Voluntary consensus standardisation in the British wire industry c1880

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Abstract:

In 1883, the British wire manufacturers were eventually able to agree on a standardised system of wire sizes that helped to resolve many of the agency issues plaguing the industry. Asymmetric information due to standardised sizes were the main source of these agency issues, leading to opportunistic behaviour. When faced with intense competition from German manufacturers, British firms had to overcome mutual rivalry and cooperate to agree on a negotiated standard. This was a political process that created consensus amongst firms. The 'public' standards voluntarily adopted by firms helped the industry survive into the twentieth century. In this essay, I argue that this mixed strategy of standardisation was what the industry 'got right'. Firms were allowed to use available economic and political institutions to reach consensus.

1. Introduction

In 1883, the British wire industry adopted a standard gauge to measure sizes of wire and wire products. Wire sizes were one of the indicators of the quality of wire products and wire gauges were the crucial technology that made such measurements possible. The standard gauge replaced more than the 40 different gauges that were in use in different parts of the country. The emergence of the standardised version of the gauge was the result of intense negotiation, acrimonious debate and reluctant compromise between rival manufacturers and users of wire products. In an industry characterised by horizontal and vertical specialisation, and widespread agency issues due to multiple quality standards, the entrenched interests of small and large firms prevented the introduction of a scientifically derived solution. The state acted as an arbitrator between rival interests as firms cooperated with potential competitors to prevent the industry from being locked into what each perceived to be the 'wrong' standards. The 1883 standard potentially solved many of the agency issues that firms faced in market transactions and very likely helped the industry to survive in the face of intense global competition.

In this essay, I argue that the cooperation between firms that led to the emergence of a voluntary consensus standard helped to overcome the agency issues that the industry faced. The consensus emerged out of the material politics of the market, that took into account the socio-cultural and economic aspects of wire production. The process involved producers, buyers as well as state agencies and resulted in a path-dependent solution that could not be anticipated *ex ante*. What they 'got right' in this standardisation episode was to let market discipline emerge through a political process, not through bureaucratic direction or a hands-off attitude of a laissez faire state.

These observations have several broad implications. Voluntary consensus standards are the result of what Farrell and Saloner (1988) describe as a mixed strategy by firms, wherein standardisation is the result of action through markets as well as formal standards committees. This process allows firms to cooperate and form standards alliances, whilst enabling them to use the most appropriate institutions to achieve consensus. Such institutions include formal standards organisations (e.g. ISO) or other state and quasi-state agencies (Austin and Milner, 2001). Langlois

(2007) considers standards alliances to be institutions, which enable smaller firms to compete with larger firms.

The case of the wire gauge also highlights a particular role of the state in the context of ensuring market discipline. The Victorian state at times played a conciliatory role, rather than imposing a bureaucratic discipline or letting untrammelled competition impose it's harsh discipline. Many Victorians did indeed see markets to be comprised of complex interactions between principles and agents, who often had conflicting duties and liabilities (Johnson, 2006). Market exchange and discipline was shaped not only by demand and supply, but also by value judgements about morality, equity and protection (against opportunism). In this context, the state viewed itself as more than a policeman, regulator or lawmaker. On occasion it 'felt itself bound to act fairly as arbitrator' between various stakeholders in the market.[1]

I will first discuss the broad historical context in which the standardisation of the British wire gauge occurred. In the rest of the essay, I will then draw out the salient features of this episode as they relate to the above discussion. The detailed case history has been described in (Velkar, 2009b), and I will draw upon these facts frequently to illustrate my arguments.

2. Standards and Victorian markets (c1860-1900)

Expansion of industrial activity in nineteenth century Britain was accompanied by changes in the organization of such activity. A growing proportion of output in many manufacturing sectors became factory-produced in Britain during this period. There was also increased regional specialization and concentration of manufacturing (Langton, 1984). Even so, a vast majority of the firms engaged in industrial activity continued to be small in size, indicating a coexistence of a range of different firm sizes - large enterprises employing hundreds of people as well as smaller, workshop based firms.[2] In fact, small firms also proliferated alongside large factories because of the widespread practice of subcontracting (Riello, 2008). Thus, greater specialization and division of labour coexisted with integration of activities as merchant-manufacturers emerged by combining activities from merchanting, financing and entrepreneurship to manufacturing. The persistence of workshops during the years of industrial expansion indicates that the scale and location of industrial activity, and its dispersion, depended upon the relative costs of organizing people, materials and information, and the shifts in those relative costs (Mokyr, 2002). Indeed, integration, agglomeration and specialization in a range of organizational forms created newer interdependencies and relied upon expanding networks of information and trust.

Consequently, industrial organizations in the nineteenth-century were confronted with several issues, such as the organization and management of expanding value chains, technological convergence and interdependence, the ability to generate competitive advantages, management and control of information, etc. Economic growth and the increasing sophistication of industrial activity in the nineteenth-century made the organization and management of complex value chains an important issue for British businesses. Specialization and agglomeration meant sorting out how the interdependent relationships between various firms along the value chains were to be coordinated. These considerations were particularly important in the case of heterogeneous industrial commodities, such as cotton, coal or wheat, but also in the manufacture and trade of manufactures such as wire products and textiles. Merchant-manufacturers were faced with decisions involving the organization of production, storage and transportation, quality testing and assurance, enforcement of contracts, distribution of products to dealer-merchants, etc. The patterns of interactions between firms, suppliers and customers, and across firms in an industry, lead to the creation of formal and informal organizations. Often, such organizations co-evolved alongside industry structures. Industry associations, exchanges, technical societies and institutes, etc. helped to give an industry its form, lobby power, and protection from outside competition, create and enhance social capital, and strengthen and complement market activities (Nelson, 1995) (Ville, 2007) (Merrett et al., 2008).

