The London School of Economics and Political Science

Markets, Standards and Transactions:
Measurements in Nineteenth-Century British Economy

Aashish Velkar

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Declaration

I certify that the thesis I have presented for examination for the PhD degree of the London School of Economics and Political Science is solely my own work other than where I have clearly indicated that it is the work of others (in which case the extent of any work carried out jointly by me and any other person is clearly identified in it).

Abstract

This thesis is concerned with measurements used in economic activity and investigates how historical markets managed transactional problems due to unreliable measurements. Existing literature has generally associated the problems of measurements in historical markets with the lack of uniformity in weights and measures. This thesis shows that metrological standardization was not sufficient to ensure reliability of measurements. Markets developed mensuration practices that enabled markets to address specific transactional issues in micro-contexts. This involved, in addition to the use of standardized metrology, improved governance of transactions, third party monitoring and guaranteeing, and other institutional solutions. Historical institutional arrangements were altered or replaced as a result of changing or standardizing mensuration practices.

The thesis also makes a conceptual contribution in terms of understanding the process of standardization. It shows how, while *standards* can be inflexible and rationalized (i.e. limited in number), *standardized practices* can incorporate a number of such standards and be flexible in terms which standard to be used in a given context. Analytically, standardized practices are institutional objects that are determined endogenously and are formed in 'packages' that create interlinks between standards, other artefacts, rules and people.

These arguments are developed by studying three detailed cases of mensuration practices in the British economy during the nineteenth-century. The case of the London Coal Trade examines how altered mensuration practices gave buyers greater assurance that the amount of coal they received was actually the amount they purchased. The case of the wire industry illustrates the struggles to define a uniform set of wire sizes that could overcome the disputes arising from incompatible and multiple ways of measuring wire sizes. The case of the wheat markets illustrates the complexity involved in developing standards of measurements such that quality could be reliably measured *ex-ante*. Through these case studies, the thesis shows how markets developed different mensuration practices to manage measurements in a given context.

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Throughout the years that I have dedicated to the pursuit of my academic interest, my family and friends have remained ever supportive. I only wish I was able to show greater appreciation for their support. None more so than Apara, who against all odds believed in my decision to pursue my selfish interests and gave me the strength to 'be bold'. To her I owe everything.

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Chapter 1

Markets, Standards and Measurements

> 'As we trace the history of our metrology from the beginning we shall have ample evidence of [considerable] effort which ensured that the exchange of goods was equitable, with the consumer relying ultimately on kingly support of his claim for justice in the market-place.' (R D Connor, 1987)[1]

1.1 Introduction

This thesis is concerned with the issue of measurements and measurement standards used in economic activity. It investigates the manner in which historical markets managed transactional problems due to unreliable measurements. Historical literature has generally associated measurement issues in transactions with the existence of multiple measurement units and a lack of uniform 'measures' i.e. a system of weights and measures. Some historians hold the view that the existence of multiplicity of 'measures' in historical markets point to a local or regional economy, and that this multiplicity tended to disrupt internal trade. Martin Daunton wrote that

> 'There were marked differences in weights and measures, which created uncertainties and costs. These variations in weights and measures were, complained reformers, so many internal barriers to free trade by creating uncertainty and imperfect competition, and the long process of standardization provides one measure of the emergence of an integrated national market.'[2]

Joan Thirsk wrote that

> 'The multitude of differing weights and measures used in the sale of agricultural produce in 1750 provides one of the most vivid reminders of how much more

[1] R. D. Connor, *The weights and measures of England* (HMSO, London, 1987).

[2] M. J. Daunton, *Progress and poverty: An economic and social history of Britain 1700-1850* (Oxford University Press, Oxford, 1995), p. 278.

> accurately England and Wales could be described as a chain of local and regional markets at this date than as one emerging national economy.'[3]

Similarly, Julian Hoppit wrote that

> 'Far from there being a uniform and coherent [system of weights and measures before the middle of the nineteenth century] local anomalies and customs created considerable disparity, complicating internal trade.'[4]

To Hoppit, lack of uniformity is evidence of regionalism suggesting traditionality in the forms of production and an economy that could not be assumed to behave in 'a *modern* way to variations in supply and demand.'[5] The view expressed in this context is that the existence of multiple 'measures' made markets non-modern and/or regional in nature: the corollary to this begin that modern, integrated, national markets are likely to use some form of uniform 'measures'. The underlying implication is that multiplicity of 'measures' tended to have a considerable, often detrimental, impact on transactions, exchange, and market integration.

There are actually two assumptions that are subsumed within such historical views concerning markets, transactions, and measurements. The first assumption is that there existed a correspondence between 'measures' – the measurement units or a system of such units – and 'measurements' – the information that the act of measuring captures. In the context of the historical views expressed above, this means that multiplicity, non-uniformity, or incoherency of 'measures' is somehow assumed to have translated into multiplicity, non-uniformity, or incoherency of 'measurements'. The other assumption is that the introduction of uniform, invariable or standardized 'measures' helped to make 'measurements' manageable within the economy, simplified economic transactions, and helped to integrate markets.

A rich historiography exists concerning the introduction of metric 'measures' in France, its impact on the local economy, and an appreciation of who gained and who lost in the process.[6] Considerably less is written about the standardization of the

[3] J. Thirsk, ed. *The agrarian history of England and Wales - Vol. V: 1640-1750* (Cambridge University Press, Cambridge, 1985), p. 815, Appendix I: Agricultural Weights and Measures.

[4] J. Hoppit, 'Reforming Britain's weights and measures, 1660-1824', *The English Historical Review* 108 No. 426 (1993): p. 82.

[5] Ibid., emphasis added.

[6] K. Alder, 'A revolution to measure: The political economy of the metric system in the ancien régime', in *The values of precision*, M. N. Wise. ed. (Princeton University Press, Princeton, 1995); J. L. Heilbron,

Imperial measures, very little about its impact on the economy, and almost nothing about who gained and who lost in the process.[7] There is little distinction in most historical accounts between standardizing 'measures' and standardizing 'measurements', and the former is expected to have translated into the latter. Ken Alder alludes to this distinction when he wrote that the scientifically motivated thrust of the French metric reforms of the 1790s was to replace an older economic system with a newer one.[8] Sidney Pollard captured the essence of this distinction when he remarked that 'the objectives of businessmen are not to attain perfection [of 'measures'], but to keep down costs and increase efficiency.'[9] Nevertheless, most historians fail to clearly emphasize the difference between the *abstract* systems of 'measures' and the *practical* issues of making 'measurements', and how standardizing the former can help to manage the latter.

Generally, there is little understanding amongst economic historians about 'measurements' *per se*, how they were made in economic contexts, and how markets managed problems surrounding them. Simply put, measurements could be related to varied economic concerns and decisions, such as what type of products to produce and how to produce them (measurements of specifications), how much quantity of a given product is traded or exchanged and how reliable is this estimate (measurements of quantity or amount), or what is the condition of the product and how functional is it (measurements of quality). These kinds of measurements - in fact any economic measurements - are assumed by institutional economists to structure basic incentives for exchange and form a fundamental part of economic transactions.[10] Given the lack of historiography about how these issues were managed, we are left with a conclusion that as and when the standardized Metric and Imperial measurement units were introduced, they somehow solved existing

'The measure of enlightenment', in *The quantifying spirit in the 18th century*, T. Frangsmyr et al. eds. (University of California Press, 1990); W. Kula, *Measures and men* (Princeton University Press, Princeton, New Jersey, 1986).

[7] Hoppit, 'Reforming Britain's measures'; Connor, *English Measures;* R. E. Zupko, *Revolution in measurement: Western European weights and measures since the age of science* (The American Philosophical Society, Philadelphia, 1990).

[8] Alder, 'Revolution to measure', p. 59.

[9] S. Pollard, 'Capitalism and rationality: A study of measurements in British coal mining, ca. 1750-1850', *Explorations in Economic History* 20 No. 1 (1983): p. 125.

[10] D. C. North, *Institutions, institutional change and economic performance* (Cambridge University Press, 1990), p. 27; Y. Barzel, 'Measurement cost and the organization of markets', *Journal of Law and Economics* 25 No. 1 (1982): p. 27; Pollard, 'Coal measurements': p. 110.

'measurement' problems. In short, standardizing 'measures' led to reliable 'measurements'.

Unsatisfied with this explanation, I propose a different approach in this thesis to unpack the issue of managing measurements. I do not make the assumptions that standardizing 'measures' makes 'measurements' reliable. I begin by highlighting the difference between **metrology**, i.e. the system of measures, and **mensuration**, i.e. the practice of measurement. I argue that this is an important distinction in terms of understanding how historical markets managed product measurements - a distinction that is missing from most historical accounts.[11] I then focus on mensuration, i.e. the activity through which particular information is captured in historical markets. This enables me to highlight particular issues historical markets faced in managing measurements and how they were solved, whether through the standardization of 'measures' or through some other means.

I do not imply that the two aspects - metrology and mensuration - were historically independent. On the contrary, they appear to be inextricably linked in most circumstances. Witold Kula gave a fairly broad definition of historical systems of measurements, in which he included 'all the elements associated with measuring', including systems and instruments of counting, methods of using instruments, different methods of measuring in different social situations, as well as the 'entire associated complex of interlinked, varied, and often conflicting social interests.'[12] He clearly considered 'measurements' to be broader than 'measures'. But where Kula sought to combine, I seek to separate. His view is that historical systems of measurements combine the elements that he lists (as above) into 'an internally articulated structured whole', and that the 'task of science is to investigate this system within the social reality that produced it and within whose framework it functions.'[13] In other words, he proposes to study the system as a whole.

[11] The Oxford English Dictionary defines the two terms as follows: **metrology**, (*n.*) **1.** A system of measures, *esp.* one used by a particular nation, culture, etc., **2.** The study of systems of measurement; the science of measurement; the branch of technology that deals with accurate measurement; **mensuration**, (*n.*) **1.** The action, process, or art of measuring; measurement, **2.** The branch of geometry that deals with the measurement of lengths, areas, and volumes; the process of measuring the lengths, areas, and volumes of geometrical figures. (accessed online on June 2, 2008)

[12] Kula, *Measures and men*, p. 94.

[13] Ibid.

I differ in this view and argue that metrology and mensuration – and their development and standardization – should be treated as separate processes and studied as such. An important distinction that could be made, for example, is that metrology – in its post nineteenth-century form – is a macro level i.e. national or international institutional system that transcends markets and industries. Mensuration by contrast is a micro level activity and, although common in concept across markets, has distinct mechanisms in each micro context. These mechanisms need to be understood, which is my particular interest in this thesis. The groups that influence these processes, the manner in which mensuration and metrology are used, and the purposes for which they are used were different in each historical context. Different mensuration practices using the same metrological standards, for instance, had substantially different implications for how measurements were managed by different groups in different contexts. The study of mensuration practices can thus potentially capture a greater dynamic of markets, standards, and transactions.

In this thesis, therefore, I have primarily focused on historical mensuration practices rather than studying how uniformity of 'measures' – metrological standardization – may have helped markets manage measurement issues. Mensuration is considered to be an activity comprising broadly of three elements: observing and recording relevant information, comparing these observations to standards, and eventually contextualizing the comparisons. Several processes, tools, instruments, standards and protocols (i.e. rules, norms or conventions) are considered to be essential in conducting this activity. Analytically, 'measurements' are thought to be the end result of this activity (chapter 3). The thesis examines historically how markets conducted this activity within different economic contexts, the different groups that were involved in the process, the various measurement issues that were encountered, and how they were managed in the context of such practices. The thesis focuses on investigating measurement reliability in terms of its consistency, conformity or uniformity. In other words, reliability is assumed to be derived from the 'sameness' of measurements, rather than minimizing the deviation from an absolute or 'true' value.

The terms 'manage' or 'management' in this context relate to the processes or mechanisms through which the mensuration activity is organized, supervised or coordinated to achieve a particular aim or desired objective. The terms convey a degree of control and influence that markets exercise over measurements, that markets can manipulate measurements to meet desired objectives and that the methods and tools by which they are made can be changed or altered. This view of measurements is different from theoretical discussions about measurements, particularly about measurements in science or measurements of phenomenon, where invariability of measurements is taken to be of primary importance.[14] This view is also different from various existing historical accounts which seeks to explore if and why uniformity of 'measures' was or was not achieved and how these changed over time.[15]

The distinctiveness of this approach is one of the important contributions of my thesis. Few historical studies of mensuration practices exist, particularly for the nineteenth-century. This study fills an important gap in the literature i.e. on historical markets and the management of the measurement aspect of transaction issues. This approach, which differs from previous historical accounts, also enables me to make some original arguments about the measurement issues facing historical markets, how they were managed, and the implications of this historical research.

The thesis also contributes to the historical standardization literature by a detailed study of how *macro*-historical metrological standards link with *micro*-historical mensuration practices. Due to the widespread and general nature of measurement issues, they have largely been studied on the basis of macro-level changes to the metrological infrastructure. This thesis studies micro-level mensuration practices within individual economic sectors and demonstrates that standardization of measurements, whenever it occurred, was a dynamic, micro-level process and was not limited to the introduction of metrological standards at a national or macro level.

1.2 *Main Arguments*

There are three main arguments that I develop in this thesis. First, metrological standardization was not the only way in which markets solved measurement problems. Other ways of managing measurements were equally important including strategies involving improved governance of transactions, third party monitoring (of measurements), and guarantees, etc.

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[14] M. N. Wise, ed. *The values of precision* (Princeton University Press, Princeton, NJ, 1995); M. Boumans, ed. *Measurement in economics: a handbook* (Elsevier Inc, London & Amsterdam, 2007).

[15] Pollard, 'Coal measurements'; Kula, *Measures and men*; Connor, *English Measures*; Zupko, *Revolution in Measurement*; Hoppit, 'Reforming Britain's measures'; Alder, 'Revolution to measure', etc.

Second, development of mensuration standards, whenever and in whichever context they were used, involved the pre-selection of product attributes to be measured, the manner in which they were measured, and the pre-determination of what these measurements meant in a given context. This involved the standardization of methods of recording and observation, the use of specific standards for comparison, pre-agreed ways of using the instruments and standards for observation and comparison, and the acceptance of certain protocols for observation, comparison and contextualization: that is, developing mensuration practices. In this regard institutions continued to play an important role in managing measurement problems despite metrological standardization.

Finally, standardization of mensuration practices was a historically distinct process: distinct from metrological standardization. This is because the groups involved in the process, the elements that were standardized, the mechanics of standardization, and the measurement issues that they addressed were different. The nature of mensuration standards was also different from metrological standards, which emphasized traceability and invariability among other attributes. Mensuration standards were concerned with measurement reliability in a variety of economic contexts.

1.2.1 Managing Measurements

Metrological standards have historically been used in market transactions to manage measurement problems. Nevertheless, complete standardization – whereby a single uniform metrological standard is used - proved difficult to achieve.[16] The state's attempts to enforce the use of metrological standards in market transactions can be traced back to medieval times. Even so, parliamentary committees in early the nineteenth-century lamented the non-uniformity of metrological standards, implying that their uniformity and accuracy would reduce measurement problems that markets were reputed to encounter frequently.[17]

[16] See for instance R. Sheldon et al., 'Popular protest and the persistence of customary corn measures: Resistance to the Winchester bushel in the English west', in *Markets, Market Culture and Popular Protest in Eighteenth-Century Britain and Ireland*, A. Randall and A. Charlesworth. eds. (Liverpool University Press, Liverpool, 1996); N. Biggs, 'A tale untangled: Measuring the fineness of yarn', *Textile History* 35 No. 1 (2004); C. R. Fay, 'The sale of corn in the nineteenth century', *The Economic Journal* 34 No. 134 (1924).

[17] Reports of various parliamentary committees on weights and measures in *[P]arliamentary [P]apers 1813-14 Vol. III; PP 1819 Vol. XI; PP 1820 Vol. VII; PP 1821 Vol. IV.*

Nevertheless, the existence of non-standardized metrological units did not totally inhibit trade between markets using different 'measures'. Merchants, middlemen and dealers would regularly use ready-reckoners to convert between different measures.[18] These merchants in fact acted as the translators between local measures, relying upon local norms or market rules to convert from one measure to another along established trade routes.[19] Additionally, other institutions were developed to ensure that proper measurements were meted during delivery or exchange of commodities. The institution of publicly measuring essential commodities such as coal and corn, referred to as the metage system, was important in monitoring measurements and acted as a governance mechanism. Such mechanisms developed in medieval times and there is sufficient evidence to suggest that they persisted until the end of the nineteenth-century. Rules of verification also emerged to manage measurement issues, particularly those related to measurements of quality. The practice of using the 'count' as a measure of fineness of silk thread or cotton yarn, or the use of 'natural weights' as a measure of grain quality transcended local or legal metrological standards.[20] In such cases, reliability of measurements depended not only upon the 'measures' in use, but also upon adherence to certain market rules. Thus, markets depended upon various institutional methods to manage measurement issues, particularly in the presence of multiple 'measures'.

Historically, reducing multiplicity of 'measures' involved introducing standardized measurement units at a national (or even at an international) level, such as the Imperial or Metric systems in the nineteenth-century. Although local 'measures' persisted for many decades after the introduction of these metrological standards, the latter's use eventually became virtually universal wherever they were introduced.[21] Such standards were applicable in a large variety of situations and

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[18] Examples of such ready-reckoners include J. Hewitt, *The corn dealer's assistant* (London, 1736).; E. Hodgkins, *A series of mercantile letters, with the weights, measures and monies reduced into the English Standard, etc.* (London, 1815); A. Bald, *The Farmer and Corn-Dealer's Assistant; or, the Knowledge of weights and measures made easy, by a variety of tables, etc.* (Stirling, 1780).

