ideal into mechanical reality?" *Technology and Culture* 29, no. 4 (1988): 744-78.

Griffiths, Herbert W. *Iron and steel manufacturers of Great Britain*. London, 1883.

Hatcher, John. *The history of the British coal industry (Volume 1: Before-1700)*. Oxford: Clarendon Press, 1993.

Holtzapffel, Charles. *Turning and mechanical manipulation - Vol. 2*. London, 1847.

Hounshell, David A. *From the American system to mass production 1800-1932 : the development of manufacturing technology in the United States.* Baltimore; London: John Hopkins University Press, 1984.

Hughes, Thomas. *The English Wire Gauge*. London, 1879.

Hunt, Bruce J. "The ohm is where the art is: British telegraph engineers and development of electrical standards." *Osiris* 9 (1994): 48-63.

Janes, Herford. *Rylands of Warrington: 1805-1955*: Harley Publishing Co., 1956.

Johnson, Paul. "Market Disciplines." In *Liberty and Authority in Victorian Britain*, edited by Mandler, Peter. Oxford: Oxford University Press, 2006: 203-223.

Jones, S R H. "Price Associations and Competition in the British Pin Industry, 1814-40." *The Economic History Review* 26, no. 2 (1973): 236-53.

Katz, Michael L and Carl Shapiro. "Network Externalities, Competition and Compatibility." *The American Economic Review* 75, no. 3 (1985): 424-440.

Kindelberger, Charles. "Standards as public, collective and private goods." *Kyklos* 36 (1983).

Koski, Heli and Tobias Kretschmer. "Entry, standards and competition: Firm strategies and the diffusion of mobile telephony." *Review of Industrial Organization* 26 (2005): 89-113.

---. "Survey on competing in network industries: Firm strategies, market outcomes, and policy implications." *Journal of Industry, Competition and Trade* 4, no. 1 (2004): 5-31.

Laman, N K. "The Development of the wire-drawing industry." *Metallurgist* 3, no. 6 (1959): 267-270.

Landes, David S. "Watchmaking: A case study in enterprise and change." *Business History Review* 53, no. 1 (1979): 1-39.

Lean, Charles. "Wire drawing and steel wire, and its uses." In *The resources, products and industrial history of Birmingham and the Midland hardware district*, edited by Timmins, Samuel. London: Robert Hardwicke, 1866: 591-595.

Mallock, H and W H Preece. "On a new telegraph wire gauge." *Journal of the Society of Telegraph Engineers* 1 (1872): 79-83.

Metcalfe, J S and Ian Miles. "Standards, selection and variety: An evolutionary approach." *Information Economics and Policy* 6, no. 3-4 (1994).

Pöll, J S. "The story of the gauge." *Anaesthesia* 54, no. 6 (1999): 575-581.

Pollard, Sidney. "Capitalism and rationality: A study of measurements in British coal mining, ca. 1750-1850." *Explorations in Economic History* 20, no. 1 (1983): 110-129.

Romer, Paul M. "Endogenous technological change." *The Journal of Political Economy* 98, no. 5-Part 2 (1990): S71-S102.

Rosenberg, Nathan. "Technological change in the machine tool industry, 1840-1910." *Journal of Economic History* 23, no. 4 (1963): 414-443.

Saul, S B. "The market and the development of the mechanical engineering industries in Britain, 1860-1914." *The Economic History Review* 20, no. 1 (1967): 111-130.

Searle, G R. *Morality and the market in Victorian Britain*. Oxford: Clarendon Press, 1998.

Seth-Smith, Michael. *Two hundred years of Richard Johnson & Nephew*. Manchester: Richard Johnson & Nephew Limited, 1973.

Sinclair, Bruce. "At the turn of the screw: William Sellers, the Franklin Institute, and a standard American thread." *Technology and Culture* 10, no. 1 (1969): 20-34.

Smith, J Bucknall. *Wire, its manufacture and uses*. London & New York: John Wiley and Sons, 1891.

Stones, Frank. *The British Ferrous Wire Industry*. Sheffield: J W Northend Limited, 1977.

Swann, Peter, Paul Temple and Mark Shurmer. "Standards and trade performance: the UK experience." *The Economic Journal* 106, no. 438 (1996).

Teece, David J and Edward F Sherry. "Standards setting and antitrust." *Minnesota Law Review* 87, no. 6 (2003).

Thomas, Leslie. *The development of wire rod production*. London, 1949.

Walker, C V. "On the unit of the Birmingham Wire Gauge." *Journal of the Society of Telegraph Engineers* 7 (1878): 215-223.

Wengenroth, Ulrich. *Enterprise and technology: The German and British steel industries, 1865-1895*. Translated by Tenison, Sarah Hanbury: Cambridge University Press, 1994.

White, Francis. *Commercial and trades directory of Birmingham, Vol. 2*. Birmingham, 1875.

Whitworth, Joseph. *Papers on mechanical subjects*. London: E&F N Spon, 1882.

LONDON SCHOOL OF ECONOMICS
DEPARTMENT OF ECONOMIC HISTORY

WORKING PAPERS IN: THE NATURE OF EVIDENCE: HOW WELL DO “FACTS” TRAVEL?

For further copies of this, and to see other titles in the department’s group of working paper series, visit our website at:
http://www.lse.ac.uk/collections/economichistory/

2005

2006

08/06: How The Mind Worked: Some Obstacles And Developments In The Popularisation of Psychology
Jon Adams

09/06: Mapping Poverty in Agar Town: Economic Conditions Prior to the Development of St. Pancras Station in 1866
Steven P. Swenson

10/06: "A Thing Ridiculous"? Chemical Medicines and the Prolongation of Human Life in Seventeenth-Century England
David Boyd Haycock

11/06: Institutional Facts and Standardisation: The Case of Measurements in the London Coal Trade.
Aashish Velkar

12/06: Confronting the Stigma of Perfection: Genetic Demography, Diversity and the Quest for a Democratic Eugenics in the Post-war United States
Edmund Ramsden

13/06: Measuring Instruments in Economics and the Velocity of Money
Mary S. Morgan

14/06: The Roofs of Wren and Jones: A Seventeenth-Century Migration of Technical Knowledge from Italy to England
Simona Valeriani

15/06: Rodney Hilton, Marxism, and the Transition from Feudalism to Capitalism
Stephan R. Epstein

2007

16/07: Battle in the Planning Office: Biased Experts versus Normative Statisticians
Marcel Boumans

17/07: Trading Facts: Arrow's Fundamental Paradox and the Emergence of Global News Networks, 1750-1900
Gerben Bakker

18/07: Accurate Measurements and Design Standards: Consistency of Design and the Travel of ‘Facts’ Between Heterogeneous Groups
Aashish Velkar