Expanding industrial activity was also intimately connected with technical changes, and the introduction of new technologies. Although, different organizational architectures emerged within industries, a convergence of technologies is discernible during the nineteenth-century. Technologies employed along vertical dimensions in different productive activities converged towards similar skills, techniques and facilities in a process of 'technological convergence' (Rosenberg, 1963). This was especially apparent in metalworking and machinery industries, which involved the cutting of metal into precise shapes and forms using a relatively small number of operations: turning, boring, drilling, grinding, drawing, etc.

Such convergence had two implications. First, they created complementarities and interdependencies between different firms, particularly in industries with higher degrees of specialization (Rosenberg, 1976). This made the governance issues especially important as organizational interdependencies had to be managed alongside technological ones. Second, technological convergence reinforced the need for a given firm to develop new knowledge, new skills and new firm capabilities synchronous to other firms. Many of these new skills and capabilities developed alongside traditional or artisanal skills and shaped the manner and extent to which technologies matured (Gordon, 1988) (Alder, 1998) (Mokyr, 1992).

Economic and industrial growth, coupled with dynamic organisations and industrial structure, presented information and coordination problems for firms and business groups. Standardisation was one of the strategies that firms adopted to manage these issues. For manufactured products there was a gradual, but definite, move towards interchangeability that involved 'making things the same'. The development of the techniques of interchangeable manufacturing may be traced to the state armouries of eighteenth-century France. Such techniques were further refined and effectively 'reinvented' as the American system of manufacturing (Alder, 1997) (Alder, 1998) (Saul, 1967) (Hounshell, 1984) (Musson and Robinson, 1960) (Musson, 1990). Interchangeability depended upon standardised design and specification in addition to standardised machining techniques and tools. This is what gave the products the 'sameness' quality.[3]

While such convergence helped firms to address a host of information and coordination problems, this was but one of the forms of standardisation that dotted the nineteenth-century landscape. Apart from sameness, businesses depended upon the ability of standards to distinguish between products. This was particularly apparent in situations where a range of products and commodities were exchanged. Businesses had to make distinctions between products that were close substitutes whilst ensuring individual products retained their sameness – after all, no business sold, purchased or distributed a single product. The Railway Clearing House, for instance, grappled with the unenviable task of distinguishing between different goods and passengers. Its General Classification of Goods described thousands of separate items within various classes and filled a 129-page book (Bagwell, 1968). Commodity exchanges that introduced quality grading systems for internationally traded commodities such as wheat or cotton dealt with similar issues: how to standardise goods so that they could be distinguished from other similar looking goods (Olmstead and Rhode, 2003) (Velkar, 2009a).

But for many manufactured commodities, there were no 'clearing houses' that effectively and reliably distinguished between close substitutes. Manufacturer's marks and brands was one way of resolving the sameness-distinctiveness dilemma, and the trademarks legislation of the 1860s and 1870s was intended to do just that. Even so, not all trade and exchange issues could be resolved by marking and branding. Firms in vertically and horizontally specialised industries had to address two key issues of quality. How to ensure that other firms in the industry manufactured products using uniform quality standards, such that it reduced search costs in market exchanges (i.e. non-customised contracts)? How effectively could such standards distinguish between poor quality and intentional fraud?

Caveat emptor: 'let the buyer beware'

By the late nineteenth century, the dominant legal doctrine was that commercial contracts should be entered upon in 'good faith' and that the buyer would not be accorded legal protection in the event of a bad bargain; i.e. paying a higher price for a poor quality substitute. However, legal protection would be extended to the buyer against deliberate fraud or misrepresentation.

> seller…ought to disclose unusual facts known to him, but not known to the other party to the transaction…good faith forbids either party, by concealing what he privately knows, to draw the other into a bargain, from his ignorance of that fact and his believing the contrary.[4]

Legislation protected the buyer in instances where visual examination of goods was insufficient to highlight its defects, such as incorrect measurements. If the use of false measurements, or giving 'short measure', was not evident from the buyer's due vigilance, but depended upon the sellers assurance, then legislation tended to protect the buyer's reliance on the seller. Such legal principles could be upheld provided there were standards that were widely adopted or legally defined that the courts could use to distinguish between fraud and poor quality. The statutes could provide protection against fraud, but not other means of opportunistic behaviour. It did not, and could not, solve all problems of asymmetric information in market exchanges.

Quality conventions and standards were required to overcome problems of asymmetric information that potentially led to a bad bargain.

Material politics and untrammelled markets

Establishing a standard often meant replacing or rationalising from the several *de facto* market standards that had emerged. Whose or which standard should be the legal standard or the universally adopted industry standard? The establishment of standards was motivated by economic concerns of contract and coordination between firms. And although standards have a technological element in terms of their specifications, which particular standard prevailed sometimes depended upon the material politics of that market.