[19] London coal merchants would convert from measures used in the north of England to those locally used on the basis of long established market norms, R. A. Mott, 'The London and Newcastle chaldrons for measuring coal', in *Archaeologia Aeliana*, J. Philipson. ed. (The Society of Antiquaries, Newcastle-upon-Tyne, 1962); also, Hoppit, 'Reforming Britain's measures': p. 92.

[20] C. Poni, 'Standards, trust and civil discourse: measuring the thickness and quality of silk thread', *History of Technology* 23 (2001); S. Dumbell, 'The sale of corn in the nineteenth century', *The Economic Journal* 35 No. 137 (1925).

[21] A. E. Kennelly, *Vestiges of pre-metric weights and measures persisting in metric-system Europe 1926-1927* (Macmillan Company, New York, 1928).

across various contexts as they were composed of metrological units that were decontextualized and abstract, compared to the various local 'measures' used previously which were highly contextual (chapter 2). Metrological standards were introduced at a national level by the state that was interested in addressing various macro-level issues.[22] Its ability and interest in managing localized measurement issues was generally limited, although not completely absent.

On the other hand, many measurement issues continued to be localized ones, even those involving long-distance commodity chains. The issue of historical relevance is whether standardization of metrology at a macro-, national-level was sufficient to resolve management issues at a micro-, local-level. In this thesis, I argue that market institutions continued to play an important role in managing measurements, even after the introduction of uniform metrological standards, such as the Imperial measures introduced in Britain in 1824, or the Metric measures first introduced in France in 1799 and eventually adopted across most of Europe between c1850 and c1880. The role of these institutions in a micro-context is worth investigating to understand how markets managed product measurements. I further argue that, historically, management of measurements involved developing measurement practices within micro-contexts, incorporating available metrological standards, governance mechanisms, and other institutional rules. These practices can be understood as mensuration standards.

1.2.2 *Mensuration Standards*

Developing a mensuration practice involved making various *ex-ante* selections or choices. These included selecting the property or attribute of an object that was to be measured, choosing an appropriate measurement method, selecting the metrological standard, specifying the measuring instruments to be used, and seeking agreement regarding measurement protocols (chapters 4-6). These choices were shaped by the nature of the information that was required, the groups who required the information, their motivations, and the purpose for which the measurements were required.

[22] W. J. Ashworth, *Customs and excise: Trade, production, and consumption in England, 1640-1845* (Oxford University Press, Oxford, 2003); J. C. Scott, *Seeing like a state: How certain schemes to improve the human condition have failed* (Yale University Press, New Haven & London, 1998).

The key issue here is the extent to which a given practice was applicable to all measurement situations. If management of measurements was a localized issue, then mensuration standards that developed would have to be relevant to a specific context, even though 'universal' standards and instruments were used in the process. Thus, it is unlikely that there emerged a single, uniform mensuration standard, which was the *best* practice for markets to use in order to manage all measurement situations. This is supported by historical evidence presented in this thesis. There was seldom an 'ideal' or 'true' way of measuring a product attribute. There was no reason why the measurement of wire diameter was *inherently* better than its weight per length to sort it into different sizes (chapter 5). Neither was there any inherent reason why weight measurements of dry goods represented ideal or true measurements compared to their volumetric measurements (chapter 4). Markets struggled to develop mensuration practices that were relevant and suitable to their specific contexts rather than conform to an abstract ideal. The historical argument that I develop in this thesis is that markets constructed context-specific mensuration standards to manage specific measurement issues.

1.2.3 *Standardization Process*

The development of a mensuration practice as a standardization process can be distinguished from the process of developing 'standards'. The nineteenth-century witnessed the emergence of several engineering, product and technical standards. Equally, there were standards of form and procedure, such as accounting standards and standard commercial trading terms. The manner in which these standards emerged, the groups involved in the process and the incentives they faced, the institutions that influenced which of the competing options emerged as the standard, forms a distinct study as opposed to the study of mensuration practices. Similarly, markets relied upon methods other than metrological standardization to manage measurements. Governance and other institutional mechanisms were part of the efforts to design standardized mensuration practices.

The nature of the two elements is distinct too. Mensuration practices tended to use many different kinds of standards to manage the activity and make the resulting measurements reliable. Metrological standards on the other hand emphasized traceability and invariability. In other words, while standards value inflexibility and on many occasions rationalization (i.e. the number of 'states' or 'values' the standard can take needs to be limited), standards such as mensuration may work effectively if there is a degree of flexibility involving which standard can be chosen for a given situation. Analytically, the manner in which these two elements are studied or understood needs to be different.

1.3 Historical Context: British Economy of the 19th Century

These arguments are explored and developed in the thesis in the context of the British economy and markets of the nineteenth-century. The rapid industrial growth and trade activity, a non-coercionary metrological regime, and profound changes in the mensuration practices makes the British economy particularly suitable to explore measurement issues and draw out the main arguments of this thesis.

1.3.1 Trade and Industrial Growth

From the eighteenth-century onwards, there was a considerable expansion of domestic as well as international trade in Britain, both in terms of its scale as well as scope. Britain's international trade grew at a compound annual rate of between 2.5 and 4.5 percent during the nineteenth-century.[23] This expansion was not limited to traditional commodities such as coal, corn, wine or woollens, but included several 'new world' commodities such as cotton, sugar and tobacco, as well as luxury commodities such as tea and spices. Trade along routes that linked traditional markets with newer distant markets increased, and commodities from newer sources in the Americas as well as the Orient found industrial applications in Britain. The expanding trade included both primary commodities as well as manufactures, including traditional products, such as textiles and metalware, as well as engineered products made using new manufacturing techniques. Improvements in production technology not only allowed British firms to capture export markets with cheaper goods, but demand for raw material from British firms created a huge new import trade. Improvements in transport infrastructure also made it easier to expand trade. Technological change on the whole had a considerable impact on developments in British trade during this period.[24] Expansion in trade also presupposed the development of legal, financial and commercial institutions that enabled the

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[23] P. Deane and W. A. Cole, *British economic growth: 1688-1959 - Trends and structures* (Cambridge University Press, 1962), p. 29, table 8; the percentage growth figures are decadal averages.

[24] For example, see C. K. Harley, 'Ocean Freight Rates and Productivity, 1740-1913: The Primacy of Mechanical Invention Reaffirmed', *The Journal of Economic History* 48 No. 4 (1988).

expansion in scope and scale of trade. The 'commercial revolution' and the development of allied institutions thus supported industrial growth.

Expansion of industrial activity was accompanied by changes in the organization of such activity. A growing proportion of output in many sectors, and especially in textiles, became factory-produced in Britain during the nineteenth-century. The number of workers in manufacturing activities such as shipbuilding, blast furnaces, etc., multiplied. There was also increased regional specialization and concentration of manufacturing.[25] This is evident in industries such as wire manufacturing where West Yorkshire specialized in the manufacture of fine wire products, while in the Midlands, workshops made thick wire for different applications (chapter 5). 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.[26] In fact, small firms also proliferated alongside large factories because of the widespread practice of subcontracting.[27] 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.[28] Indeed, integration, agglomeration and specialization in a range of organizational forms created newer interdependencies and relied upon expanding networks of information and trust - both existing networks as well as newly established ones.

Accompanying the concentration of industrial activity was the concentration of consumption centres with the rapid growth in the urban share of total population by

[25] J. Langton, 'The industrial revolution and the regional geography of England', *Transactions of the Institute of British Geographers* 9 No. 2 (1984).

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

[27] G. Riello, 'Strategies and Boundaries: Subcontracting and the London Trades in the Long Eighteenth Century', *Enterprise & Society* 9 No. 2 (2008).

[28] J. Mokyr, *The gifts of Athena* (Princeton University Press, Princeton & Oxford, 2002), p. 119 ff.

the nineteenth-century.[29] This had a significant impact on the occupational structure, with nearly two-thirds to three-quarters of the workforce employed in non-agricultural occupations. Real wages, on the whole, did increase during the nineteenth-century, although the extent of increase appears to be a more modest than previously thought.[30] Paralleling this, shifts in consumer preferences during the eighteenth-century meant that commodities such as tea and sugar no longer remained luxuries, but became necessities. The crucial shifts in consumer behaviour were also generated in the context of new goods and luxuries, and discerning consumers demanded a greater consistency of quality as well as novelty.[31]

Industrial organizations in the nineteenth-century consequently faced several important issues: the organization and management of expanding commodity chains, technological convergence and interdependence, the ability to generate competitive advantages, management and control of information, etc. which bear further thought.

The expanding trade and the increasing sophistication of industrial activity in the nineteenth-century made the organization and management of complex value chains an important issue for the British economy. Specialization and agglomeration meant sorting out how the interdependent relationships between various firms along the value chains were to be organized. The question of which economic activities (production, distribution, retailing, etc.) to integrate and which ones to disintegrate became relevant.[32] 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

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[29] E. A. Wrigley, *People, cities and wealth: the transformation of traditional society* (Basil Blackwell, Oxford, 1987)., especially chapter 7.

[30] For example, see C. H. Feinstein, 'Pessimism Perpetuated: Real Wages and the Standard of Living in Britain during and after the Industrial Revolution', *The Journal of Economic History* 58 No. 3 (1998).

[31] M. Berg, 'From Imitation to Invention: Creating Commodities in Eighteenth-Century Britain', *The Economic History Review* 55 No. 1 (2002).

[32] M. Rothstein, 'Multinationals in the grain trade, 1850-1914', *Business and Economic History* 12 (2nd Series) (1983); C. R. Fay, 'The London corn market at the beginning of the nineteenth century', *The American Economic Review* 15 No. 1 (1925); N. Hall, 'The emergence of the Liverpool raw cotton market, 1800-1850', *Northern History* 38 No. 1 (2001); R. C. Feenstra, 'Integration of trade and disintegration of production in the global economy', *The Journal of Economic Perspectives* 12 No. 4 (1998), for a conceptual discussion on the disintegration of production and trade integration in the global economy; F. M. Santos and K. M. Eisenhardt, 'Organizational boundaries and Theories of Organization', *Organization Science* 16 No. 5 (2005), for a theoretical discussion about organizations and organizational boundaries and an alternative to transactions cost approach.

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. Trade associations, exchanges, technical societies and institutes, etc. helped to give an industry its form, lobby power, and protection from outside competition.[33] Industries thus would have evolved distinct 'architectures', with each industry developing one or a number of distinct architectures, i.e. different ways in which roles were distributed between interdependent firms.[34]

Expanding industrial activity was also intimately connected with technical changes, and the introduction and maturing of new technologies. Although, different organizational architectures emerged within industries, historians have identified a *convergence* of technologies 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.'[35] 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, etc. Technological convergence is discernible in other industrial and commercial sectors.

Such convergence had two implications. First, they created complementarities and interdependencies between different firms, particularly in industries with higher degrees of specialization.[36] 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

[33] R. R. Nelson, 'Co-evolution of industry structure, technology and supporting institutions, and the making of comparative advantage', *International Journal of the Economics of Business* 2 No. 2 (1995): p. 176.

[34] M. G. Jacobides et al., 'Benefiting from innovation: Value creation, value appropriation and the role of industry architectures', *Research Policy* 35 (2006), for a discussion on how and why distinct 'industry architectures' tend to evolve.

[35] N. Rosenberg, 'Technological change in the machine tool industry, 1840-1910', *Journal of Economic History* 23 No. 4 (1963): p. 423.

[36] N. Rosenberg, *Perspective on technology* (Cambridge University Press, Cambridge, 1976).

and shaped the manner and extent to which technologies matured.[37] Industry architectures both influenced, and were in turn influenced, by maturing technologies, through a combination of market processes, collective bodies, governmental policies and political action. This co-evolution of technology, organizations and institutions was a complex process requiring coordinated actions at various levels and between different groups. [38]

Firms also struggled to generate competitive advantages through innovations, and markets sought to determine who stood to benefit from such advantages and how.[39] Innovation may be defined in very broad terms and included the opening of new markets or new ways of marketing, new sources of materials, new ways of organizing, etc. in addition to product or process innovation due to technological change.[40] Who stood to benefit from the innovation depended upon how the interdependent relationships were managed in an industry and how property rights were delineated along these relationships. On the one hand, national factor endowments affected the competitive (or comparative) advantage that some firms could secure, while on the other, market structure, managerial capability and firm level behaviour were crucially (if not more) important in determining who benefited from the competitive advantage.[41] Nevertheless, the issue of who benefited from innovations appears to be more complex than the factor endowment or the firm capability explanations and could be heavily influenced by the structure of the industry itself.[42] The set of 'rules' that governed an industry architecture, and which were highly localized, not only defined the value creation and division of labour, i.e. who could do what, but also how that value was to be appropriated and divided, i.e.

[37] R. B. Gordon, 'Who turned the mechanical ideal into mechanical reality?', *Technology and Culture* 29 No. 4 (1988); K. Alder, 'Making things the same: Representation, tolerance and the end of the *ancien régime* in France', *Social Studies of Science* 28 No. 4 (1998); J. Mokyr, 'Technological inertia in economic history', *The Journal of Economic History* 52 No. 2 (1992).

[38] Nelson, 'Industry structure'.

[39] Michael Porter and David Teece had raised this issue in the 1980s, but have addressed mainly technological innovations; D. J. Teece, 'Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy', *Research Policy* 15 No. 6 (1986); M. E. Porter, 'Technology and competitive advantage', *Journal of Business Strategy* 5 No. 3 (1985).

[40] J. A. Schumpeter, *The theory of economic development*, tr. R. Opie, (Hayward University Press, Cambridge, 1934)., Chapter 2.

[41] S. B. Saul, 'The market and the development of the mechanical engineering industries in Britain, 1860-1914', *The Economic History Review* 20 No. 1 (1967); R. C. Floud, 'The adolescence of American engineering competition, 1860-1900', *The Economic History Review* 27 No. 1 (1974); R. C. Allen, 'International Competition in Iron and Steel, 1850-1913', *The Journal of Economic History* 39 No. 4 (1979), etc. for a review of the relative competitiveness of British industry vis-à-vis other industrial nations.

[42] Nelson, 'Industry structure'.

who got what.[43] Division of labour and value appropriation depended as much upon interdependencies as distinguishing oneself from others; competitive advantages could be derived from conformity as well as differentiation.

Against this backdrop of industrial and trade expansion, technological change and competitive pressures, a relevant issue that emerges is how organizations solved the increasing informational problems, particularly those arising from unreliable measurements. The problem of measurement unreliability is discussed at some length in chapter 2, however, *prima facie*, the contemporary view in the late eighteenth and nineteenth-century was that variations in 'measures' were an impediment to trade.[44] The thesis explores this issue specifically in the context of the nineteenth-century, rather than assume that multiple 'measures' led to transactional issues. Did unreliable measurements amplify the informational – and transactional – problems that organizations faced as a result of expanding trade and industrial activity? What was the nature of these problems? How did the markets manage them? These are important questions that remain unanswered.

1.3.2 *Transactions and Measurements*

Rapid expansion and internationalization of many commodity value chains during the nineteenth-century meant that firms had to exercise greater control over products and commodities (product specifications), method of manufacture (design specifications), delivery and contract terms (quality & quantity), traded quantities and price, etc.[45] However, I hesitate to propose these trends to be the reasons behind the standardization of both metrology as well as mensuration practices. Historians have shown how growth by itself did not guarantee standardization in the sense of systematizing practices, and neither did technological development.[46] Historical market practices were shaped by a complex interplay of social, political, and

[43] Jacobides et al., 'Benefiting from innovation'.

[44] Hoppit, 'Reforming Britain's measures': p. 91.

[45] S. Ponte and P. Gibbon, 'Quality standards, conventions and the governance of global value chains', *Economy and Society* 34 No. 1 (2005).

[46] J. Yates, *Control through communication: the rise of system in American management* (John Hopkins University Press, Baltimore, 1989), p. 271 ff. Yates has shown how growth or technological advances were not sufficient reasons for the systematization of communications in American businesses. Indeed, several context specific factors – such as the need to exercise control and the ideology of individual managers – influenced the adoption of systematic (or standardized) means of communicating within large corporations.

economic factors, which redefined existing, market relationships. [47] Many of these relationships required different kinds of measurements for decision-making, monitoring and control of economic activity. For instance, consider the management and control of product quality, which in this case can be broadly defined as the specification, composition and condition of products manufactured, traded or consumed. Many primary commodities such as grain were relatively non-standardized or indeed non-standardizable (chapter 6). The uniformity of such products depended upon several controllable factors (variety of the crop, application of fertilizers, water and soil condition, field preparation and other crop management techniques, mode of transportation, length of storage, etc.) as well as factors that were beyond the control of the producer (climate, war and conflict, availability and skill of labour, etc.). Management of quality in this case required dynamic methods of assessing and measuring product attributes. Manufactured commodities too suffered from the quality problems, if they were not produced according to design specifications (chapter 5), or where they could alter their composition during transportation, storage or handling.

Further, heterogeneity of many of the products traded was juxtaposed with problems of asymmetric information, leading firms to make decisions with only partial access to information.[48] There were, for instance, about 25 different varieties of domestic wheat available in Britain around the mid-1880s and about 40 varieties of foreign ones. Similarly, American cotton could be classed into more than 1200 possible varieties, depending upon the attributes being used to describe its quality. The complexity of information was not limited to primary commodities but also to manufactured products; information about the composition, condition and functionality of metal products (something that could not be assessed by visual inspection methods alone) became crucial in several industrial applications (chapter 5). Industrial organizations thus had to develop complex and sophisticated mensuration practices to manage such increasing complexity of transactional requirements.

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[47] Daunton, *Progress and poverty*, p. 279.

[48] S. C. Pirrong, 'The efficient scope of private transactions-cost-reducing institutions: the successes and failures of commodity exchanges', *The Journal of Legal studies* 24 No. 1 (1995); Ponte and Gibbon, 'Quality standards'.

Even relatively straightforward issues such as the quantity of products being exchanged turned out to be anything but straightforward. Several trades had their own methods of measuring quantity: dry goods were sometimes measured according to their weight and sometimes by volume. Many markets in the nineteenth-century continued to measure coal, wheat, fish, etc. by volume as was traditionally done. At times, the product would be measured for quantity according to one method at one end of the value chain, and by another method at the other end: e.g. both coal and grain had such multiple measurement conventions (chapters 4 & 6). Added to this was the increasing complexity in the structure of value chains, which involved several merchants or manufacturing groups, each specializing in a particular aspect of value addition and with particular access to information. Reliable measurements of quantities traded, needed to ascertain both price per unit and revenue, was of major concern and on which a lot of effort was expended. Developing mensuration practices to make estimates of quantities reliable involved intense negotiations between different groups each facing a different incentive structure. At times, achieving reliability involved a radical change in the mensuration practices as when measurements by volume were replaced with measurements by weight (chapter 4).

Measurements sometimes occupied centre stage during attempts to standardize products or grades (chapters 5 & 6). Product standards that emphasized a great degree of homogeneity or exactitude in terms of specifications, such as engineering products, required a greater degree of measurement standardization. This is also true when products had to be sorted into different grades. However, standardization in such cases was not only a matter of achieving technical precision of individual repeatable measurements, but had to take into account the motivations of the different groups that used these standards (both product as well as measurement standards). There rarely was one set of 'ideal' measurements that could be used to construct a given product standard, and at times measurement reliability was a product of compromise and negotiation rather than metrology. Competition, differentiation and coordination strategies helped to shape localized (in a geographic as well as community sense) mensuration practices.

1.3.3 *Metrological Regime*

Another reason why the British case is interesting to explore measurement issues is the non-coercionary nature of the metrological regime during most of the nineteenth-century. In 1824, with the introduction of the Imperial system of weights and measures, markets could operate under a relatively standardized metrological regime. However, the new legal 'measures' did not immediately replace the local 'measures'. The reformers of British metrology had recognized the difficulty of replacing local measurement units early on. They sought to overcome the relative non-uniformity of local 'measures' by connecting them to the primary standards of the Imperial system (chapter 2). The implication of this was that the use of local 'measures' was not forbidden for most of the nineteenth-century and most markets continued to use the older measurement units. An additional layer of legal and traceable measurement units was added over the existing layer of local 'measures'. This situation changed in 1878 when the Imperial measures were made the only legally recognized measurement units in Britain. Nevertheless, the use of non-Imperial units continued even at the close of the nineteenth-century, despite the government's best efforts to make the use of Imperial measures ubiquitous throughout Britain.

A review of metrological reforms and measurement practices raises questions about the role of metrology and that of the state in managing measurements. The state, in various capacities and forms was involved in reforming the metrological regime. However, the extent to which it was willing and able to involve itself in mensuration issues is unclear. Further, what is understood by the term 'state' is often ambiguous. As the following chapters in this thesis demonstrate, private interests were often routed through certain 'arms' of the state, such as the legislature.[49] This study of measurement practices is undertaken with this perspective: the state did not or could not coerce markets to use particular metrological standards and neither was it willing or able to influence measurement practices in all circumstances. The view presented in my study is consistent with a more nuanced understanding of the relative role of the state versus the market.[50]

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[49] For example, Daunton, *Progress and poverty*, p. 271 ff.

[50] Ibid., p. 278.

1.4 Thesis Contents and Structure

The study of historical mensuration practices involves the study of how people actually made measurements within different economic contexts and the methods that were developed to ensure their reliability. The thesis studies three such economic contexts in the form of detailed case studies dealing with different measurement problems (chapters 4 to 6). The case of the London coal trade discusses the problem of reliability of quantity measurements: how to make reliable measurements such that the physical amount of product delivered/received is actually the amount contracted for? The case of uniform wire sizes discusses the problem of reliability of measurements used as product or design specifications: how to ensure that heterogeneous producers and buyers used uniform wire sizes in the sale and purchase of metal wires? Finally, the case of wheat grades discusses the problem of reliable quality measurements: how to ensure that quality measurements captured the compositional, conditional and functional aspects of a heterogeneous commodity?

These cases have been analyzed on the basis of a conceptual framework developed to study mensuration practices in a micro-context (chapter 3). The framework considers the mensuration activity in terms of its process (observation, comparison, contextualization), the tools (instruments and standards), and the protocols surrounding them. The framework assumes that various economic groups, such as producers, merchants, consumers, trade and industry associations, professional societies, state, etc. exerted their influence on the mensuration activity. The nature of this influence depends upon the different incentives that these groups faced. Historically, the manner in which these different groups affected the different aspects of the mensuration activity is explored in each of the three cases. For example, which groups influenced the selection of product attributes to measure, and how, is explored in chapter 6. Similarly, chapter 4 explores the relative influence of the various groups in the selection of measurement tools and protocols, whereas chapter 5 explores how some groups focused on the standardization of metrology, whereas others were more concerned with mensuration practices.

The framework further assumes that the incentives facing the different economic groups are structured by various factors. These factors could be economic, political, or technological in nature. The manner in which they shape the incentives of different groups is also explored in the case studies. For instance, the political-economic factors shaping the incentives of the state and how they compare with economic incentives of private merchants is specifically explored in chapter 4. Similarly, the different incentives of the buyers, who are motivated by considerations of how they use a particular product, may not always coincide with the producer's incentives, who are motivated by consideration of how they manufacture the same product. The tension that the different incentives create, and its effect on mensuration practices, is explored in chapter 5. Incentives facing a given group could also change over time, which can affect mensuration practices and how these practices in turn change over time, an issue explored in chapter 6.

In terms of organization, the thesis is divided into two parts. The first part includes the theoretical and historical reviews that help in the construction of the conceptual framework. Chapter 2 contains a historical review of the nature of product measurements, problems of measurements that markets faced, the nature of the reliability problem, and the extent to which metrological standardization helps us to understand how markets managed these problems. The introduction of the Imperial measures in 1824, the motivations of the state concerning metrological reforms and its impact on mensuration practices is also considered. Chapter 3 includes a theoretical review that informs the various aspects of the conceptual framework. For instance, review of measurement theory helps to focus on the difference between the historical quests for measurement reliability as opposed to seeking measurement accuracy. Review of the standardization literature considers the significance of some of the analytical approaches in thinking about standards and standardization. The conceptual framework to analyse mensuration practices is described in detail in this chapter. The second part contains the three micro-studies. Chapter 4 contains the case of measurements in the coal trade, chapter 5 contains the case of the uniform wire sizes and chapter 6 contains the case of wheat grades.

The findings from the case analysis are summarized in chapter 7. It highlights the different ways in which markets resolved measurement issues: metrological standardization (chapters 4 & 5), standardizing protocols (chapters 4 & 6), third party monitoring (chapters 4 & 6), coordination by trade associations (chapters 5 & 6), etc. The chapter concludes the thesis by demonstrating that studying mensuration practices, not only metrological standardization, is crucial in understanding how historical markets managed measurements and transactions. The chapter also presents an argument that mensuration standards could be thought of as institutional packages that comprise of elements such as standardized processes, instruments, standards of comparison, rules and conventions, etc. Historically, changes in mensuration standards involved making changes to the package, rather than to individual bits such as metrological standards. This is an important issue in understanding how macro-level standards, such as metrological standards, were historically linked to micro-level practices, such as mensuration.

Chapter 2

Markets and Measurements: Metrological Standardization?

> 'A general uniformity of Weights and Measures is so obviously desirable [that] its establishment has been a fundamental principle in the English constitution from time immemorial... At the same time, it has commonly been considered as one of those objects which cannot [be] very precisely defined, [and] there are many instances in which departure from complete uniformity is not only tolerated, but established by law.'
>
> Parliamentary Report on Weights and Measures (1819)[1]

2.1 *Introduction*

The main purpose of this chapter is to explore the nature and variability of historical 'measurements' and the extent to which this variability stemmed from the multiplicity of 'measures'. The chapter also reviews the metrological framework in Britain during the nineteenth-century by focussing on the reforms introduced during this period, the standardization of metrological units through the introduction of the Imperial measures, the groups that seemed to have led these reforms, and the extent to which the new metrology reduced the variability in 'measures'. The importance of this review is that it raises several outstanding issues regarding the extent to which metrological reforms helped to reduce variability and increase the reliability of measurements.

As we will see in this chapter, historical 'measures' were highly contextual i.e. their meaning, significance and usage depended upon the context in which they were used and often varied across contexts. The metrological reforms of the nineteenth-century sought to decontextualize the 'measures' and make them uniform – in meaning, significance and uses – across all contexts.

In this chapter, we will also see how 'measurements' were variable and that variability was not always undesirable. Indeed in several situations, variable

[1] *PP Vol. XI 1819, First report of the commissioners on weights and measures*, pp. 314-23., Appendix B.

'measurements' seemed to have specific economic functions and therefore in those situations they were not unreliable. We will also review examples of institutions that helped markets manage the variability in 'measurements' according to simple do's and don't rules. One of the issues that emerges in the chapter is how metrological reforms and standardization affected the organization of the institutions that managed variable 'measurements.'

The review of metrological reforms raises questions about the role of the state in comparison to the market. Although the state was involved in the reforms, the extent to which it was willing and able to be involved in reforming mensuration practices remains unclear. Also, what is understood by the term 'state' becomes a pertinent issue. The chapter thus calls for a more careful understanding of the roles of the state and the economic groups within the market and their relative abilities to influence one another.

The chapter also focuses on the issue of standardization as a solution to resolve the problem of variable measurements, insofar as variability was considered to be a problem at all. The question that is raised here is whether standardization of metrological units was necessary and indeed sufficient to eliminate measurement issues in product markets. Such a view implies that standardization at the macro level was sufficient (and necessary) to eliminate transactional issues at a micro level. It also implies that decontextualized standards (metrological units) helped to eliminate measurement variability across all contexts. The chapter raises this as an issue that has to be considered when exploring how markets managed measurement issues in specific contexts.

This chapter is organized as follows. Section 2 considers the nature and variability of historical measurements and the contextuality associated with historical 'measures'. Section 3 discusses the metrological standardization and the events leading up to the introduction of the Imperial measures in 1824. Section 4 explores the motivations of the various groups involved in the metrological reforms since the mid-eighteenth-century, while section 5 focuses on the metrology during the nineteenth-century. Outstanding issues that are explored in the following chapters are discussed in section 6.

2.2 *Nature & Variability of Historical Measurements*

2.2.1 *Historical 'Measures'*

Historical measurements were based on anthropocentric 'measures'; they were based on the human form and in time evolved into units 'derived from the conditions, objectives, and outcomes of human labour'.[2] Such measurements were based upon social contexts and became representational in addition to being functional.[3] Often, measurement units were related to the method of production, such as those in the cloth trades used to measure the width of the cloth. The *ell* and the *yard* were both used to signify the breadth or width of cloth as was produced on the looms.[4] Measurement units also represented the manner in which commodities were transported, reflecting the means as well as the method of transportation. *Wagon-loads* and *cartfuls* represented the method of transportation, whereas *sacks*, *scoops* and *vats*, signified the means of handling or distribution. Productivity signalling units included those that indicated the extent of land that could be ploughed in a day or by a team of oxen and horses.[5] Measurements based on such 'measures' indicated human labours and were embedded in the context in which they were used.

This contextuality is especially evident in measurement units that were used in specialized occupations. In the production of coal on the estates of north England 'a baffling variety' of units were in use, including *chaldrons, tens, keels, weys, tons, metts, vats, quarters, bushels, corves, scoops, rooks, dozens, works, fothers, loads* (*cart-, wain-, wagon-, horse-*, etc.) and others.[6] Units such as *chaldrons* and *keels* were fairly specific to the coal trade and signified measurements used in the delivery and transportation of the commodity. In the weighing of wool, the trade used units such as the *sack* of wool, which was to be composed of 2 *weighs* (*weys*) that in turn was to comprise of 28

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[2] Kula, *Measures and men*, p. 5. He uses the term 'anthropometric' to mean measures derived from the human body, rather than measuring human form; it is a translation of the Polish term *'antropometryczne'* (p. 24); I prefer to use the term anthropocentric to mean measurements centered not only on human form but also based upon human activities and occupations, cf. R. Tavernor, *Smoot's ear: the measure of humanity* (Yale University Press, New Haven & London, 2007), p. 2.

[3] The term 'representational' is a translation from the Polish term for 'meaning' or 'significance' (*znaczenie* or *znaczeniowy*) and connotes 'to stand for' i.e. measurement units themselves signifying that which is being measured. e.g. land was measured in units that signified how much land could be worked upon from sunrise to sunset, Kula, *Measures and men*, p. 3.

[4] Connor, *English Measures*, p. 87 ff.

[5] Ibid., p. 37 ff. Kula, *Measures and men*, p. 4.

[6] J. Hatcher, *The history of the British coal industry (Volume 1: Before-1700)* (Clarendon Press, Oxford, 1993), p. 557.

stone or 350 pounds. A *load* or *char* of lead, wool, tallow or cheese was expected to be 12 *weighs* (*weys*).[7]

The highly contextual nature of historical measurement units implies that it is difficult to classify them neatly according to the physical property that they measured i.e. weight, volume, linear measure, etc. Consider the *bushel*, a measurement unit that has been around at least since the thirteenth-century, if not earlier. One of the earliest references to this unit links it to the *gallon* - a volumetric measure - which in turn is linked to the *pound* - a weight measure.[8] This chain of weight measure (*pounds*) defining a volumetric measure (*gallons*) in turn defining a volumetric measure (*bushel*) was reaffirmed once again in the late-fifteenth-century.[9] After the seventeenth-century, the *bushel* was mainly used for the measurement of dry goods such as seeds, barley, malt, fruits and vegetables, grain and coal. But without a reference to some specific context it was never unambiguously clear whether it was used as a unit of weight or volume (figure 2.1).

A nineteenth-century survey of existing legal and customary units suggests that several different *bushel* units were in contemporary use.[10] Depending upon the commodity being measured, the *bushel* was defined using either a volumetric or a weight unit. Just as it was used to measure coal (the *coal bushel*), the *bushel* was also used to measure fruits and was equivalent to 33 *quarts* or 4 *pecks*. In contrast, the *bushel* used to measure wheat, rye, barley, oats, flour or salt was based on a unit of weight and was linked to the *pound*.[11] Not only did the nature of the *bushel* unit depend upon the commodity being measured, it also varied between geographical locations. Consider some agricultural commodities such as potatoes, wheat and barley. The *bushel* used to measure potatoes in Cheshire, Derbyshire and Lancashire was equivalent to 90 *lbs*, whereas in Leicestershire it was equivalent to 80 *lbs*, in Surrey it was 60 *lbs* and in Middlesex it was 56 *lbs*. Wheat was measured in Cheshire

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[7] Connor, *English Measures*, p. 130.

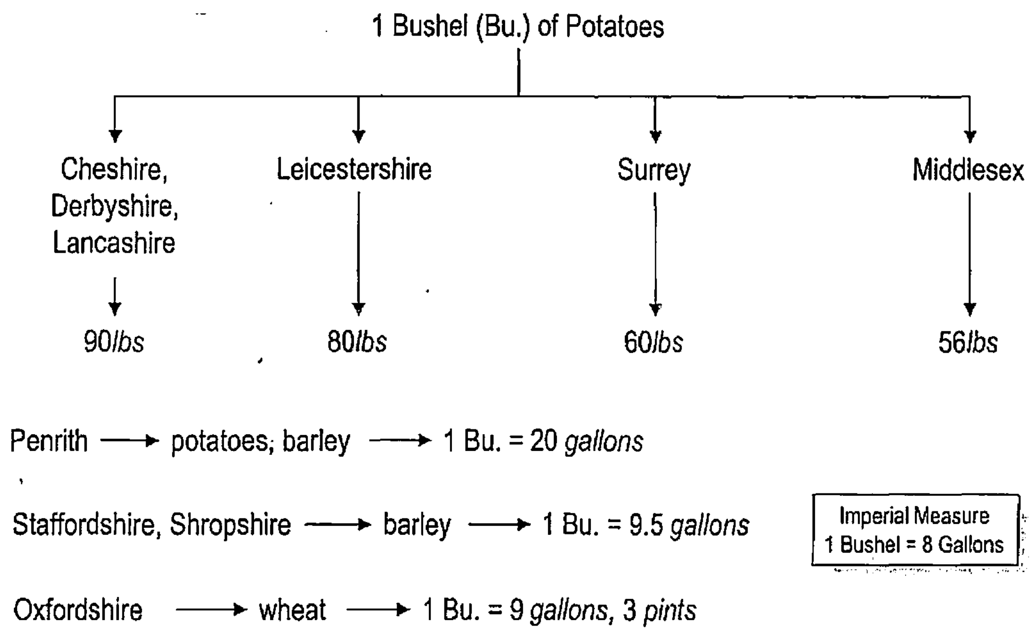
[8] Ibid., p. 151. Both the *Tractatus de Ponderibus et Mensuris* and the Assize of Bread and Ale of the mid-thirteenth-century state that 32 grains of wheat make a *sterling* (penny) and 20 pence make an *ounce* and 12 *ounces* make a *pound* and eight *pounds* make a *gallon* of wine and eight *gallons* of wine make a *bushel* of London, which is the eighth part of a *quarter*.

[9] Ibid., p. 153.