Often scientific ideals alone could not be brought upon to resolve this issue, but rather it was the 'network of trust' established between practioners and engineers that resolved the standardisation issues. Gooday (2004) shows this in his study of electricity meters and Hunt (1994) demonstrates this in the case of electrical resistance boxes. Daunton (2001) shows that the politics of consumption shaped the reliability of gas meters that validated the consumption of an 'invisible commodity'. The legal definition of a cubic foot of gas was insufficient to arbitrate between what consumers thought were reliable gas meters and what the utility companies insisted were meters of acceptable quality. On that occasion, the Board of Trade arbitrated the dispute between the consumers and producers. As I show in the following section, in the case of the wire industry, too, the standardisation solutions to transactional and contractual issues between firms, were steeped in the politics of wire manufacturing. They were shaped by how different groups conceived the market, the product, and the transactions between firms. The scientifically derived wire gauges were firmly rejected by producers to form the basis of an industry standard to distinguish between fraud and poor quality. The stalemate was not resolved until the Board of Trade acted as an arbitrator between the various groups proposing different standardisation solutions. What this industry 'got right' was that business firms were allowed to negotiate, cooperate, and voluntarily agree on an industry standard, prior to the state adjudicating and setting a *legal* standard to curtail fraudulent practices in the market. The rest of the essay shows why and how this occurred.

3. Standardising in the wire gauge

In the latter half of the nineteenth century, wire was virtually ubiquitous in its use; one contemporary writer listed no less than 25 distinct uses, including cable and telegraph wires; wire ropes employed for marine, mining, agricultural, engineering uses; manufacture of pins and needles, nails, rivets; etc. (Smith, 1891) Many of the industries using wire and wire products were located in the West Midlands, Lancashire and Yorkshire, that is, concentrated in the locations where wire was produced. In Birmingham there were about thirty-five pin manufacturers, seventy spectacle makers, forty screw manufacturers, and twenty musical instrument makers, all using a variety of wire products. Lancashire watchmakers used to purchase pinion wire from wire makers of Warrington and Manchester. Wire-netting and wire-rope products were also manufactured in the Midlands and around in Birmingham. Jewellers and brass and metal works used fine wire made from gold, silver, nickel, copper and brass. Several pianoforte manufacturers were located in Leeds and other locations in Yorkshire. Finer sizes of Yorkshire iron wire were also used for wool and cotton cards, and sieves (White, 1875) (Dane, 1973) (Landes, 1979) (Hughes, 1879).[5]

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 (Blake-Coleman, 1992). 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. Makers of fencing wire were other large users of wire products, while wire ropes were also used in mining operations (Seth-Smith, 1973); (Smith, 1891).

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 Brothers and Co. 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 (Smith, 1891). On the other end of the scale, were the smaller manufacturers of wire with far less capital and machinery and employing fewer people.

Estimates of market size for wire and wire products c1880 range from as low as 40,000 to 80,000 tons to as much as half a million tons a year (Bell, 1886); (Thomas, 1949). My own estimates, making a broad assumption that output per person between 1870 and 1890 was about 13-15 tons, suggest that domestic wire production c1881 was very likely to be between 120,000 and 140,000 tons (Table 1). The export of wire from the UK formed around 55-60 percent of the annual production around this time. 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.[6] In comparison, exports of wire from the UK around 1907 were 55,000 tons or about 25 percent of the total domestic production.

Table 1 here

The British wire industry developed a system of standard numbers to express the thickness of wires. Before the wire numbers were standardized c1880 each manufacturer or each wire-producing region used a different system of wire numbers, and hence different wire gauges. It was not unusual for these gauges to differ from one another such that wire ostensibly of the same number on any two gauges would actually differ in thickness when measured in *inches*. At first glance, this appears simply to be a matter of using more precise instruments to minimize measurement errors, which in turn would have solved the various agency issues due to non-standardisation.

But, there are an infinite number of possible wire sizes, each size different from the next size by an infinitesimal degree, and each size capable of being practically and very precisely measured. In this industry tensions arose when from this infinite set of sizes a finite number of sizes were to be selected and combined together to form a uniform set of sizes. The issue here was which was the most appropriate set of sizes that suited all various groups within the industry – buyers and sellers.

Entrenched interests of various buyer and producer groups resulted in a stalemate around c1880 with neither group willing to accept any other group's notion of reliable wire sizes. These interests stemmed from different incentives: for instance, the buyers desired sizes that enabled them to use wire products more effectively in their applications, whereas the producers desired sizes that economized their production costs. The stalemate – between producer associations, chambers of commerce and buyer associations – was overcome once the state was asked to intervene on behalf of the industry: the Board of Trade acted as an arbitrator between the various industry groups.

Multiple wire gauges and agency issues

Wire gauges used in nineteenth-century Britain were most likely introduced from Germany in the sixteenth-century. The gauges initially used a complicated system of expressing sizes in vulgar fractions of the English *inch* measure. As the number of sizes increased and became cumbersome to denote in terms of fractions they were collected into a series of nominal identification numbers. These ranged from Nos. 1 through to 20 for thicker wires, and from Nos. 20 through to 50 for finer wires - the increasing numbers signified smaller wire diameters (Dickinson and Rogers, 1943); (Hughes, 1879). As the number of applications of wire products increased, it led to the increase in the number of wire sizes. 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. By 1880, wire manufactures could manufacture really fine (i.e. thin) wires upto size 50 (i.e 0.001 *inches* or 0.00254cm in diameter). As a result of the manufacturing technique used, finer wire was costlier to manufacture than thicker wire, and thus fetched a higher price in the market compared to thicker wire.[7]

Historically, the gauges used by industry varied according to the metal used to make wire (e.g. copper, brass, iron), the geographic region (e.g. Yorkshire, Lancashire or Birmingham) and also according to the end-use for wire product (e.g. piano wire, jewellery, pins and needles). Virtually every workshop had its own wire gauge that was devised according to its experience of drawing wire.