[10] This survey was part of the second report prepared by the Royal Commission on weights and measures, see *PP Vol. VII 1820, Second report of the commissioners on weights and measures.*

[11] Ibid., p. 483, Appendix A; the pound equivalent of one bushel for these commodities was: wheat (56 or 57), rye (55), barley (49 or 50, in Sussex it could be 53), oats (38), flour (or bread or biscuit - 42 or 45), salt (56, 65, 75 or 120, foreign salt could be 84)

Figure 2.1
Variability of Measurement Units: e.g. *bushel*



Source: Parliamentary Papers (1820) Vol. VII (477-509)

and Liverpool using a *bushel* of 70 *lbs*, but in Stockton it was equivalent to 60 *lbs*. In Cheshire and Liverpool, barley was measured using a *bushel* of 60 *lbs* whereas in Devonshire it was measured using a *bushel* of 50 *lbs*. In Penrith, potatoes and barley were measured using a *bushel* of 20 *gallons*, whereas in Staffordshire and Shropshire barley was measured using a *bushel* of 9.5 *gallons*. Barley was sometimes measured in Liverpool using a *bushel* of 34.5 *quarts* or 9 *gallons* (Winchester measure), whereas wheat was measured in Oxfordshire using a *bushel* of 9 *gallons* and 3 *pints* (figure 2.1). Most of these equivalences were defined by legislation and the rest were based on local usage.

Consider another commonly used measurement unit, the *ton*. Although expressed as equivalent to 20 *cwt* or 2,240 *lbs avoirdupois*, in the early nineteenth-century a *ton* of wheat was equivalent to 20 *bushels*, a *ton* of lead equivalent to 19.5 *cwt* and a *ton* of linseed oil was equivalent to 236 *gallons*. Similarly a *ton* of barley was equivalent to 1,709 *lbs* whereas on the canals a *ton* of oak or ash could be either 40 ft^3 or 48 ft^3. There were regional variations to the *ton* and the context in which it was used. In Derbyshire, the *ton* used to measure bark, gypsum, lime, coal, straw, hay, lead ore, etc. was the equivalent of 2,400 *lbs*, whereas the *ton* used to measure grindstones was 15 ft^3, and that used to measure broken stones was 20 *bushels*. A *ton* of potatoes in Essex weighed 2,520 *lbs*, in Berwickshire they weighed 28 *cwt* (or 3,136 *lbs*)[12] and in Kincardineshire they weighed 4 *bolls*.[13] A *ton* of timber in Devonshire or Wiltshire was 40 ft^3, whereas a *ton* of sifted gravel in Stratford, Middlesex was 23 ft^3. Portland stone in Dorset was 16 ft^3 to the *ton*, whereas limestone in Leicestershire was 40 *bushels* (5 *quarters*) to the *ton*.

2.2.2 *Historical 'Measurements'*

The contextuality and variability of historical 'measures' appear to have been mirrored in historical 'measurements'. In addition to variable units, 'measurements' were based on practices, norms and conventions that varied according to context and geography. Consider the use of heaped measures while measuring dry goods using volumetric units. Traditionally, many dry goods, including grain, fruit, coal, etc, were measured for sale using capacity measures, often using vessels that were round in shape.[14] A common practice while measuring dry goods in this way was to form a heap such that the total quantity given would contain the amount within the vessel as well as in the heap on top. The practice of heaping was customary in England since the medieval period and the method in which the heap was to be provided was sometimes regulated by legislation.[15] This was not a consistent practice and dry goods were also measured using the 'stricken' measure, i.e. without the heap. A statute from the fourteenth-century, while stating that corn should generally be measured without heap, required that measurements of corn relating to the rents and farms of lords be given according to the heaped measure. The extra quantity included in the heap differed according to the location, type of commodity and according to trade.

Rules regarding the heap changed between the fourteenth and eighteenth centuries. The 'extra' amount included in the heaped *bushel* increased from about one-eighth of the physical measure, during the time of Henry VII, to about a quarter, during the

[12] If shipped for London and assuming 112 lbs make one *cwt*.

[13] Equivalent to the 'standard' English ton of 20 *cwt*.

[14] Connor, *English Measures*, pp. 178-79.

[15] Ibid., p. 179 & 56; *Act for ascertaining the coal measure, 12 Anne Stat. 2 C.17*, 1713, which regulated the coal bushel. The statute specified the shape of the container representing the measure as well as the size of the heap.

reign of Queen Anne. The practice of heaping endured for centuries, initially as the privileges of the lords, kings and even the universities of Oxford and Cambridge, and eventually becoming a part of commonly used measurements. Such practices meant that measurements were highly approximate even when nominally invariable measurement units were used. Eight heaped *bushels* could contain the equivalent volume of ten or more or less nominal *bushels*, depending upon the extent of heaping. Historically, the custom and practice in the market, as opposed to the legal standard, was to provide eight heaped *bushels* as if they were nine stricken legal *bushels*. Over time, the nine *bushel* measure had become common enough in usage to be given a name, the *fatt* (or *vat*). As a consequence, nine heaped *bushels*, or the *fatt*, became equivalent to ten stricken legal *bushels*.[16] The practice of heaping persisted until the nineteenth-century, particularly in commodity trades using volumetric measures for dry goods such as coal and grain (chapters 4 & 6).

Another example of variable measurements is the variation in the size of the bread loaf as was regulated by the Assize of Bread and Ale.[17] The assize specified different weights of loaves of bread for a fixed price of a farthing (a quarter of a penny) in inverse proportion to the price of a *quarter* of wheat. As the price of one *quarter* of wheat increased by increments, the weight of a 'farthing loaf' was to decrease proportionately as specified by the assize. This mechanism ensured that a loaf costing a farthing would always be available to the poorest customers, even though they would receive less bread for a farthing when grain prices increased.

> 'Although it is apparent that buyers would in effect pay more for the same amount of bread, the entire basis [was] predicated on the belief that poorer consumers [were] expected to simply reduce their bread intake when grain prices rose.'[18]

The assize maintained a constant price for a loaf of bread, but it adjusted for value changes by changing the quantity available per unit of price. This mechanism established a relationship between grain price and weight for each type of loaf of bread and ensured that bakers would make a sufficient return despite the

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[16] See Connor, *English Measures*, pp. 156-58.

[17] J. Davis, 'Baking for the common good: A reassessment of the assize of bread in medieval England', *Economic History Review* 57 No. 3 (2004): p. 468. The Assize was known as the *Assisa Panis et Cervisie*.

[18] Ibid.: p. 469.

fluctuations in grain price, while the poor could still afford to buy bread.[19] The assize existed until the nineteenth-century, however, its enforcement had dwindled by late-eighteenth-century and the practice was eventually abolished in 1836.[20] Such a practice was not unique to medieval England, but was common across medieval Europe.[21]

Some historians consider the variability of historical 'measurements' as evidence of the existence of a 'moral economy' of the poor (as opposed to the rich). E P Thompson, who is thought to have coined the term, wrote that while measuring grain the poor were given the right to shake the measure 'so valuable was the poor man's corn that a looseness in the measure might make the difference to him of a day without a loaf.'[22] Other historians argue that such morality – to convey generosity – was not confined to the poor alone. Measurements that captured information about productivity, such as measures of land area were used to allow farmers disadvantaged by poor soil fertility or climate to trade on equal terms with those farmers fortunate enough to till richer or more fertile lands.[23] Variation in customary measures is viewed as a 'system of handicapping, theoretically ensuring that everyone arrived at the finishing line together.'[24]

Nevertheless, it is difficult to ascribe moral values to all instances of measurement variability, which at many times could be based on privileges or opportunism. 'Heaped measures' could just as well be used for moral, discriminatory, or opportunistic reasons (chapter 4) and only the specific context can determine which of the three reasons pre-dominate. Such practices demonstrate how 'measurements' could be affected by institutional rules, norms or customs that were either regulatory or market-based.

There are further examples of institutional norms influencing historical measurements. In the grain trade, merchants in several market towns would use a

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[19] Ibid.: p. 479, especially Table 3; cf. Connor, *English Measures*, pp. 193-227.

[20] Connor, *English Measures*, p. 215; S. Webb and B. Webb, 'The assize of bread', *The Economic Journal* 14 No. 54 (1904).

[21] Kula, *Measures and men*, pp. 72-75.

[22] E. P. Thompson, 'The moral economy of the English crowd in the eighteenth century', *Past & Present* 50 No. 1 (1971): p. 102; Sheldon et al., 'Customary corn measures', p. 34. Shaking the measuring vessel while pouring the grain increased the amount of grain contained in the measure, see chapter 6.

[23] Hoppit, 'Reforming Britain's measures'. p. 90; Kula, *Measures and men*, p. 31.

[24] Hoppit, 'Reforming Britain's measures'. pp. 89-90.

'weighted' *bushel*, where the grain measures were expressed in terms of its density i.e. weight per volume or 'natural weight' as it was sometimes known. For example around 1830, wheat brought into market towns such as Sheffield from other towns such as Gainsborough and Lynn was sold by the *bushel* weighing 63 *lbs* - or in equivalent terms a *quarter* weighing 504 *lbs* - whereas wheat from Hull was to be delivered on the basis of 60 *lbs* per *bushel* (480 *lbs* per *quarter*).[25] Such measurements captured not only the amount of grain involved in the exchange - expressed by the *bushel* measure - but also the quality of grain - expressed by the density measure. The reasoning in this case was that grain of higher density was of better quality than grain of lower density, and was highly valued by buyers for its bread making ability (chapter 6). There is evidence of similar practices across medieval and early modern Europe.[26] As a result, there may have existed a geography of measures, similar to a geography of prices, such that it was possible to distinguish different contours of measurements used to capture value in different ways.[27]

Another illustration of the interaction between institutions and measurements is the custom of providing the 'ingrain' present in the coal trade. This practice involved the provision of an additional unit given for every 'score' of twenty units. Thus, when twenty *chaldrons* (a measure peculiar to the coal trade) of coal were delivered, it was customary to provide an additional *chaldron* so that the total delivered was twenty-one *chaldrons* instead of twenty. The seller would charge only for twenty *chaldrons*, in effect providing a discount of five per cent on the price.[28] The merchant seller would at times withhold the additional quantity in the score, a practice called 'loading bare', which created a host of monitoring and enforcement issues. Over the centuries the practice of providing an ingrain became a statutory requirement: legislation in 1807 regulated exactly how the ingrain was supposed to be measured and the conditions in which it was to be provided (chapter 4).[29] Merchants in the coal trade, as in other trades where such practices were present, would benefit from the arbitrage the

[25] *PP Vol. XLIX, 1834, Returns from corn inspectors*, p. 262.

[26] Kula, *Measures and men*, pp. 105-08; S. L. Kaplan, *Provisioning Paris: Merchants and millers in the grain and flour trade during the eighteenth century* (Cornell University Press, Ithaca and London, 1984), pp. 52-3.

[27] Kula, *Measures and men*, p. 106; Thirsk, ed. *Agrarian history*, p. 815.

[28] *PP 1830 Vol. VIII, Report of the select committee on coal trade*, p. 361, Appendix 4(h), for an example of deliveries made using the ingrain showing a Ship Meter's delivery bill.

[29] *Act for regulating the delivery of coals, 47 George III, C.68*, 1807, para LXII.

different measurements could provide - buy using a larger measure and sell using a smaller measure.[30]

Such examples illustrate the variability of measurements, on the one hand, but also the institutional rules that emerged to manage them, on the other. The rules that specified, for example, the circumstances in which to provide the heap or the ingrain, or the size of the loaf of bread, served as mechanisms to manage measurements made within particular historical contexts. Many of the institutional practices may well be considered as the source of measurement variation, if seen from a macro perspective. However, from a narrower or micro perspective, these same institutions served to organize the measurements according to simple 'do and don't' rules. It is not unrealistic to expect these rules to have been generally known to groups who operated within those contexts. Thus, institutional rules that historically organized and managed measurements in specific circumstances existed alongside many historical 'measures' that were highly contextual.

This situation changed during the nineteenth-century when metrological standardization introduced decontextualized measurement units within the British economy. The uniformity in 'measures' that such standardization introduced was considered desirable at the time (see quote from a parliamentary report at the beginning of this chapter).

2.3 *Metrological Standardization & Introducing Imperial Measures (1824)*

Abstraction and decontextualization of measurement units from their anthropocentric origins is a historical fact and seems to have occurred at different stages throughout history. Transitions from the concrete to abstract or notional concepts of measurement units - from the particular *my bushel, your bushel* to the general *the bushel* - are important turning points in historical metrology.[31] Abstraction is a complex mental act demanding the ability to abstract a single common (physical) property from several qualitatively different objects, and subsequently to use that property as a comparator.[32] Thus, from the *wine gallon* and the *ale gallon,* two separate measurement units in use since the Middle Ages with slightly different cubic

[30] Kula, *Measures and men.* provides examples of similar practices in the grain trade.

[31] Ibid., p. 24.

[32] Ibid., p. 43.

capacities, abstraction involved first selecting one particular attribute to measure: the property to occupy a given volume of space.[33] This then made it possible to define a single notional measurement unit, the *gallon,* in order to measure volume in any context (whether liquids or dry goods) and thereby replace all the other different types of gallons that were in use earlier. This abstracted measurement unit did not require any further qualification and came to signify only the information about the physical property it measured, *irrespective of the context,* in which it could be used: this made it decontextualized.

The Imperial measures, introduced in 1824, defined the various measurement units either as units of volumetric measure (or capacity), weight, or linear measure. They were expressed purely on a notional basis without any reference to the geographic, occupational, functional, or social contexts in which they were to be used.[34] In other words, they were decontextualized. The notionalization of units, whether a result of anchoring them to some arbitrary artefact or to some artefact linked to a naturally occurring phenomenon, is an important event in the metrological standardization of the nineteenth-century, as we shall see.[35]

Attempts to standardize British 'measures' have had a chequered history. The Crown's efforts to unify the standards of weights and measures are often traced to the Magna Carta of 1225, which stated that

> "There shall be [through] our Realm, one Measure of Wine, and one Measure of Ale, and one Measure of Corn; that is to say, the Quarter of London; and one Breadth of dyed Cloth, Ruffets and Haberjects, that is to say, two Yards Culne within the Lifts; And it shall be of Weights as it is of Measures."[36]

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[33] The wine gallon equalled 231 inches^3, whereas the ale gallon equalled 282 inches^3; Connor, *English Measures,* p. 162.

[34] *Act for ascertaining and establishing on uniformity of weights and measures, 5 George IV C. 74,* 1824., Para VI

[35] S. Schaffer, 'Metrology, metrication and Victorian values', in *Victorian Science in Context,* B. Lightman. ed. (University of Chicago Press, Chicago & London, 1997), pp. 440-43; cf. Kula, *Measures and men,* chapter 17, who writes that the traditional measures were 'human' and that the modern measures (i.e. the metric measures), are conventional, 'dehumanized' and alienated, p. 123; also Alder, 'Revolution to measure'; Hoppit, 'Reforming Britain's measures': p. 90.

[36] *Magna Charta, 9th of Henry the third AD 1225, § 25* as reproduced in House of Commons Reports (1738-65) Vol. II 1758, *Report of the Carysfort committee on weights and measures,* p. 413. Nevertheless, many customary British units are pre-Norman or Saxon, or even Roman in origin, Connor, *English Measures.*

Efforts to make measurement units traceable to some natural phenomenon were made at various times since the medieval times. For instance, the 'Assize of Weights and Measures' attributed to the year 1302 or 1303 stated that the 'English penny [shall] weigh thirty-two grains of wheat dry in the midst of the ear.[37] A statute of Edward II from the fourteenth-century states that three barleycorns, round and dry, make an inch, twelve inches a foot, three feet a yard, etc.[38]

Irrespective of this, other statutes attempted to link measurement units to each other or to some arbitrary artefact, rather than a natural standard. The statute of Henry VIII from 1531 defined a *beer barrel* to be equivalent to thirty-six *gallons*. In the same statute, the *barrel* for measuring ale is defined as being equivalent to thirty-two *gallons*. Similarly, the *firkin* used to measure beer was to be nine *gallons*, whereas that used for measuring ale was to be eight *gallons*; and so also for the unit known as *kilderkin* - eighteen *gallons* for measuring beer and sixteen *gallons* for measuring ale.[39] An earlier statute from the fifteenth-century had defined the *barrel* to measure wine to be equivalent to thirty-one and a half *gallons*.[40] Later, during the reign of Elizabeth I, physical artefacts were made that represented legal standards, such as the Exchequer standard *gallon*, which was a metal vessel stamped with a crown signifying its authenticity. This primary standard was defined as an arbitrary physical artefact with no apparent relation to any naturally occurring standard.[41]

Historically, standardizing measurement units did not always involve rationalization of number of units that could be legally used. Often, it meant establishing equivalences between the various units in use. In the eighteenth-century, the ale and

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37 Connor, *English Measures*, p. 320. See Appendix A (d), which contains the text (in English) of the Assize titled *'Tractatus de Ponderibus et Mensuris'*. This phrase also appears verbatim in 51 Henry III of 1266, which is referred to in the parliamentary select committee report, *PP 1813-14 Vol. III, Report from the committee on weights and measures*, p. 134. The entire text of the clause is "that an English Penny called the Sterling, round without clipping, should weigh 32 grains of wheat, well dried and gathered out of the middle of the ear; and 20 pence to make an ounce, 12 ounces a pound, 8 pounds a gallon of wine, and 8 gallons of wine a bushel of London."

38 *PP 1819 Vol. XI*, pp. 314-23, Appendix B.

39 *Carysfort Committee Report (1758)* p. 416.

40 Ibid.; the statute of *1 Richard III C.13, 1485* as reproduced in this report. The statute also defined other units to measure wine or oil such as the *ton*, which was to be 'twelve *score* and twelve *gallons*', a *pipe* equivalent to 'six *score* and six *gallons*', a *Tertian* composed of 'four *score* and four *gallons*' and a *Hogshead* equivalent to 'sixty three *gallons*.'

41 Connor, *English Measures*, p. 159; the Elizabethan standards in turn were derived from older standards of Henry VII.

beer *barrels* were unified and made equivalent to thirty-six *gallons* (43 George III).[42] Nevertheless, a *barrel* of anchovies was defined to be equivalent to sixteen *pounds* (27 George III), that of apples to be equivalent to three *bushels* (12 Charles II), of barilla to be equivalent to 2 *cwt* (12 Charles II), and that of beef to be equivalent to 32 *wine gallons* (38 George III). A *barrel* of eels was to be equivalent to forty *gallons* according to 32 Edward IV, but equivalent to thirty *gallons* according to 2 Henry VI. A *barrel* of honey was to be thirty-two *wine gallons* according to 23 Elizabeth, but otherwise could be forty-two *gallons* of twelve *pounds* each.[43] Various legislative efforts also attempted to enforce the use of particular measurement units to regularize the income of the Crown.[44] For instance, a revenue Act of 1660 defined the *barrel* to be used for beer, ale and other liquors, whereas a finance Act of 1701 made it obligatory for the malt trade to use the Winchester *bushel*.

Reformers in the eighteenth- and nineteenth-century, interested in overhauling existing British 'measures' bemoaned the 'despotic influence of custom', which they thought was responsible for the existence of the hundreds of measurement units in use. They argued that historical attempts to standardize British 'measures' were undertaken on a case-by-case basis and the result of such uncoordinated and 'shabby' attempts was that 'every new law gave room for exceptions [which] being a departure from the Principle of Uniformity, was probably a precedent for another [departure].'[45] They also argued that errors in the construction of the physical artefacts, either deliberately or due to poor workmanship, were often perpetuated. Such variations, according to the reformers, crept into general use and were in turn repeatedly sanctioned by their adoption in legislation, leading to the vast diversity of measures.[46] The efforts to standardize British 'measures' from the eighteenth-century onwards became rooted in attempts to reduce its diversity.

Two parliamentary committees chaired by Lord Carysfort in 1758 and 1759 made a comprehensive study of legal 'measures' in force at the time and also made a detailed review of all the existing statues and legislation regulating weights and measures. The committee recommended that all previous legislation relating to

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[42] The following examples are taken from the *PP 1820 Vol. VII.*, Appendix A.

[43] Ibid., p. 478., Appendix A.

[44] Hoppit, 'Reforming Britain's measures': pp. 92-93.

[45] Ibid.; *Carysfort Committee Report (1758)*, p. 421.

[46] *PP 1819 Vol. XI*, pp. 314-23, Appendix B; *Carysfort Committee Report (1758)* p. 421.

weights and measures be abolished and reduced into a single act. It sought to declare the *yard* promulgated by Elizabeth as the standard measure of length, derive the measures of capacity and weight on the basis of this length measure, and reduce all such measures into a hierarchical arrangement.[47] No legislative action followed this committee's reports in 1758-59, and for the next half a century no other official efforts were made to reform British metrology.[48] Even so, legislation such as the Act of 1791 regulating the payment of duty on import and export of corn, provided for the trade to use customary measures while being taxed by the state on the basis of standardized measurement units.[49] Subsequent attempts by the parliament in defining standards of weights and measures were made in the early nineteenth-century with the appointment of the Select Committee of Weights and Measures that reported in 1814. Various parliamentary and select committee reports were tabled between 1814 and 1821 and this process eventually culminated in the establishment of the Imperial standards by legislation of 1824.[50]

Between 1760 and 1800 reformers sought to construct more precise copies of the physical standards. Initial attempts revolved around comparing the existing standards kept with the Exchequer and the Royal Society to copies made with newer materials and greater precision. John Bird's copies of the standard *yard*, commissioned by the Carysfort Committee, were compared to those developed by General William Roy, Sir George Shucksburg and Edward Troughton.[51] Subsequent attempts tried to define the standard *yard* in comparison to an invariable natural phenomenon such as the arc of the meridian or the length of a pendulum.[52] The French meter was being defined around the same time as the ten-millionth part of the arc of the meridian stretching from the pole to the equator. Based on the

[47] *Carysfort Committee Report (1758)* p. 438; a copy of the medieval yard had been recently prepared by John Bird , an instrument maker and an acknowledged authority on scale division.

[48] Zupko, *Revolution in Measurement*, p. 74; A. D. C. Simpson, 'The pendulum as the British length standard: A nineteenth-century legal aberration', in *Making instruments count: Essays on historical scientific instruments presented to Gerard L'Estrange Turner*, R. G. W. Anderson et al. eds. (Variorum, 1993), p. 180; Hoppit, 'Reforming Britain's measures': p. 95. A few individual parliamentarians, however, remained active in promoting the need to unify 'measures' according to some sources, see R. Adell, 'The British metrological standardization debate, 1756-1824: The importance of parliamentary sources in its reassessment', *Parliamentary History* 22 No. 2 (2003); Hoppit, 'Reforming Britain's measures'.

[49] Adell, 'British metrology': p. 173. See also *An Act for regulating the importation and exportation of corn... 31 George III C 30*, 1791, clause LVII.

[50] Zupko, *Revolution in Measurement*; Adel, Hoppit, 'Reforming Britain's measures'.

[51] Simpson, 'British length standard', pp. 180-82; Connor, *English Measures*, pp. 249-50.

[52] *PP 1813-14 Vol. III*, pp. 134-35.

recommendations of Dr. W Hyde Wollaston of the Royal Society and Professor Playfair from Edinburgh, the standard *yard* was re-defined by the length of a pendulum that had a frequency of 60 vibrations per minute (or once every second).

Once the existing standard *yard* was pegged to a natural or abstract phenomenon, the standards of weight and capacity too were defined in a similar fashion. It was discovered that the specific gravity of distilled water was invariable at a given temperature and that one cubic foot of water would weigh 1000 *avoirdupois ounces* at 52.5 degrees Fahrenheit. In this manner, all the three primary standards of linear measure, weight and capacity could be linked together using some naturally occurring phenomenon, the reformers argued. Figure 2.2 shows these links and how the various standard measures were defined in relation to each other. The reformers were also keen to achieve economy in the number of units as well as the simplicity in which units within a given hierarchy were calibrated with each other. In defining the equivalence between the different measures using the weight of water as a reference, the reformers suggested that

> 'It is desirable that all minute fractions of weight should be avoided. There will be much less chance of error [if] only one or two weights are employed, than if a greater number were necessary, which would be the case if fractional parts were required'.[53]

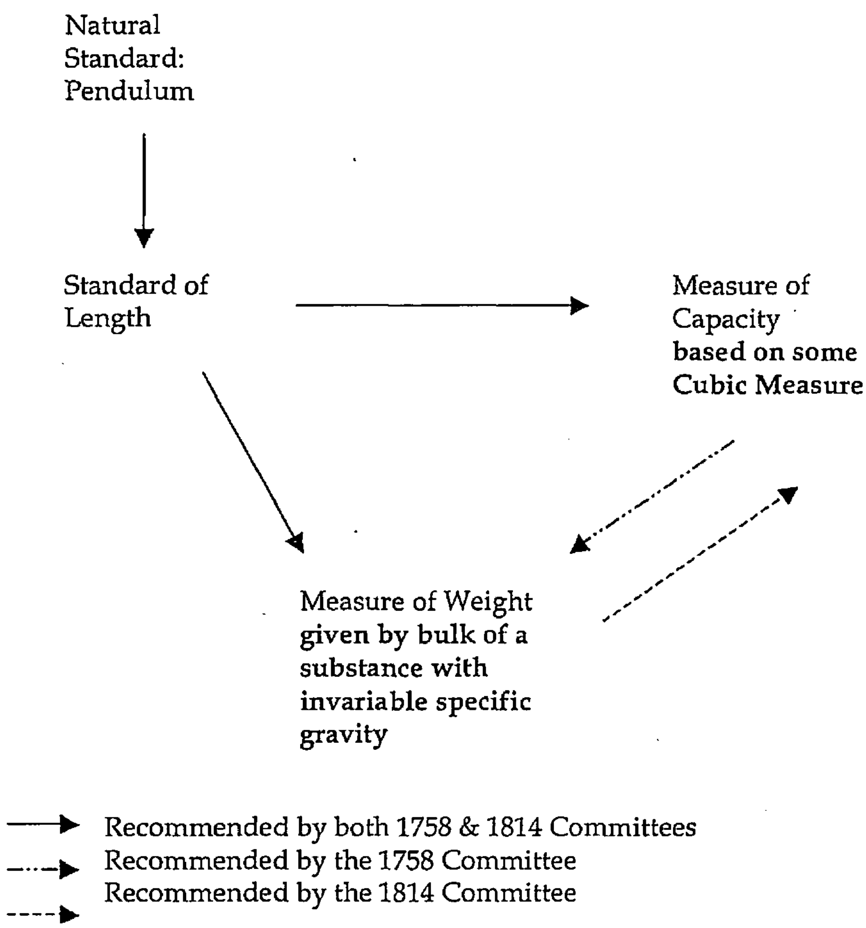
In this fashion, the 1824 Act introduced legal standards that were devoid of significance in any particular geographic or occupational context, and were linked to abstract and natural phenomena that were considered to be invariable (figure 2.3). Or were they?

The new Imperial units were not completely devoid of any social context. The eighteenth-century attempts to define the standard *yard* were efforts to re-define an existing measurement unit in invariable terms, rather than defining a new measurement unit as the French *savants* attempted with the *meter*.[54] The nineteenth-century attempts to peg the standard *yard* of 36 *inches* to the seconds pendulum was really an attempt to discover a natural phenomenon that would correspond to a measurement unit that had been arbitrarily determined and generally accepted

[53] Ibid., p. 135.

[54] Connor, *English Measures*, p. 243; Simpson, 'British length standard', p. 179; K. Alder, *The measure of all things: The seven-year odyssey and hidden error that transformed the world* (Free Press, New York, 2003).

Figure 2.2
Traceability of Primary Measurement Units



Source: PP 1813-14, Vol. III p. 135

through long usage and custom. The 36 *inches* of this standard *yard* could be linked to the pendulum in an invariable fashion only under some particular circumstances. The length of the pendulum vibrating 60 times a minute when measured in London at a temperature of 52.5 degrees Fahrenheit measured a little more than 39 *inches*. The reformers equated the standard *yard* to 36 of these 39 (and some more) *inches*. Some extraordinary efforts were made to link an existing artefact to a natural phenomenon!

It appears that the primary objectives of the reformers in this case were twofold. By relating an existing standard to a naturally occurring phenomenon they were legitimizing an already existing measurement unit. Simultaneously, they also

Figure 2.3
Imperial System of Weights & Measures 1824

Length	*Weight*	*Capacity*
Yard (Primary Measure)	Troy Pound (Primary Measure)	Gallon (Primary Measure)
1 Yard = 3 Feet	1 Troy lbs = 5,760 grains	1 Gallon = 10 Avoirdupois lbs
1 Foot = 12 inches	1 Avoirdupois lbs = 7,000 grains	1 Gallon = 4 Quarts
5½ Yards = 1 Pole/Perch		1 Gallon = 8 Pints
220 Yards = 1 Furlong		2 Gallons = 1 Peck
1,760 Yards = 1 Mile		8 Gallons = 1 Bushel
		8 Bushels = 1 Quarter

Troy Measures	Avoirdupois Measures
1 lbs = 12 ounces	1 lbs = 16 ounces
1 ounce = 20 Pennyweight	1 ounce = 16 drams
1 Pennyweight = 24 grains	

Source: 'An Act for Ascertaining and Establishing Uniformity of Weights and Measures', 1824 (5 George IV C. 74)

intended to codify a method of reconstructing the primary linear standard from what was ostensibly a neutral, objective, natural, and invariable phenomenon.[55] Even the definition of the new standards of weight and capacity were attempts to relate existing customary units to some natural phenomena rather than the other way around. In this manner, the British reformers mirrored the efforts of the French *savants* of the 1790s and their efforts to define new metric measures by starting with the natural phenomena.[56]

But were the new Imperial standards invariable, or based upon a phenomenon that was invariable and reproducible? The reliability of the seconds-pendulum, as the natural basis for the length standard, depended upon the exact and unvarying relationship between its length and periodicity. But, the periodicity of the pendulum is also affected by the local strength of the Earth's gravitational field. The field shows

[55] Simpson, 'British length standard', p. 182. Edward Troughton was able to define a complete system of weights and measures based on a very precisely constructed linear measure that was, in theory, independent of an arbitrary physical artefact.

[56] *PP 1813-14 Vol. III*. This would not be the first time that British and French concurrently made efforts to standardize their respective 'measures'. In the mid-eighteenth century, there was an attempt to compare the 'measures' used in the two countries with a view to developing some way of standardizing the conversion from one to another; 'An anonymous account of comparison of measurement standards between England & France', *Philosophical Transactions (1683-1775)* 42 No. 470 (1742-43).

sufficient variance across locations to necessitate the adjustment of the length to maintain a constant period. In other words, the invariability of the length of the pendulum to reconstruct the primary length standard could not be assured, a realization that dawned upon the reformers after 1824.[57] Doubts regarding the reliability of the density of water and the accuracy with which it could be measured also surfaced around the same time.[58] This raised questions regarding the basis of reconstructing or re-defining the primary weight and capacity standards. By the mid-nineteenth-century the reformers sought a complete separation from any natural basis of defining measurement standards.[59] The 'natural constants' that had been so essential to earlier reformers were abandoned in favour physical reference standards. The new basis for defining the standard of length, for instance, was in reference to the length of a piece of metal preserved in a prescribed fashion at a prescribed temperature.[60]

The entire exercise of initially basing the physical standards on some natural phenomenon had served to initiate an intellectual and institutional transition in British metrology. It created a legal metrology that was based mainly upon measurement units that were notional and devoid of any context. Previously, the *ton* and the *bushel* were either a unit of weight or of volumetric capacity, depending upon the commodity being measured and the geographical context (figure 2.1). Some of this flexibility was due to usage, but some of it had legal sanction. The *Imperial ton* and *bushel* that replaced these older units did not have this flexibility. Legally, the *ton* was defined as a unit of weight, whereas the *bushel* was defined as a unit of capacity. Also, the legal metrology was based upon measurement units that were traceable and linked with each other in a hierarchical manner. Traceability was intended to

[57] Simpson, 'British length standard', p. 174.

[58] Zupko, *Revolution in Measurement*, p. 190.

[59] Simpson, 'British length standard', p. 190. The primary standards of the 1824 Imperial measures were held in the Houses of Parliament and were destroyed in the fire that engulfed the building complex in 1834. The fire was apparently caused by overstoking the furnaces that heated the House of Lords when old papers and tallies held by the Exchequer were burnt; Connor, *English Measures*, p. 261.

[60] Zupko, *Revolution in Measurement*, p. 190. Coincidentally, the *meter* that had been defined on the basis of the length of the meridian was also detached from this natural standard and defined with reference to a physical artefact, after the variability of the meridian and errors in its estimation were exposed; Alder, *Measure of all things*. In the twentieth century the meter was once again pegged to a natural phenomenon, the speed of light. BIPM (Bureau Internationale des Poids et Mesures) now defines the meter as 'the length of path travelled by light in a vacuum during a time interval of 1/299792458 of a second'; www.bipm.org/en/si/base_units/ accessed online on April 16, 2008.

make the measurement units enforceable (assuming proper infrastructure and political will) and the individual units reconstructable.

2.4 *Who led the Metrological Reforms?*

If we accept the view that the introduction of the Imperial measures in 1824 was a historical watershed and that there were deliberate efforts made to reform the existing British 'measures', the question that arises is why such reforms were considered necessary and by whom. Also, the issue is whether these were market-led/private initiatives or did the state impose these 'measures' on the market/economy to solve transactional issues. Three contrasting views may be identified in historical literature of this period. One view proposes the need of the state bureaucracy to standardize 'measures' to enhance governance and control of economic activities that generated fiscal revenue.[61] An alternative view presents the impetus for metrological reform to be derived from private initiatives, either by individual parliamentarians or by the scientific community.[62] Other historians have stressed the primacy of technological innovation and the role of scientists and scientific societies in influencing metrological reforms.[63] These views need not be mutually exclusive and in fact this section does not offer reconciliation between the three views. But by examining them we have an appreciation of the various groups involved in the metrological standardization of the late eighteenth and early nineteenth-century. The review also provides a basis for understanding the extent to which state-managed standardization at a macro level helped to address transactional issues at a market level. One of the key insights from this review is that the **bureaucratic** need of the government coincided with a **political** need for uniformity of 'measures'. To this extent, different parts of the 'state' were involved in the process: administrative departments representing the bureaucracy, and the parliament representing political interests. Each had different motivations and incentives, but had a similar purpose: reform existing 'measures' and introduce a uniform and standardized metrology.

[61] Ashworth, *Customs and excise*; Scott, *Seeing like a state*.

[62] Hoppit, 'Reforming Britain's measures'; Adell, 'British metrology'.

[63] Zupko, *Revolution in Measurement*; Schaffer, 'Metrology'.