The most widely known of the gauges was the Birmingham Wire Gauge (BWG), although no single gauge can be traced which could be termed as *the* authoritative BWG. This gauge 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.[8] 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. Hughes (1879) describes nearly 45 different wire gauges used in the UK alone, with about 10 other international variants known to UK manufacturers.

The sizes of wire measured by many of these different gauges varied marginally in terms of actual dimension. The difference was apparent only when the measurements were expressed using decimal units rather than fractional units of the inch. Nevertheless, there were several distinct gauges where the correspondence between diameters and gauge numbers differed significantly.

Consider two different wire gauges used in Warrington and Birmingham around 1879. Comparing these gauges, we discover, for example, that No. 30 size 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 size on the Warrington gauge would be approximately one-third smaller in diameter to that drawn on the No. 30 size on the Birmingham gauge and wire drawn on No. 34 size to the Warrington gauge would be almost half as thick as that drawn to the same size on the Birmingham scale. The Birmingham No. 34 was actually closer to the Warrington No. 30 than the No. 34 on that gauge.

This non-standardisation led to a whole host of agency issues in commercial contracts involving wire and wire products. Different wire numbers on two different gauges could refer to the same diameter of wire (in terms of inches). Or, to put it differently, the *same* wire number as measured by two different gauges could refer to *different* diameters of wire. Thomas Hughes wrote of an order from New York for a No. 36 Birmingham gauge wire, where

> '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 [would have been] £28 per ton'.[9]

Latimer Clark, the eminent telegraph engineer, claimed that he was involved in a contract where the use of one gauge instead of another would have made a difference of about £8,000 to the contract value, which proved the 'uselessness of the present system' (Clark, 1878) 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.'[10]

Further, wire manufacturers would supply buyers a thicker wire for a given gauge number, which cost less to produce. For example, a No. 21½ in Warrington, Liverpool, or Staffordshire could be sold as No. 22 copper wire according to the gauge used in Birmingham, giving the seller an extra margin of £4 or £5 per ton. Consumers also took advantage of such information asymmetry 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.[11] Hughes narrates the following anecdote.

> 'A customer used No. 25 wire largely; notch 24 on his gauge was the same size as No. 25 on any ordinary gauge; he thereby obtained wire No. 25 at the price of No. 24, saving £4 10s per ton.'[12]

Buyers purchasing wire in bulk from multiple manufacturers, overseas buyers acquiring wire from British manufacturers, buyers whose gauge did not match the manufacturers gauge and vice-versa, etc., faced transaction problems arising from non-uniform wire sizes. There were distinct advantages in making standard sizes uniform. However, many groups could benefit by maintaining an ambiguity between wire sizes and gauge numbers – opportunistic behaviour was quite rampant in this market. Between 1878 and 1883, the industry attempted to define a uniform wire gauge, which they hoped would alleviate problems arising from multiple gauges.

Standardisation through consensus

In May 1878 the Society of Telegraph Engineers (STE) appointed a committee to consider the standardisation of the wire sizes used by the manufacturers. Carl Siemens was a prime mover in getting the STE committee appointed in May 1878.[13] The committee, consisted mainly of telegraph engineers (Latimer Clark, C V Walker, etc.), but also included J Thewlis Johnson of Richard Johnson and Nephew, who provided the manufacturer's perspective.[14] The gauge proposed by the committee as the British Standard Gauge (BSG) was basically very similar to the one proposed by Latimer Clark earlier in 1867. Although, the BSG was supposed to conform closely to the existing gauges, the committee stressed 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'.[15]

Towards the end of the 1870s, the British wire industry was experiencing stiff competition from foreign manufacturers, both in its domestic as well as overseas markets. German wire production had nearly doubled between 1878 and 1882 and its exports of wire increased sevenfold during the same period. Production from 179,000 tons in 1878 to 250,000 tons in 1881, and further to 378,000 tons in 1882.[16] The German manufacturers exported around 30 percent of their production in 1878, which increased to about 60 percent by 1881-82. 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 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. (Smith, 1891).

In contrast, growth in British production and exports was quite modest. By the 1880s, German wire was outselling British wire in the international markets by a factor of two to one (Velkar, 2009b). British firms were losing market share in the North American, Russian, European and Australian markets. US manufacturers, including Washburn & Moen and others, were able to meet domestic demand, particularly telegraph and fencing wire, assisted by tariff protection.[17] 'America drew all the wire wanted for her own use, and supplied Canada, [a] portion of the wire trade has gone, probably never to return. Is the rest to go too?' was a comment heard at a meeting of the Steel Wire Manufacturers in 1878 (Seth-Smith, 1973).

Also, German wire was drawn to standard sizes by the 1880s. Although the BWG was 'extensively adopted' in Germany, the millimetre gauge was used to measure Westphalian wire by the late 1870s. This gauge was based on the metric measures and expressed wire diameters in millimetres. The system of numbering wire sizes on this gauge easily indicated the actual diameter of the wire, and was far less complicated and confusing than the British system of wire numbers and multiple gauges.

In this environment of stiff international competition, in October 1878, the Birmingham Chamber of Commerce (BCC) canvassed the principal dealers in metals and wire, and jewellers to seek their opinion about a uniform wire gauge.[18] Subsequently, in March 1879, at the annual general meeting of the Associated Chambers of Commerce (ACC), the BCC representatives obtained a resolution to establish 'one uniform standard gauge' and demanded that its use should be made 'if necessary compulsory by law'. A committee of ACC members first met in October 1879 to discuss the issue of uniform wire gauges and was chaired by T R Harding, a pin-maker from Leeds.[19] The committee was unable to report until 1882, as it was difficult to reach a consensus on the form of the standard gauge. The individual members were determined to have their own proposals accepted as the standard gauge.

> '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 [held] to the gauge in general use amongst its manufacturers'.[20]

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. Each group had its own distinct opinion on what constituted an appropriate standard. 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 of 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'. Nevertheless, in March 1882, the ACC adopted Harding's proposal as the basis for their standard wire gauge.[21] Harding's proposed gauge differed little from the existing Stubs gauge used in Lancashire, except for finer sizes below No. 30.

The ACC subsequently tried to get the industry to accept its proposals. It tried to make the Harding gauge the only legally recognized wire gauge in Britain. In March 1882, the ACC sent a memorial to the Board of Trade (BoT) strongly urging it to consider their proposal 'for the purpose of its being legalized [as] the British Standard Wire Gauge'. Immediately thereafter, the BoT invited reactions and opinions from the rest of the industry on the ACC proposal. Several large users of wire products approved the proposal, especially cable wire users such as the General Post Office. Several chambers of commerce also approved the BoT proposal, including the chambers of London, Birmingham, Leeds and Wolverhampton. Also, many small and medium sized Birmingham engineering and metalworking firms approved the proposal.[22]

However, the large wire makers were opposed to the ACC proposal from the beginning. In May 1882, several wire manufacturers formed the Iron and Steel Wire Manufacturers Association (ISWMA) 'to decide upon the course to be taken [in] the matter of a standard wire gauge'. The ISWMA wrote to the Board of Trade stating that the sizes it proposed were arbitrarily specified 'without regard to the method of production', and were different from the sizes 'most generally known to consumers'. The association came up with its proposed list of sizes – the Lancashire wire makers proposing the sizes up to No. 20 and the Yorkshire manufacturers proposing the finer sizes from Nos. 21 to 50.[23] Although the wire sizes in the ACC and ISWMA proposals appear to be virtually identical, the difference between the sizes seemed to be of material importance to the wire manufacturers.

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

> 'Because the major quantity is supposed to be drawn in Warrington all the others must submit to the Warrington wire gauge. [If] iron wire can be drawn to the BWG [in] Birmingham, Yorkshire, Wales, etc., why not in Warrington?'[24]

Even within the ISWMA there was a difference of 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 (Stones, 1977).

As the major wire manufacturers rejected the ACC proposal, 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, despite the fact that its April 1882 proposal was acceptable to the rest of the industry. The wire makers objected to the November proposal also, and the BoT had to propose a further modified scale in February 1883.[25] Negotiations between the manufacturers on the one hand, the rest of the industry (including the major buyers) on the other hand, and with the BoT as the facilitator, dragged on for many months. Claude Morris of Rylands, and the chairman of the ISWMA cogently summarized the rivalry between the ACC and 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 endeavoring to force the government to establish as legal the sizes which the trade say will be ruin to them!'[26]

The BoT's February 1883 proposal appears to have met the views of all the major industry groups. Eventually, in August 1883, an Order in Council was passed which introduced the Standard Wire Gauge (SWG) making it a legally recognized standard for wire sizes in Britain. Interestingly, it appears that the BoT had no power to enforce the use of the standard even though it was a legal standard. We thus have a case here of a legal standard whose adoption was left to the market on a voluntary basis.[27] 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'.[28]

The narrative above reveals 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. 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. But why did the dominant manufacturers oppose the rival ACC proposal? And why did they cooperate amongst themselves and agree on an industry standard?

Standardisation and politics of wire manufacturing

In 1847, Charles Holtzapffel made one of the earliest attempts at standardizing the system of gauges used by the wire industry. 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 to express wire sizes (Holtzapffel, 1847). Joseph Whitworth too proposed a decimal scale of sizes for the wire gauges in 1856 (Whitworth, 1882). Between 1867 and 1869, Latimer Clark presented two papers to the British Association wherein he proposed a scale based on decimal divisions of the inch, where the wire diameters were arranged to a geometric scale (Clark, 1878). These proposals involved replacing existing methods to yield the desired wire sizes, either in terms of using decimal measurements or altering the numbers-diameter correspondence. Whitworth's proposal involved reversing gauge numbers such that larger numbers signified larger diameters. 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 how the industry reacted to these proposals. However, as the industry continued to use of multiple wire gauges persisted until the 1880s, it is clear that manufacturers ignored these proposals that were based on scientific or engineering logic and which deviated substantially from existing industry practice.

We have seen how the dominant wire producers cooperated to agree on their own standard gauge *after* BoT's decision to introduce the ACC proposal as the legal standard in 1882. They strongly objected to the BoT proposal forming the *only* legal and uniform gauge for wire sizes. These objections were born out of their reaction to the German firms that were out-competing them in international markets and threatening their domestic markets as well.

British response to German competition centred on the rationalization of 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. The association met with the wire workers union and proposed a reduction in 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. As soon as the wage cuts were made, the manufacturers association was disbanded. A second round of wage reductions was attempted again in 1883, with the same results: a general strike of wire workers, followed by the workers returning to work in 1884 at substantially reduced wages. 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.'[29] 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 was reportedly common, creating an intensely competitive domestic market environment.[30]

Apart from cost rationalization, some firms diversified into related product markets. 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.[31] Other firms such as Nettlefolds began amalgamating or merging with other, smaller firms producing screws in Smethwick (Birmingham), Stourport (West Midlands), Manchester, etc. 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.[32] Thus, British response was to control costs, improve capacity utilization through diversification, or to amalgamate and merge, in order to protect domestic markets.