2.4.1 Governance and Control

The historical view supporting state-led reforms suggests that effective central monitoring and the bureaucratization of fiscal revenue required a standardization of measurement units and suppression of local 'measures'.[64] The state's capacity to generate fiscal revenue, as a whole, had increased towards the end of the eighteenth-century, and gave rise to a fiscal-military state.[65] This required collection of extensive local knowledge of production and trading practices, and surveillance and control of the 'common' economy (pilfering, smuggling, adulteration, etc.). Throughout the eighteenth-century, the state sought ways to make the taxable commodities more amenable and conformable to its system of gauging. It tried to shape the production of taxed goods while centralizing administrative functions, such as installing a uniform method of gauging taxed goods predominantly at the source of production or distribution. In short, this view argues that achieving a uniform system of taxation, and a national market linked together by a uniform fiscal code, meant accounting for, and eventually reducing, the variations in 'measures' used in Britain. Consequently, local and regional 'measures', as well as packaging and production practices, had to be suppressed as the state's revenue activities tried to 'recast such things to aid its own activities.'[66]

This view further suggests that the state bureaucracy turned to the rhetoric of 'quantification' and the associated notion of objectivity to achieve these aims and that the standardization of measurement units was sought within this context.[67] The reason why this occurred is unclear. It is also unclear if the state considered 'quantification' to be the only or the best approach for standardizing metrology, and whether it was influenced by developments in French metrology around the late

[64] Ashworth, *Customs and excise*, pp. 7-8, 259 ff.; Scott, *Seeing like a state*, p. 30 ff.

[65] P. K. O'Brien, 'The Political Economy of British Taxation, 1660-1815', *Economic History Review* 41 No. 1 (1988).

[66] Ashworth, *Customs and excise*, pp. 7, 280 ff.

[67] Ibid., pp. 261, 83. Ashworth has based his argument on this theme rather than an abstract notion of quantification arising from increasing values of precision and accuracy. The use of 'quantification' and standardization by the state as a rhetoric of objectivity is presented in T. M. Porter, 'Objectivity as standardization: The rhetoric of impersonality in measurement, statistics, and cost-benefit analysis', in *Rethinking objectivity*, A. Megill. ed. (Duke University Press, London, 1994), and T. M. Porter, *Trust in numbers: The pursuit of objectivity in science and public life* (Princeton University Press, Princeton, New Jersey, 1995). Also, Wise, ed. *The values of precision.*; J. L. Heilbron, 'Introductory essay', in *The quantifying spirit in the 18th century*, T. Frangsmyr et al. eds. (University of California Press, 1990).

eighteenth and early nineteenth-century to follow this route.[68] This reliance on quantification may very well be linked to the state's ability to legitimately generate fiscal revenue: 'a vital requirement in legitimating the excise was for the fiscal form of measurement to be perceived as objective and therefore just.'[69] If the public were unwilling to shoulder the increased fiscal burden through taxation, any changes to the key institution of legal metrology may have been possible only if they could be made to appear just and not unduly favouring any one particular group, i.e. based on abstract principles and therefore objective.[70]

Such arguments may perhaps explain why the state bureaucracy got involved in metrological standardization and why it supported this particular system of decontextualized (and therefore 'objective') measurement units. However, it does not take into account that the initiatives to unify the 'measures' during the eighteenth-century were largely private initiatives. It does not acknowledge the efforts of individual parliamentarians and the reluctance of government to be involved in a complete reform of existing measures before the turn of the nineteenth-century.

2.4.2 *Private Initiatives*

Non-state initiatives to reform British metrology can be traced to the middle of the eighteenth-century if not earlier. In c1743, some members of the Royal Society attempted to compare the British 'standard measures', such as the *yard* and the *pound,* to their French equivalents, such as the *French half-toise* and the *French two marc.*[71] Although, this was not strictly an attempt to 'determine the absolute and legal' value of these measures, it nevertheless demonstrates the interest that private individuals had began taking in understanding metrology at a national or macro level, as opposed to the narrower local or regional levels. Private support for standardization of metrological units had been strong in some circumstances. The support for the standardization of the Winchester bushel in the early eighteenth-

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68 Heilbron, 'Measures'; Schaffer, 'Metrology'.

69 Ashworth, *Customs and excise,* p. 261. In a reformulation of Thomas Paine's arguments he writes that the fiscal-military state that had emerged in the eighteenth century was increasingly coming under criticism with allegations of 'greedy consumption of the people's wealth to fund a corrupt political system revolving upon an obsolete constitution.' A bloated bureaucracy, expensive wars, and a new commercial world required a transparent, cheap and simple administrative system - one that required 'a different species of knowledge to direct its operations.' (p. 341); see also O'Brien, 'British taxation, 1660-1815'.

70 Ashworth, *Customs and excise,* p. 378.

71 'An anonymous account of comparison of English and French standards'.

century in corn markets of the southwest had come from larger farmers, and landholders, even as officials in charge of setting the assize of bread were keen on such standardization.[72]

The first parliamentary attempt was also a private initiative by Lord Carysfort, who, as we have seen, chaired two committees between 1758 and 1759 and reported on the state of British 'measures' along with recommendations regarding their standardization. It would appear that the expenses of these committees were met from private sources and that they were not set up due to the government's interest in standardizing 'measures'.[73] These committees were one of the first efforts through which the Parliament 'was first made painfully aware of the gross inadequacies of [existing measures].'[74] Towards the end of that century, another parliamentarian, Sir John Riggs Miller, was instrumental in keeping the issue of multiple and local variation in 'measures' alive and before the Parliament.[75] What motivated Carysfort and Miller to raise these issues in Parliament is difficult to establish, although it may have been some sense of social justice stemming from unreliability of measurements, particularly in the case of essential commodities such as corn.[76]

Private efforts to highlight the multiplicity of 'measures' in use, particularly in the agricultural sector, generated interest within certain government departments. The Board of Agriculture's county reports began to highlight the existence of variations between local 'measures' used in different counties, and in fact one of the reports of 1795 suggested that the existence of so many local 'measures' was an 'incumbrance to the general intercourse of business.'[77] The Board's involvement signalled the beginning of the government's interest in the existence of multiple 'measures' and the potential confusion that it may cause in inter-regional trade.

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72 Sheldon et al., 'Customary corn measures', p. 32.

73 Hoppit, 'Reforming Britain's measures': p. 94. The Duke of Newcastle apparently bore the expenses of these committees, and Carysfort, an Irish peer, was acting on his own initiative. See also, *Carysfort Committee Report (1758).*

74 Hoppit, 'Reforming Britain's measures': p. 94.

75 Ibid.: p. 95; Adell, 'British metrology': pp. 173-4.

76 Hoppit, 'Reforming Britain's measures'; Adell, 'British metrology': p. 173.

77 Hoppit, 'Reforming Britain's measures': p. 84. The chairman of the Board of Agriculture, Sir John Sinclair was on the committee headed by John Miller to review weights and measures in 1790, *House of Commons Journals*, Apr 1. 1790, p. 359; H. John, *General view of the agriculture of the county of Lancaster...* (Reprint Edition by David and Charles of original published in 1795, Newton Abbot Devon, 1969).

These private parliamentary efforts, likely motivated by commercial and mercantile interests, appear to have coincided with the Royal Society's quest for increasingly precise measurements. Experiments by individuals such as General Roy, Wollaston, Playfair, Troughton, Henry Kater, etc., as we have seen earlier, did much to improve the instrumentation and precision with which certain measurements for scientific purposes could be made.[78] Men of science, in fact, interacted with men of commerce on this subject: Patrick Kelly, a book-keeping authority and an 'executive business astronomer', and the man credited with coining the term 'metrology', was a close colleague of William Herschel the astronomer.[79] Many of these men of science served on the parliamentary committees that examined the issue of standardizing Britain's 'measures' or testified before them. They served to nurture a view that a major reform of existing 'measures' was necessary and that this required metrological standardization based on decontextualized measurement units defined in relation to abstract, absolute, and natural phenomena.[80]

The parliament, as we have also seen, eventually appointed a series of committees and royal commissions to study the possibility of introducing a standardized metrology between 1814 and 1821. The efforts of these committees to define metrological units, and the subsequent introduction of the Imperial measures, have been discussed earlier. What is pertinent here is the fact that it was largely these private efforts that eventually resulted in the view that the establishment of uniform measures required a hierarchy of measurement units and a system of traceability based upon measurement units that are related to each other through a system of comparisons and references.[81] In other words, one of the early conclusions of the parliamentary committee was that standardized measurement units had to be traceable.[82]

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[78] Zupko, *Revolution in Measurement*, pp. 69-75.

[79] Schaffer, 'Metrology', p. 440; W. J. Ashworth, 'The Calculating Eye: Baily, Herschel, Babbage and the Business of Astronomy', *The British Journal for the History of Science* 27 No. 4 (1994): pp. 422-23.

[80] Zupko, *Revolution in Measurement*; Hoppit, 'Reforming Britain's measures'; Adell, 'British metrology'; Also *PP 1813-14 Vol. III.*; *PP 1819 Vol. XI.*; etc.

[81] *PP 1813-14 Vol. III.*, which concluded that an important reason preventing the establishment of uniform weights and measures before the nineteenth-century was *'the want of a fixed standard in nature, with which the standards of measure might at all times be easily compared; [the] want of a simple mode of connecting the measures of length, with those of capacity and weight; [and] the want of proper Tables of Equalization [i.e. comparison]'.*

[82] The National Institute of Science and Technology (NIST), an agency of the US Department of Commerce, adopts for its own use this definition of traceability provided in the International

According to them

> 'The simple connection [established] between the standard of weight and measures of capacity, will [preserve] the uniformity of those measures which are found to be most liable to error.'[83]

Private individuals initiated the reform of the British metrology, and the particular form of standardization, in the guise of the Imperial units. Parliamentarians sponsored efforts to bring what they considered to be the source of measurement problems, i.e. the existence of multiple 'measures' and the wide variations amongst them, into the public focus. Scientific experiments to develop precise physical standards were conducted largely by private individuals. The bureaucracy and the government had initially stayed away from these initiatives and became involved only in the early nineteenth-century. Further, as we will see in the next section, the state did not try and impose the new metrology on the market in the years following its introduction. Existing local units could be used permissively, unlike the French metric reforms which were driven by the *savants* and the government and which were imposed on the local economy.

2.5 *Metrology in the 19th Century*

2.5.1 *Further Reforms of the Imperial Measures*

The new legislation of 1824 did not make the use of the new Imperial units obligatory and several local measurement units continued to be used throughout the nineteenth-century. The reformers of British metrology had recognized the difficulty of replacing local measurement units early on. Although the first report of the Carysfort Committee in 1758 recommended that all local units be replaced by uniform and certain standards, by the following year the committee's stance had

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Vocabulary of Basic and General Terms in Metrology: "property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties." (International Vocabulary of Basic and General Terms in Metrology (VIM), 2nd ed., 1993, definition 6.10) accessed online at http://ts.nist.gov/Traceability/nist_traceability_policy-external.cfm on January 15, 2008. Traceability is an important issue in modern metrological systems, such as the present UK National Measurement System (NMS) where international traceability of standards forms one of NMS's key activities. Department of Trade and Industry National Measurement System Policy Unit 1999, *Review of the rationale for and economic benefit of the UK national measurement system.*

[83] *PP 1813-14 Vol. III*, p. 135; Connor, *English Measures.* Efforts to link existing standards to natural standards resulted in some strange equivalences, such as standard avoirdupois pound being equivalent to the weight of water contained in 27.648 cubic inches.

softened somewhat when in the second report they acknowledged the propriety of preserving local measurement customs and measurement units.[84] Nearly sixty years later, another group of reformers were deliberating the same issues. A parliamentary report of 1819 stated that

> '[There is] great difficulty of effecting any radical changes, to so considerable an extent, as might in some respects be desirable'.[85]

A subsequent select committee report of 1821 recommended that non-uniformity of local measurement units should be remedied by connecting them in simple ratios to the primary standards of the Imperial measures.[86] The report recommended that existing subdivisions of weights and measures be retained and stated that the existing fractional units were better suited for 'common practical purposes than the decimal scale'.[87] Accordingly the 1824 Act contained a clause stating that generally people

> "Should be allowed to use the several weights and measures which they may have in their possession, although such weights and measures may not be in conformity with the Standard Weights & Measures established by this Act, [that] it shall and may be lawful for any person or persons to buy and sell goods and merchandize by any weights or measures established either by local custom or founded on special Agreement, [and] that the Ratio or Proportion which all such measures and weights shall bear to standard weights & measures established by this Act, shall be and become a matter of common notoriety...,"[88]

Thus, the new notional Imperial measurement units did not immediately replace the local measurement units, although it introduced notional, traceable, and legal metrological measurement units alongside those in local use.

In the decades following 1824, various attempts were made to promote the use of the new Imperial units. Legislation was passed between 1835 and 1858, which

[84] *Carysfort Committee Report (1758)*, p. 438; House of Commons Reports (1738-65) Vol. II 1759, *Second report of the Carysfort committee on weights and measures*, p. 456.

[85] *PP 1819 Vol. XI*, pp. 309-12.

[86] *PP Vol. IV 1821, Report from the committee on weights and measures*, p. 291. The ratios of local units to Imperial measures had to 'prove most accordant with generally received usage, and with such analogies as may connect the different quantities in the most simple ratios'.

[87] Ibid.

[88] *5 George IV C. 74.*, Para XVI.

established rules for weighing goods and carts in markets, directed market authorities to provide weighing houses and scales for general use by merchants and customers, and encouraged the use of Imperial standards in markets.[89] Legislation attempted to abolish measurement practices that were 'liable to considerable variation', such as heaping or measuring dry goods by volume.[90] Legislation also attempted to provide common access to reliable standards in cases of dispute and mandated that inspectors examine the weights and measures of anyone selling goods in streets and public places.[91] Zupko writes that the 'law was now extended to every conceivable commercial transaction' and that 'the web of law designed to protect buyers from unscrupulous sellers expanded more in this one decade [i.e. 1850s] than it had over the previous thousand years.'[92] The Weights and Measures Act of 1878 sought to abolish the use of local measurement units by making commercial transactions that used local units, i.e. units other than the Imperial units or their multiples, illegal.[93] At the same time, the Board of Trade was given custody of the Imperial standards and control over the entire aspect of British metrology.[94] The process of introducing a standardized metrology was thus taken one major step ahead by making the Imperial measurement units the only legally recognized ones in Britain.

Concomitant to the legislative changes to encourage, facilitate or coerce people into using the Imperial measures, changes were also made at an organizational level. This included the creation of a professional metrological officer corps. Zupko claims that monitoring and enforcement of legal standards had been the responsibility of 'thousands of non-qualified personnel who dominated these tasks since the Middle Ages.'[95] The nineteenth-century metrological reforms sought to centralize this function, wherein the task of verification and certification was no longer under the

[89] Zupko, *Revolution in Measurement*, p. 183.

[90] *Weights and measures (amendment) act, 5 & 6 William IV, C.63*, 1835, para VII & VIII; cf. Connor, *English Measures*, p. 180.

[91] Zupko, *Revolution in Measurement*, p. 184; particularly note 5 which lists legislation enacted between 1824 and 1870 that mentions weights and measures in relation to specific trades and products, especially foodstuff and essential commodities such as coal.

[92] Ibid., pp. 183-84.

[93] *Weights and Measures Act, 41 & 42 Victoria C. 49*, 1878.

[94] Ibid., see para 8.

[95] Zupko, *Revolution in Measurement*, p. 200.

purview of local authorities, but was to be conducted by centrally appointed inspectors who had 'entered into a "recognizance to the Crown"'.[96]

Yet, Zupko may have overstated the novelty of this arrangement. In the Middle Ages, the Office of the Clerk of the Market effectively functioned as a medieval metrological corps. The principal clerk was that of the King's Household and each shire and city had their own clerks. The principal clerk maintained the royal standard measures and would compare those in use throughout the Kingdom with these royal standards.[97] This arrangement continued until about the seventeenth-century when livery companies, craft guilds and even local magistrates began verifying and certifying standards. Broadly speaking though, the significant issue is that the nineteenth-century witnessed the professionalization of metrological inspectors, as some form of training and assessment became necessary to ensure that the inspectors were appropriately qualified to perform their functions.[98]

Despite the state's efforts to make the Imperial standards ubiquitous, many local units and practices persisted throughout the nineteenth-century. The Winchester *bushel*, for example, which was abolished in 1835 and the use of which was made illegal, continued to be used in some market towns for measuring grain throughout most of the nineteenth-century.[99] The use of non-Imperial units such as *coombs, keels, pecks, firlots,* etc. continued throughout the nineteenth-century. Local 'measures' persisted alongside the newer, decontextualized, legal units of the Imperial system, and although their use diminished over time, it was not uncommon to come across them throughout the nineteenth-century. The practice of heaping continued for several years after it was outlawed, and dry goods, such as grain, continued to be sold by volume rather than weight.[100] This experience was not unlike the French attempts to introduce the metric system in 1799 and to replace the metrological institutions of the *ancien régime* that had developed over the centuries. By abstracting measurements from objects and labour, French reformers sought to break the custom

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[96] Ibid., pp. 204, 206.

[97] Connor, *English Measures*, p. 325.

[98] Ibid., p. 334.

[99] [T]he [N]ational [A]rchives, Board of Trade Papers, BT 101/138, Letter from the Clerk of the Peace, Lincolnshire dated Feb. 19, 1886;

[100] See chapter 6

of using local measurement units within local economies. But even the sanctions of the state were not enough to force compliance.[101]

It is unclear the extent to which local measurement units continued to be used in Britain in the nineteenth-century. Undoubtedly, the 1878 Act helped in diminishing the use of local units and increasing the use of legal Imperial units in most trades, such as the grain trade (chapter 6). The state intervened in selective sectors, such as coal, foodstuffs and other essential commodities, including certain manufacturing sectors to encourage the use of the legal metrological units. The issue is why did the state intervene if its overall approach to metrological standardization was non-coercionary: this issue is studied in chapters 4-6. Apart from local measurement units, the advocates of the Imperial standards had to resist attempts to introduce Metric measures after c1860.

2.5.2 *Metric Measures and British Recalcitrance*

The Weights and Measures (Metric System) Bill, which was introduced in July 1871, was defeated in Parliament by a slender margin of five votes - 82 noes and 77 ayes.[102] It was a private bill, sponsored by Mr. J. B. Smith, Sir Charles Adderly and others, and was hotly debated during the Commons session. This event signified the closest that Britain had come to metrication in the nineteenth-century. It remains an example of the 'fiercely fought campaigns' waged in Great Britain to secure the exclusive adoption of a 'universal language of weights and measures.'[103] An account of the rapid diffusion of the metric system within Europe between 1850 and 1875, and the British resistance to the use of metric unit, is beyond the scope of this thesis; others have adequately covered it elsewhere.[104] Instead, I draw out two important points from the 'battle of the standards'. First, the debate focused on the use of decimal as opposed to non-decimal measurement units, and the practicality of using the decimal numbers to manipulate everyday measurements. The preference to use decimal units was not universal, even though several groups had proposed their use

[101] Alder, 'Revolution to measure', pp. 54-59.

[102] Hansard *Parl. Deb.*, July 26 1871, 'Debate on Weights & Measures (Metric System) Bill.'

[103] E. F. Cox, 'The metric system: A quarter-century of acceptance (1851-1876)', *Osiris* 13 (1958): p. 359. Others have also compared the metric system to a language; see J. C. Smith, 'Take me to your liter: A history of metrication in the United States', *Journal of Government Information* 25 No. 5 (1998); Alder, *Measure of all things*, p. 1. The meter itself was supposed to be eternal as it was based on the dimensions of the earth which were considered, at that time, to be eternal.

[104] Cox, 'Metric system'; Kula, *Measures and men*; Zupko, *Revolution in Measurement*.

within the Imperial measurement system itself, without adopting the metric units. Second, the political economy issues surrounding the use of metric measures were solved by their permissive use, rather than making them obligatory.

There were several advocates of the decimal 'measures' including Professor Leone Levi and Sir Joseph Whitworth.[105] Levi was an ardent supporter of the metric measures and was a prominent force in trying to popularize their use in Britain in the latter part of the nineteenth-century. Whitworth in contrast sought the use of decimal divisions to Imperial measurement units. He wrote that

> 'Great and rapid progress would be made in many branches of the mechanical arts, if the decimal system of measures could be generally introduced. [Instead] of our engineers and machinists thinking in eights, sixteenths and thirty-seconds of an inch, it is desirable that they should think and speak in tenths, hundredths and thousandths. [The change from] fractional system [to] the more perfect decimal one is easy of attainment, and, when once made, it will from its usefulness and convenience amply repay any trouble which may have attended its acquirement.'[106]

In the mechanical engineering sectors, the use of decimal divisions using Imperial measurement units, and measuring instruments based upon them became widespread. An example would be cylindrical, flat surface and external plane gauges devised by Whitworth using decimal divisions of the *inch*. These gauges in fact were made into legal standards of length under the Weights and Measures Act, 1878.[107] Measurements used in the wire trade to gauge the diameter of wire became based upon decimal divisions of the *inch*, rather than its fractional divisions. The engineering sector valued the advantages of decimal manipulation of minute measurements in achieving the precision required in their trades. However, they rejected the use of the metric *meter* or its subdivisions, the centimeter or the millimeter, preferring to use the *inch* as the standard of measure (chapter 5).

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105 L. Levi, *The theory and practice of the metric system of weights and measures* (Griffith and Farran, London, 1871); also see Cox, 'Metric system'.

106 Whitworth, 'On a Standard Decimal Measure of Length for Mechanical Engineering Work, etc (Excerpt Munites of Proceedings of the Meeting of the Institution of Mechanical Engineers at Manchester, 25th June 1857)' pp 45-55.

107 TNA, BT 101/76, letter dated Dec 28, 1880; BT 101/182.

Use of decimal measurement units was attempted in other trades as well, although its use was not as common as in the engineering sectors. Grain merchants in Liverpool, for instance, began using the *cental*, a unit of weight measure equivalent to 100 Imperial *pounds*. The intention in this case was to replace the allegedly cumbersome *hundredweight* of 112 pounds with the *cental* as its subdivision into smaller units was considered to be easier. The use of the *cental*, which became recognized as a legal measurement unit in 1879, did not extend much beyond the wheat trade in the immediate vicinity of Liverpool, although it experienced a brief surge in popularity in the United States between c1860 and c1900.[108]

Many societies and associations were also formed to promote the use of metric measures themselves, such as the International Association for Obtaining a Uniform Decimal System of Measures, Weights and Coins, with branches in Britain. However, the use of metric measurement units, such as the meter and the kilogram was strongly opposed, as we have seen earlier in the case of the Metric Measures Bill of 1871. Arguing against any use of decimal divisions, a parliamentary report of 1869 had claimed that

> 'The natural inclination of the mind [is] to halve and quarter continually...[The] Metric system does not offer the same facility [for] continued binary subdivision. [Any] attempt to force its use [would] probably be felt as a needless grievance.'[109]

Similar arguments were made several years later, in 1871 with some passion on the floor of the House of Commons:

> 'The decimal notation, with all its advantages, had points at which it broke down. It was good in multiplication, but when it they came to division its artificial nature asserted itself. When they had to do with halving and quartering – processes, on which a vast proportion of the transactions of ordinary life depended – then its weakness was obvious. [The] notation rightly claimed to be scientific and strictly mathematical, but it was not natural.'[110]

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[108] L. D. Hill, *Grain, grades and standards: Historical issues shaping the future* (University of Illinois Press, Urbana & Chicago, 1990), Appendix A; G. J. S. Broomhall and J. H. Hubback, *Corn trade memories: recent and remote* (Northern Publishing Co. Ltd, Liverpool, 1930), p. 23.

[109] *PP 1868-69 Vol. XXIII, Royal Commission to inquire into Condition of Exchequer Standards (of Weights and Measures) Second Report*, p. 736.

[110] *Parl. Deb.*, July 26 1871.

The parliamentary committees, however, did admit to the convenience of decima division in large factories or for commercial reasons. But they considered these to be decisions that were to be left to the market rather than requiring state sanction 'owners of those factories can, however, arrange such matters [i.e. use of decimal divisions to measure] to a great extent without legislative assistance.'[111]

In this manner, British industry selectively, adopted the use of decimal divisions within Imperial measurement units, even though the use of metric units *per se* did not catch on. It is important to consider the reasons behind the increasing use of decimal units at the market level. We would expect markets to switch to decimal units provided the benefits accruing from this switch outweighed the costs of making the switch. Such a trade-off was not universally favoured, but those sectors where a greater degree of precision was required, such as in the engineering industries, made the transition sometime during the latter half of the nineteenth-century. The question this raises is to what extent did the adoption of decimal division help to make measurements reliable? This issue is discussed in detail in Chapter 5.

The logic of using metric units was also promoted on the basis of using common measurement units in the expanding international trade of the period. British trade, particularly with countries that began using metric units after c1850, had expanded rapidly by the mid-nineteenth-century (table 2.1). This was sufficient justification for the advocates of the metric system to demand the switch of British legal metrology exclusively to these standards.[112] Such arguments were given a further boost with the Cobden-Chevalier trade treaty of 1860, which sought to increase the Anglo-French trade, as well as European trade in general. Metric units, its proponents argued, would help to overcome the great inconveniences arising from metrological diversity in use around many of the European countries.[113]

Many European nations adopted the metric system between 1850 and 1875 as their exclusive metrological standards. In Britain this economic logic of uniform measurement units had to be balanced with the political decision to abandon British

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[111] *PP 1868-69 Vol. XXIII*, p. 736.

[112] *PP 1862 Vol. VII, Report from the committee on weight and measures.* See the testimony of Frank Perks Fellows on 16th May 1862.

[113] A. B. Cox, 'Relation of the price and quality of cotton', *Journal of Farm Economics* 11 No. 4 (1929): pp. 365-66; Zupko, *Revolution in Measurement*, pp. 235-6.

units in favour of French ones, particularly as the Metric units were associated with the bloodiness of the Revolution. The reaction of the state to the growing pressure to make the metric measures legal was to make them permissive, initially in international contracts, and eventually, grudgingly even, for regular use in domestic trade.[114] The metric units were never made obligatory and their use formed a very small proportion of British trade. By the close of the nineteenth-century

> 'The vast majority of transactions were still being made in Imperial measures. Indeed, with few exceptions, the entire retail trade was being conducted, as before in the old units'[115]

Table 2.1
Trends in British Exports to countries using various measurement standards

(figs. in £s)	1847[a]		1861	
To Countries using Metric units	23,692,811	40.5%	55,243,699	44.5%
To Countries using Imperial units	16,261,568	27.8%	24,211,429	19.5%
To Countries using other standards	18,536,482	31.7%	44,564,767	35.9%
Total Value of British Exports	58,490,861		124,019,895	

Notes: [a] Apart from France, Belgium and The Netherlands, no other European nation had legally adopted the metric 'measures' before 1850. Thus, the figures for 1847 are for those countries that in 1861 had either fully or partially adopted the metric standard or were 'in the process of adoption'. The percentage figures in the parenthesis represent the proportion of total export value.

Source: Parliamentary Papers [PP] Vol. VII 1862, *Report from the committee on weight and measures;* evidence given by Frank Perks Fellows on 16th May 1862 p. 241-242

2.6 *Markets and Measurements: Outstanding Issues*

The historical views presented in this chapter suggest that at the beginning of the nineteenth-century, markets were characterized by multiple local 'measures' and various institutions that directed their use in specific economic contexts. By the end of the century, multiple 'measures' had been replaced by a standardized metrology, which was largely adopted within the economy. The question is whether this was

[114] Connor, *English Measures*, pp. 284-86; Zupko, *Revolution in Measurement*, pp. 249-50.

[115] Connor, *English Measures*, p. 286.

sufficient to make measurements reliable and reduce transactional problems due to measurement issues.

The significance of this question is the link between changes at a macro level, such as the emergence of a standardized metrology, and the changes in the mensuration activity at the industry or market level. Standardization of metrological units involving decontextualization, as discussed in this chapter, occurred at a macro level, and replaced local 'measures', which were micro level standards.

Notwithstanding this, there may be a case for arguing that markets continued to rely upon institutions, standards, etc. to manage measurement issues, despite the metrological standardization. If this is broadly true then we need to further probe how these institutions, etc. helped markets to address specific transactional issues. How did markets address the problem of monitoring traded quantities during exchanges or deliveries? How was product quality measured, in terms of its composition, condition, or functionality? How was production and manufacturing activity controlled by specifying product designs based on reliable measurements?

These questions lead us to wonder whether managing measurements and specific transactional issues involved standardizing *mensuration practices* in addition to standardizing *metrology*. This may involve, for instance, standardizing the use of particular measurement units for measuring particular product attributes by using methods that are pre-specified in that context. Furthermore, we need to identify who was involved in making these decisions and what their motivations were. Moreover, we need to understand how these mensuration practices fit within the changing institutional framework.

I aim to answer these questions by studying measurements and mensuration activity in diverse economic contexts. Chapter 3 develops a conceptual framework to analyze measurement activities described in chapters 4 to 6.

Chapter 3

Mensuration: Analyzing the Measurement Activity

3.1 *Introduction*

The focus of this historical inquiry is on measurements used in commercial transactions, and measurements that helped to coordinate economic activity and recognize income rights. Scientific, technical and statistical measurements are not specifically excluded, but are considered only on the basis of their role in commercial and economic activity. Consequently, measurements relating to product specification (how to make it), or quality (what is it made of, is it usable, etc.), or delivery amounts (how much does it weigh) are the focus of this thesis. Measurements used in trade, commerce and other related activities could often be non-quantifiable, because the attributes they measure did not easily lend themselves to quantitative measurements. Such measurements are not excluded and are within the scope of this inquiry. Correspondingly, the nature and extent of quantification, as an explicit method of abstracting information about qualities is not of focus either. These considerations present specific parameters within which the measurement activity, and the standardization of that activity, is considered.

The mensuration process that is described in this chapter, the way in which the measurement tools are considered, the nature of standards, and the framework to understand the standardization process reflects this focus. Mensuration itself is thought to comprise of three broad stages: observing and recording, comparing observations to standards, and contextualizing the comparisons. Analytically, 'measurements', i.e. the 'facts' that the act of measuring provides, are considered to be the end result of this mensuration process. The process is aided by the use of measurement tools, such as instruments, metrological standards and protocols (rules and conventions), as well as other tools, instruments, standards and institutional rules. The mensuration practices in each specific context are thought to be influenced by different groups that have an interest in the measurements, often for different purposes. These groups could be merchants, traders and middlemen, producers, buyers and consumers, state departments and legislature, local government authorities, market associations, scientific societies, etc. These groups in turn face several factors that are social, economic, political and technological in nature. Sucl factors help shape the incentives and decisions of these various groups. The group and the incentives determine how the mensuration activity is conducted in varyin(degrees of complexity.

The aim of this chapter is to present the variety of theoretical approaches that have informed this framework for analyzing measurement activity. The result of these reflections is a series of broad questions that are considered in a historical context in the following chapters. First, given that the objects or phenomenon I am interested in here are heterogeneous in nature, how was the choice of which property (or attribute) to measure made? This question is significant as measurements in commerce and related economic activities need not have some 'natural law' guiding this selection process. Second, how did the rules, surrounding the process of making measurements and the tools used to make them, emerge? Third, what was involved in the standardization of mensuration practices and what were the likely issues that markets faced? Fourth, was standardization the only way in which the mensuration activity was coordinated?

This chapter is organized as follows. Section 2 describes the framework used to analyze the measurement activity by describing the important aspects of the mensuration process, while section 3 describes the 'tools' used in the mensuration process. Section 4 develops some themes to consider in context of the standardization of mensuration practices, including the standardization of tools involved in the process. Finally, section 5 describes how the themes developed in this chapter are investigated through the detailed case studies included in chapters 4 through 6.

3.2 *Mensuration and Measurements*

3.2.1 *Observation and Recording*

The process of mensuration involves three broad aspects – observation, comparison and contextualization. During observation and recording several steps are involved. These include determining the information required, selecting the property or aspect of an object that is to be observed in order to obtain particular information, choosing appropriate measurement methods, metrological standards, measuring instruments, measurement protocols, etc., actual observation and recording, etc.[1] To a large extent, the particular information sought about an object influences the rest of the mensuration process. Depending upon the information required, the property or aspect of the economic asset being observed is chosen. Historically, how this choice was made is one of the central issues explored in the rest of this thesis.

Consequently, the issue of whether the measurement sought at a particular time or place could be made directly or was dependent upon one or more other measurements is of relevance here. Consider an illustrative example. Suppose that the sellers and buyers required information regarding the amount of product being exchanged through a contract. Further suppose that the aspect or property that needed to be measured was the weight of product being exchanged. The relevant question here is whether the measure of weight was directly observable (by using some sort of weighing scales) or did it depend upon one or more other measurements (estimating weight by measuring the volume displacement of the object).[2] Assuming that most measurements in everyday economic life are not directly observable, but depend upon other measurements, a further question that emerges is how do groups decide which other measurements are to be made. For this, the groups must decide upon which other properties of an object associate closely with the property they are interested in. They must also agree on the principle by which the two, or more, properties are correlated.[3]

This can be illustrated through the example of the length of a tea-leaf. Let us assume that the sellers and buyers were interested in obtaining information about the quality of a product that they wished to exchange, say tea. The quality of tea is not directly observable or measurable, and requires the measurement of another property; say

[1] P. Kircher, 'Measurements and managerial decisions', in *Measurement: Definition and Theories*, C. W. Churchman and P. Ratoosh. eds. (John Wiley & Sons, Inc., New York, 1959), p. 68.

[2] B. Ellis, *Basic concepts of Measurements* (Cambridge University Press, Cambridge, UK, 1966), Chap. IV, for a discussion on *direct* and *indirect* measurements. Strictly speaking the first type of measurement in our example above is not directly observable if we consider the definition of weight to be a function of mass of the object in conjunction with the gravitational force that acts upon it. However, for our illustrative example we can disregard this distinction.

[3] Ibid., p. 90 ff. Ellis' distinction is based on N R Campbell's classification of measurement scales. Common example of associative measurements are temperature measurements, also p. 183, appendix I; see also H. Chang, *Inventing Temperature: Measurement and Scientific Progress* (Oxford University Press, New York, 2004). Ellis defines associative measurements as those that 'depend on there being some quantity *p* associated with quantity *q* to be measured, such that when things are arranged in the order of *p*, under certain specified conditions, they are also arranged in the order of *q*', (p. 90).

the length of the leaf.[4] To measure quality in this case using the leaf length measurements required making two decisions. That the length of the leaf is an associative property of the quality of tea was the first decision made. That a specific length of the leaf corresponded to a specific level of quality was the other decision made. For any leaf-property : tea-quality or *specific* leaf-length : *specific* tea-quality correspondences, several different relationships could be established and choosing one required deliberate decision-making.

The associative decisions that sellers, merchants, and buyers made were distinct compared to abstracting a set of attributes to measure from amongst all the attributes that could be measured. The abstractive decisions may have been influenced by the ability to obtain information about different product attributes: e.g. information about all possible attributes in addition to leaf length to assess the quality of tea. Both types of decisions - the associative as well as abstractive - were usually made in the initial stage of the mensuration activity. Who made these choices (or decisions), which groups were involved in making the choice, and how they were made are non-trivial questions.

3.2.2 *Comparison*

Another important aspect of the mensuration process involves the comparison of the observations to some comparator or standard in order to ascertain their reliability. This aspect of mensuration can potentially reveal the source of many transactional problems that markets faced due to measurements.