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 adopting the new gauges involved altering existing industry practices. This change would have resulted in substantially increasing the cost of producing wire, a large component of which was labour costs. The Lancashire manufacturers, especially of wire sizes 6 to 18, would have been affected by this proposed change (Velkar, 2009b).

Production costs for copper and brass wire of finer sizes (smaller than No. 30) were also expected to increase anywhere from £18 to £56 per ton. Considering the price of copper wire was a little more than 9s per *pound* or £84 per *ton*, this was a substantial increase in production costs. However, a switch to the ACC gauge was not expected to affect costs of iron and steel wire finer than No. 20 as there was little difference between the existing Yorkshire gauges and the ACC/Harding gauge: finer wire was mostly drawn in Yorkshire.[33]

The dominant wire manufacturers fiercely objected to the ACC gauge becoming the legal industry standard. The ISWMA argued that the ACC gauge would require them to draw the wire to a smaller number just to maintain the same diameter of wire as per existing gauges. This contributed to the increased cost of manufacturing 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'.[34] Further, changes in the wire numbers, as opposed to changes in the diameter sizes, implied 'arranging new prices with the workmen and warehousemen' – a difficult proposition given the extent of wage-reductions that were recently extracted from the workers.[35] Thus, the switchover was likely to result in a short as well as a long-term impact on the competitiveness of the British manufacturers.

The ISWMA also had to overcome differences between the large manufacturers themselves. In effect, it proposed that all the iron and steel wire and brass and copper wire manufacturers accept Lancashire sizes up to No. 20. In return all the

Lancashire manufacturers would accept finer sizes below Nos. 21 that were set by the Birmingham and Yorkshire manufacturers of fine wire.[36] The standard gauge that ISWMA proposed to the BoT thus aimed to address the production concerns of the manufacturers of different kinds of wire. The standard wire sizes were an amalgamation of sizes from different existing gauges or the 'ideal' sizes desired by the different groups of manufacturers. The *production*-centred desirable sizes of the ISWMA more or less clashed with the *application*-cantered desirable sizes proposed by the ACC.

Until 1882, the large manufacturers dominated the industry and remained competitive 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. There is no evidence that the German wire makers were able to compete more effectively due to standardized wire sizes. It was their cost structures and productivity that gave them the edge over the British wire makers. Individual wire makers such as Thewlis Johnson and Thomas Rylands were involved in discussions with the telegraph engineers regarding standard wire sizes. However, until a legal gauge seemed imminent there is no evidence of cooperation between the large wire makers regarding a uniform industry 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' proposed by the ACC. The ISWMA served as a lobby group to oppose the ACC 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. Thus, before 1882 it suited the manufacturers to use their own separate gauges. But after 1882, they preferred to make wire using a standard *they* had set rather than letting the industry get locked into the 'wrong' ACC standards.

4. Discussion

Did the adoption of uniform wire sizes assist the British industry to regain its dominant market position after 1883? Trends in British exports of wire suggest that they remained more or less stable for the rest of the nineteenth century. In contrast, exports of German wire after 1880 and that of US wire after 1898 overtook those from Britain. Uniformity in wire sizes does not appear to have enabled British manufacturers to once again secure *dominance* in the export trade that they enjoyed before 1878. However, many of the large wire manufacturers such as Rylands, Nettlefolds, Richard Johnson, etc. continued to remain large wire manufacturers, both internationally as well as domestically, well into the twentieth century.

The standardisation solution was born out of the socio-political processes, rather than the problem-solving, decision-making processes of a visible bureaucratic hand or the invisible hand of untrammelled markets. The issues of product quality that typified this sector defined the interchangeable manufacturing techniques and specialised vertical and horizontal relationships between firms. Resolving these at a transactional level depended upon the firms reaching an agreement on a standardised way of measuring the wire sizes. This became imminent for survival when the British firms were faced with intense global competition, particularly from more efficient German firms.

The standard wire gauge is an example of what Henson and Humphrey (2008) term as 'public' voluntary standards, although they were privately initiated by business firms. The public nature of these standards was crucial in preventing opportunistic behaviour, something that the principle of caveat emptor or 'buyer beware' could not prevent. A legally mandated standard was necessary. However, the non-obligatory nature of the standard meant the firms had the flexibility to alter product quality as they considered appropriate. No firm was bound to use these wire sizes in their contracts, but if they did, they had to adhere to those specific measurements defined by law – 'optional laws' as Brunsson and Jacobsson (2000) terms them. This enabled British manufacturers to remain competitive and flexible to account for changes to the market and demand patterns, and may have helped the industry survive into the twentieth century.

Table 1
Estimates of Domestic Production and Exports of Wire (England and Wales)

	No. of Wire Drawers	**Annual Output**			**UK Exports**	**Exports as % of Prod.**
		Assuming 10 tons per worker	*Assuming 13 tons per worker*	*Assuming 15 tons per worker*		
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%

Source: (Velkar, 2009b)

Bibliography

Alder, Ken. 1997. "Innovation and amnesia: Engineering rationality and the fate of interchangeable parts manufacturing in France." *Technology and Culture* 38 (2)**:** 273-311.

Alder, Ken. 1998. "Making things the same: Representation, tolerance and the end of the ancien régime in France." *Social Studies of Science* 28 (4)**:** 499-545.

Atiyah, P S. 1979. *The rise and fall of freedom of contract.* Oxford: Clarendon Press.

Austin, Marc T. & Helen V. Milner. 2001. "Strategies of European Standardization." *Journal of European Public Policy* 8 (3: Special Issue)**:** 411-431.

Bagwell, Philip S. 1968. *The Railway Clearing House in the British economy 1842-1922.* London: Allen & Unwin.

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

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

Brunsson, Nils & Bengt Jacobsson. 2000. "The contemporary expansion of standardisation." in Brunsson, N. & Jacobsson, B., (Eds.) *A World of Standards*. Oxford: Oxford University Press.

Bullen, Andrew. 1992. *Drawn together: One hundred and fifty years of wire workers' trade unionism.* Wigan: Wire Workers Section of the Iron and Steel Trades Confederation.

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

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

Daunton, M J. 2001. "The material politics of natural monopoly: consuming gas in Victorian Britian." in Daunton, M. J. & Hilton, M., (Eds.) *The politics of consumption: material culture and citizenship in Europe and America*. 69-88 Oxford, UK: Berg Publishers.

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

Farrell, Joseph & Garth Saloner. 1988. "Coordination Through Committees and Markets." *The RAND Journal of Economics* 19 (2)**:** 235-252.

Gooday, Graeme J N. 2004. *The Morals of Measurement: Accuracy, Irony and Trust in Late Victorian Electrical Practice.* Cambridge, UK & New York: Cambridge University Press.

Gordon, Robert B. 1988. "Who turned the mechanical ideal into mechanical reality?" *Technology and Culture* 29 (4)**:** 744-78.

Henson, Spencer & John Humphrey. 2008. Understanding the Complexities of Private Standards in Global Agri-Food Chains. *paper presented at 'International Workshop on Globalization, Global Governance and Private Standards', Leuven.*

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

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

Hughes, Thomas. 1879. *The English Wire Gauge.* London: E. & F.N. Spon.

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

Johnson, Paul. 2006. "Market Disciplines." in Mandler, P., (Ed.) *Liberty and Authority in Victorian Britain*. 203-223 Oxford: Oxford University Press.

Landes, David S. 1979. "Watchmaking: A case study in enterprise and change." *Business History Review* 53 (1)**:** 1-39.

Langlois, Richard N. 2007. "Competition through institutional form: the case of cluster tools standards." in Greenstein, S. M. & Stango, V., (Eds.) *Standards and public policy*. Cambridge: Cambridge University Press.

Langton, John. 1984. "The industrial revolution and the regional geography of England." *Transactions of the Insitutue of British Geographers* 9 (2)**:** 145-167.

Merrett, David, Stephen Morgan & Simon Ville. 2008. "Industry associations as facilitators of social capital: The establishment and early operations of the Melbourne Woolbrokers Association." *Business History* 50 (6)**:** 781-794.

Mokyr, Joel. 1992. "Technological inertia in economic history." *The Journal of Economic History* 52 (2)**:** 325-338.

Mokyr, Joel. 2002. *The gifts of Athena.* Princeton & Oxford: Princeton University Press.

Musson, a E. 1990. "Joseph Whitworth and the growth of mass-production engineering." in Davenport-Hines, R. P. T., (Ed.) *Capital, Entrepreneurs and Profits*. 232-272 London: Frank Cass.

Musson, a E & E Robinson. 1960. "The origins of engineering in Lancashire." *The Journal of Economic History* 20 (2)**:** 209-233.

Nelson, Richard R. 1995. "Co-evolution of industry structure, technology and supporting institutions, and the making of comparative advantage." *International Journal of the Economics of Business* 2 (2)**:** 171-184.

Olmstead, Alan L & Paul W Rhode. 2003. "Hog-round marketing, seed quality, and government policy: institutional change in US cotton production, 1920-1960." *The Journal of Economic History* 63 (2)**:** 447-488.

Riello, Giorgio. 2008. "Strategies and Boundaries: Subcontracting and the London Trades in the Long Eighteenth Century." *Enterprise & Society* 9 (2)**:** 243-280.

Rosenberg, Nathan. 1963. "Technological change in the machine tool industry, 1840-1910." *Journal of Economic History* 23 (4)**:** 414-443.

Rosenberg, Nathan. 1976. *Perspectives on technology.* Cambridge, UK: Cambridge University Press.

Saul, S B. 1967. "The market and the development of the mechanical engineering industries in Britain, 1860-1914." *The Economic History Review* 20 (1)**:** 111-130.

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

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

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

Thomas, Leslie. 1949. *The development of wire rod production.* Cardiff: Guest, Keen & Nettlefolds.

Timmins, Samuel (Ed.) 1866. *The resources, products and industrial history of Birmingham and the Midland hardware district.* London: Robert Hardwicke.

Velkar, Aashish. 2009a. "Quality standards and travelling facts in the British wheat markets of the nineteenth century." *Graduate Journal of Social Science* 6 (2: Special Issue)**:** 64-93.

Velkar, Aashish. 2009b. "Transactions, standardisation and competition: Establishing uniform sizes in the British wire industry c.1880." *Business History* 51 (2)**:** 222-247.

Ville, Simon. 2007. "Rent Seeking or Market Strengthening? Industry Associations in New Zealand Wool Broking." *Business History Review* 81 (2)**:** 297-321.

White, Francis. 1875. *Commercial and trades directory of Birmingham, Vol. 2.* Sheffield: Francis White & Co.

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

Notes:

[1] *House of Commons Papers*, 1876 Vol. VI, 'Report from Select Committee on the Metropolis Gas', p. 12, evidence given by T H Farrer, permenant secretary of the Board of Trade.

[2] For instance, see contemporary accounts of various manufacturing activities in the Midlands included in Timmins, Samuel (Ed.) 1866. *The resources, products and industrial history of Birmingham and the Midland hardware district.* London: Robert Hardwicke.

[3] James Nasmyth, 'Remarks on the introduction of the slide principle', in *Practical essays on mill work and other machinery*, Robertson Buchanan. ed. (John Weale, London, 1841).

[4] Lord Mansfield's as cited in Atiyah, P S. 1979. *The rise and fall of freedom of contract.* Oxford: Clarendon Press.

[5] See also, *Ironmonger and Metal Trades Advertiser* (hereafter *Ironmonger*), Feb. 26, 1881, p. 261

[6] *Ironmonger*, Jan 13, 1883 p. 56, extract from Board of Trade Returns.

[7] Stones, Frank. 1977. *The British Ferrous Wire Industry.* Sheffield: J W Northend Limited., see price list from 1884 between p. 12 & 13. See Velkar (2009) for details of the manufacturing technique

[8] Clark, Latimer. 1878. "On the Birmingham wire gauge (Paper Presented to the British Association in 1867)." *Journal of the Society of Telegraph Engineers* 7**:** 332-335.; *Ironmonger*, Feb 14, 1880, editorial note.

[9] Hughes, Thomas. 1879. *The English Wire Gauge.* London: E. & F.N. Spon.

[10] Reprinted in *Ironmonger*, Mar. 12, 1881, p. 345.

[11] *Ironmonger*, Jan 1, 1881, pp. 18-20.

[12] Hughes, Thomas. 1879. *The English Wire Gauge.* London: E. & F.N. Spon.

[13] 1878. Society of Telegraph Engineers, Minutes of Council Meetings. *Council Papers.* London, IET Archives., entry for May 23, 1878.

[14] C V Walker was a past president of the STE and had presented a paper on the wire gauge in April 1878.

[15] Report on the BWG, STE Journal, 1879, p. 493.

[16] *Ironmonger*, Apr 9, 1881, p. 510; Bell, Lowthian. 1886. *The iron trade of United Kingdom.* London: British Iron Trade Association.; France, Belgium and the United States were also important wire making countries.

[17] *Ironmonger*, Jan 28, 1882 & Sep 7, 1878; also Blake-Coleman, B C. 1992. *Copper wire and electrical conductors - The shaping of a technology.* Reading: Harwood Academic Publishers.

[18] [T]he [N]ational [A]rchives, BT 101/114, Report of the Associated Chambers of Commerce (hereafter ACC) on Wire Gauge; 1875-1883. Birmingham Chamber of Commerce, Council Minutes Books. *Council Papers.* Birmingham, Birmingham City Archives., entries for Oct. 23, Nov 20 and Dec 18, 1878.

[19] 1876-83. Association of Chambers of Commerce, Executive Council Minutes: Vol 3. *Council Papers.* London, Guildhall Library., entry for Oct 29, 1878.

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

[21] *Ironmonger*, Feb. 25, 1881, p. 281; 1876-83. Association of Chambers of Commerce, Executive Council Minutes: Vol 3. *Council Papers.* London, Guildhall Library., entry dated Mar. 1, 1882; TNA, BT 101/114.

[22] TNA, BT 101/114; BT 101/115; BT 101/116; BT 101/119.

[23] Stones, Frank. 1977. *The British Ferrous Wire Industry.* Sheffield: J W Northend Limited.; TNA, BT 101/116, Letter from the ACC to the BoT dated July 7, 1882.

[24] *Ironmonger*, May 20, 1882, Letters to the Editor, pp. 686-7.

[25] TNA, BT 101/119, memo dated Jul 28, 1882; BT 101/123, letter dated Jan 5, 1883; BT 101/124; Stones, Frank. 1977. *The British Ferrous Wire Industry.* Sheffield: J W Northend Limited.

[26] *Ironmonger*, Feb 24, 1883, letters to the editor, p. 249-50 (emphasis in the original).

[27] TNA, BT 101/943, letter from BoT to Stelp & Leighton Ltd.

[28] *Ironmonger*, Mar 17, 1883, editorial p. 386, and letter by Thomas Hughes p. 392; Stones, Frank. 1977. *The British Ferrous Wire Industry.* Sheffield: J W Northend Limited.

[29] Seth-Smith, Michael. 1973. *Two hundred years of Richard Johnson & Nephew.* Manchester: Richard Johnson & Nephew Limited.; Stones, Frank. 1977. *The British Ferrous Wire Industry.* Sheffield: J W Northend Limited.; Bullen, Andrew. 1992. *Drawn together: One hundred and fifty years of wire workers' trade unionism.* Wigan: Wire Workers Section of the Iron and Steel Trades Confederation.; Ironmonger, Apr 1880; May 24, 1884, p. 711.

[30] *Ironmonger*, Jan 22, 1881, p. 110.

[31] *Ironmonger*, June 7, 1879, p. 763.

[32] *Ironmonger*, Apr 9, 1881, p. 511; Nov 3, 1883, p. 650-51; May 24, 1884, p. 711.

[33] Price of copper wire from Blake-Coleman, B C. 1992. *Copper wire and electrical conductors - The shaping of a technology.* Reading: Harwood Academic Publishers.; *Ironmonger*, Mar 25, 1882, letter by Thomas Hughes; also, Mar 5, 1881, p. 304-306.

[34] TNA, BT 101/116, letter to the Board of Trade dated Jul 7, 1882.

[35] *Ironmonger*, Dec 2, 1882, p. 749

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