Transactions-cost literature normally treats measurement problems in economic transactions as arising due to measurement error, which could be theoretically established by comparing measurements to a standard. For example, Barzel writes that 'measurements [of product information] are subject to error. The greater the variability of the measurement around the *true* value, the lesser the information about the commodity.' Thus, 'the presence of random errors [in measurements] introduces the opportunity for costly transfers of wealth.'[5] Such errors are considered in this literature to form the accuracy problem in measurement, leading to failed or

[4] D. M. Forrest, *A hundred years of Ceylon tea: 1867-1967* (Chatto & Windus, London, 1967), Appendix III; 'Orange Pekoe' grade (OP) may be defined as 'long, thin, wiry leaves,...', whereas 'Pekoe' grade may be defined as 'shorter leaves, and not so wiry as OP...'

[5] Barzel, 'Measurement cost': p. 28, emphasis added.

ineffective markets: 'accuracy in measuring asset values, both physical and human, defines the effectiveness of markets.'[6]

Measurement accuracy, however, can be an elusive, nebulous concept, as historians and philosophers have demonstrated. Accuracy could be understood by comparing it to precision. As Marcel Boumans puts it

> 'Precision [can] be objectively established for any chosen metric, [it is] considered to be a quantitative concept. However, accuracy [depends] much more on qualitative knowledge [and] cannot be assessed in the same objective way.'[7]

According to Ted Porter

> 'Precision requires nothing more than a tight clustering of the measurements which, like the bullet holes in a target made by a marksman with a bias, may be very near to each other but some distance from the bull's eye.'[8]

Eliminating the bias is tantamount to reducing measurement error and making them accurate.

I consider measurement reliability, or rather unreliability, to be somewhat different from measurement error. This is because historical evidence suggests that there need not be one 'true' or 'ideal' value for product measurements. To return to our example of the quality of tea, there is no natural law or theory that suggests that tea quality is necessarily dependent upon the length of the tea-leaf, or that a particular leaf-length represents the 'true' measure of tea quality. Different groups may measure quality using other attributes, such as colour, or may prefer different leaf-lengths to indicate a particular kind of quality. Measurements of product quality could vary for a host of reasons, other than due to random error, instrument bias, or some other reason introducing measurement error.

As a result, I propose to investigate measurement reliability in terms of its consistency, conformity or uniformity. In other words, reliability derives from the

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[6] L. Poppo and T. Zenger, 'Testing Alternative Theories of the Firm: Transaction Cost, Knowledge-Based, and Measurement Explanations for Make-or-Buy Decisions in Information Services', *Strategic Management Journal* 19 No. 9 (1998): p. 858 ff.

[7] Boumans, ed. *Measurement*, p. 15.

[8] T. M. Porter, 'Precision', in *Measurement in economics: a handbook*, M. Boumans. ed. (Elsevier Inc, London & Amsterdam, 2007), p. 343; also Wise, ed. *The values of precision*, p. 9.

'sameness' of measurements, rather than less deviation from an absolute value. This point can best be illustrated through some historical examples. An important consideration for many historical markets was whether measurements remained *consistent* over time, i.e. were the measurements made in a given month consistent with measurements made a month ago, a year ago, a few years before, a decade earlier, etc. Heaped measurements are a case in point on inconsistency (chapter 2). As the amount contained in the heap, on top of say the *bushel* measure, varied or changed depending upon the context or over time, the actual amount measured also varied, even though the nominal value remained the same, say one *bushel*. In practical terms, whether grain was sold using the heaped measure or the stricken measure from one year to another in the same market affected the consistency of measurements. The analytical issue here is whether it is the institutional practices that make the measurements inconsistent, even when the metrological standards remain consistent, and whether this made them unreliable.

Another way of thinking about reliability is to consider measurement *conformity*. Did the measurements over repeated observations closely resemble an acceptable or pre-specified value? This was particularly significant in the case of manufactured products such as screw threads, metal strips or wire, interlocking pieces of machinery, etc. The issue here was to determine whether several pieces of a product measured using a given attribute (length, weight, etc.) all conformed to a pre-agreed specification. Such measurements were useful tools in decision-making: if measurements conform to specifications, then do *x*, otherwise take alternative action. The source of variation in this case need not be due to instrument error, or errors in making measurements, or due to some other random factors, but due to confusion, or disagreement, regarding the measurement specification. We will come across a good example of this problem in chapter 5 where confusion or disagreement regarding whether wire size no. 32 should be 0.009th or 0.0115th of an *inch* contributed to the imprecision in the measurement of wire sizes, regardless of the sophistication of the measurement instrument. Confusion about metrological standards is also evident in the system of 'counts' used to measure the fineness of cotton yarn. This system used a confusing variety of *avoirdupois ounces* and *troy grains* as units of weight along with units of length, leading one contemporary observer to claim that the system was a 'disadvantage in so far that nobody understands it.'[9] The analytical issue is whether observations conform to a pre-agreed standard and the source of confusion or disagreement about whether they do or do not, assuming that the instruments and metrology used are precise.

A third way to think about reliability is to consider whether measurements were *uniform* across geographies or groups, i.e. do all groups use or make a given set of measurements in a uniform manner. Historically, dry goods such as coal, grain, fish, etc. were sold either on the basis of their weight or volume, depending upon the market. In the nineteenth-century, almost three-fifths of British market towns sold wheat using volumetric measurements, slightly less than two-fifths sold it using a combination of weight and volume, and the balance few towns sold wheat using weight measures.[10] In commodities like coal, different parts of the same trade route would use different ways of measuring the same commodity, or use different measurement units altogether.[11] Even when the same measurement unit was used, the value of that unit could differ. In the early nineteenth-century, the Imperial *bushel* was equivalent to 59 *lbs* if wheat was measured, 51 *lbs* if barley was measured, 39 *lbs* if oats were measured, or 64 *lbs* if peas were measured.[12] The question of unreliability arose when such variations in practices and local norms were either not generally known, difficult to ascertain, or where merchants dealing with multiple markets or sellers found it difficult to manage the great amount of variation. The analytical issue is if this non-uniformity became a source of unreliability in the nineteenth-century and the manner in which markets addressed this issue.

Practically, reliability of measurements was dependent upon a combination of the above. It is not evident that in any of the three examples described above, variation in measurements resulted only from a lack of unchanging, invariable metrological units. Nor is it obvious that any of the measurements described above had to cluster around some 'true', or an 'ideal' value - a value derived from some natural, physical phenomenon, which could be indisputably ascertained. In this sense, measurement issues were not limited only to the invariability of the metrological units (the

[9] *PP Vol. XIII 1895, Report of the select committee on weights and measures*, p. 735, evidence by H E Wollmer on 26th March 1895; see Biggs, 'Measuring Yarn', for a more complete discussion of this remarkable system of quality measurements.

[10] *PP 1834 Vol. XLIX*, p. 251, report on 'Different Customs or Practices of Selling corn and other Grains.'

[11] Pollard, 'Coal measurements'.

[12] *PP 1834 Vol. XLIX*, p. 256.

precision problem) or to minimizing the error around some 'true' value (the accuracy problem). If reliability can be considered in a broader sense to be derived from 'sameness', then the problems of consistency, conformity and uniformity also had to be managed by the markets.

A pertinent question is whether variability in the manner described above - inconsistency, non-uniformity, non-conformity, etc. - usually translated into unreliable measurements. The problem with equating reliability to variability is that, historically, variability of measurements was sometimes a desired attribute (chapter 2).[13] Variable measurements at times had a moral function: a system of handicapping the less privileged.[14] Sometimes they had an economic function: e.g. adjusting for changes in the market value without a corresponding change in money value, as with the Assize of Bread where the weight of the bread-loaf was altered according to the price of grain without changing the price of the loaf.[15] At other times, variability was the result of persistence of local custom stemming from some symbolic meaning or communal memory: 'we have always measured it in this manner around here.'[16] Thus, invariability - to mean 'sameness' - was not universally desired. In the late eighteenth- and early nineteenth-century, the issue of who demanded invariability, and why, became an important historical issue.[17]

To summarize, the second aspect of mensuration activity, where the observations are compared to some comparator or standard to ascertain their reliability, raises some issues that are of historical importance. The first issue is the appropriateness of the standard or the comparator used. This involved the choice of the metrological units and the rules and norms surrounding their use. The second issue is the method of making the comparisons themselves. The consideration here was whether the standards and methods in use resulted in reliable comparisons. Here the question of 'sameness' becomes pertinent in terms of whether it mattered to certain groups if 'sameness' in measurements was possible or not. The third issue is how markets attempted to achieve 'sameness' in measurements, or managed transactions if this could not be achieved. To understand these issues requires an understanding of the

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[13] Kula, *Measures and men*; Alder, 'Revolution to measure'.

[14] Hoppit, 'Reforming Britain's measures': pp. 89-90.

[15] Davis, 'Assize of bread'.

[16] Sheldon et al., 'Customary corn measures', pp. 34-35.

[17] Hoppit, 'Reforming Britain's measures'.

measurement 'tools' used (instruments, methods, and standards), as well as how groups contextualize the observations subsequent to comparison.

3.2.3 *Contextualization*

The third aspect in the mensuration process involves contextualizing the observations made and their comparisons with standards. This means establishing the significance of the information recorded by the instruments: what information does the observations and its comparisons convey about the economic activity that people are interested in? It is an important aspect of the mensuration activity because people take decisions or make assessments about the economic activity based on the significance of the information. Contextualization is a method of turning the observations into 'measurements'. This aspect involves classifying or sorting the information (observation-comparison) on the basis of one or many (qualitative) parameters: good-bad, acceptable-unacceptable, reliable-unreliable, adequate-inadequate, etc. Contextualizing also involves making decisions based on established 'if-then-else' rules: if the outcome of the comparison is *x*, then the action taken should be A, otherwise the action should be B. Context is important for comprehension and people take into account the socio-cultural environment while contextualizing objects or information.[18] Individuals also respond strongly to incentives and their comprehension is also shaped by (external) institutional factors.[19] Both these considerations contribute to the process by which individuals contextualize information and objects: people are remarkably clever contextualizers.[20]

Relating this discussion to the mensuration activity, I argue that measurements had particular meanings with reference to particular contexts. Figure 2.1 illustrates this argument especially well: the meaning of a *bushel* of potato can only be made clear with reference to particular contexts. In the example illustrated by this figure, the

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[18] 'Situated cognition: origins', *International Encyclopaedia of the Social & Behavioural Sciences*, 21, 14126-29; E. Hutchins, *Cognition in the wild* (The MIT Press, Cambridge, Mass. & London, England, 1996); E. Hutchins, 'How a cockpit remembers its speeds', *Cognitive Science* 19 (1995); H. Artman and Y. Waern, 'Distributed cognition in an emergency co-ordination center', *Cognition, Technology & Work* 1 (1999).

[19] A. T. Denzau and D. C. North, 'Shared mental models: ideologies and institutions', *Kyklos* 47 No. 1 (1994): p. 4. Steven Landsburg remarks in his book that 'People respond to incentives. The rest is commentary'; S. E. Landsburg, *The armchair economist: economics and everyday life* (The Free Press, New York, 1995), p. 3.

[20] G. A. Miller, 'Contextuality', in *Mental Models in Cognitive Science*, J. Oakhill and A. Garnham. eds. (Psychology Press, UK, 1996), pp. 2-3; G. A. Miller, 'On knowing a word', *Annual Review of Psychology* 50 (1999): p. 11 ff.; also G. L. Murphy, 'Comprehending complex concepts', *Cognitive Science* 12 (1988).

measurement of a *bushel* of potato must be contextualized in terms of a geographical location for it to be meaningful, especially since the meaning changes according to location in this case. Thus, our measurement of a *bushel* becomes a 'measurement' once it is placed in a relevant context (e.g. a *bushel* of potatoes in Cheshire, Leicestershire, Surrey, etc.). Until then it must remain an observation, a recorded piece of information.

The argument is significant if we consider the problem of reliability of 'measurements' in the manner discussed previously: the consistency, conformity and uniformity of measurements. The way in which individuals and groups of individuals contextualized observations-comparisons and turned them into 'measurements' also determined whether they were reliable or not. Changes in mensuration activities may have been initiated when different groups began to contextualize the measurement information in different ways. In other words, whether particular measurements were reliable or not depended very much upon the contexts in which the mensuration process occurred and the measurement tools used.

3.3 Measurement Tools

Several kinds of measurement 'tools' may be used during the mensuration process. I distinguish between three types: instruments, protocols and standards. Fundamentally, to make measurements requires measuring instruments. They could be either physical artefacts or mental constructs. For instance, metrological units are often represented as physical objects or measuring vessels of particular dimensions, e.g. the *kilogram, meter, yard, bushel,* etc. Similarly, engineering gauges (such as cylindrical gauges, wire gauges, sheet metal gauges, etc.) are measurement instruments, just as thermometers or voltmeters are. Equally, metrological units are often just mental constructs, derived with reference to some physical phenomenon or object or other mental constructs, but without a physical form of their own. For example, the *ton, chaldron, acre, kilometre,* etc. are all mental constructs of metrological units that have no representative physical artefact, but can be understood with reference to some other artefacts. In the same perspective, measurement instruments would also include accounting and auditing tools as well as economic models. In fact, any construct that enables us to observe and record phenomenon of interest by 'picking them out in a particular way' can be considered to be a measurement instrument.[21] This broad definition then includes metrological units - such as the Imperial units (pounds, bushels, inches, etc.) and Metric/SI units (kilograms, litres, meters, etc.) - as well as weighing scales, measuring cups (even cigarette tins!), 'foot rules', and many other scientific and non-scientific instruments.

The histories of measuring instruments mirror the histories of technologies to some extent. This thesis does not track the histories of any individual or specific measuring instruments, although Chapter 2 reviewed the development of British metrological units in the nineteenth-century. The histories of measurement instruments are important in terms of the impact that development of certain instruments or measuring technologies had on mensuration practices. For instance, improvements in weighing technology made it possible to directly observe the weight of bulky objects, an activity that was usually difficult to conduct before the nineteenth-century (chapters 4 and 6). This made it more effective to begin weighing commodities such as coal, grain, etc. The relevant issue is what impact this development had on mensuration practices in those markets. Similarly, what impact did development of measuring instruments such as the chrondometer (for measuring density of grain), the 'ohm' (to measure electrical resistance), the decimal measuring system, the micrometer gauge, etc. have on mensuration practices? This issue needs to be explored to understand the changes in the mensuration process.

One way to operationalize this is to study the manner in which instruments made measurements reliable (see previous section). Historically, increasing the accuracy or precision of instruments in some cases was not sufficient. For instance, several measuring instruments capable of achieving a high degree of precision were developed during the nineteenth-century. Joseph Whitworth's 'millionth' measuring machine was a very precise measurement instrument capable of achieving a precision of up to one-millionth part of an inch.[22] However, the reliability of the wire sizes did not increase with the degree of precision in which wire diameters were measured (in hundredth or thousandth parts of the inch). Reliability involved 'fixing' a pre-agreed set of wire sizes: a process that involved standardizing a measuring instrument, the wire gauge (chapter 5).

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[21] M. Morgan, 'Making measuring instruments', *History of Political Economy* 33 No. Annual Supplement: The Age of Economic Measurement (2001): pp. 236-38; M. Power, 'Counting, control and calculation', *Human Relations* 57 No. 6 (2004).

[22] T. Kilburn, *Joseph Whitworth: Toolmaker* (Scarthin Books, Cromford, Derbyshire, 1987), p. 24, which contains an image of Whitworth's famous measuring machine of 1851.

Thus, the development or standardization of measurement instruments, and the manner in which they were employed in the mensuration process was governed by rules, regulations and conventions: collectively termed here as measurement protocols. These are as much the 'tools' within the mensuration process as the instruments themselves. Protocols could be formal legal rules and regulations, or they could be informal, *de facto* conventions that emerged through long usage, common knowledge, or practical considerations. Another way of distinguishing them is to consider protocols at a macro level (of the economy or the country) and those at a micro level of individual mensuration activities. For example, macro-level legal metrological institutions regulated the construction of legally recognized measurement instruments; they specified the steps to be observed in their construction, the materials that the physical artefacts should be made of, the methods of testing their accuracy, the manner in which they should be calibrated and authenticated, the acceptable and unacceptable ways of using them, and the penalties and recourse in the event of improper or fraudulent use. Similarly, other institutions, such as scientific or professional bodies, developed their own conventions and methodologies that governed the construction and use of other measurement instruments. Such macro-level protocols influenced mensuration activity at the micro-market level.

The link between the macro and micro protocols was often through formal regulatory means - such as legislation that directed the use of particular metrological units in specific activities (e.g. certain kinds of weights for measuring dry goods) or by the rules of a professional or trade associations that specified the use of particular instruments.[23] At a the other end of the spectrum, individual firms and organizations developed or adopted measurement instruments based upon their particular experience or manufacturing methods. The prevalence of wire gauges, which were often specific to individual workshops or regions (such as Birmingham, Lancashire, etc.), is an example of this. At this micro level, protocols directed the manner in which the instruments were used: pouring the grain into a vessel from a particular height, drawing the wire through a particular sequence of holes on the wire gauge, etc. (chapters 5 & 6).

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[23] *5 & 6 William IV, C.63* and *Weights and Measures in the Sale of Corn Act, 11 & 12 George V C. 35*, 1921 are examples of such legislation.

The analytical issue here is the degree to which protocols are a result of institutional processes. It may be difficult to practically distinguish between the procedural and institutional rules. However, I consider protocols to be institutional in nature. This is because they potentially coordinate actions between individuals, or between groups and organizations, or are externally imposed rules that regulate the behaviour of individuals and groups, etc. Protocols may emerge due to incentives that different groups face, which could be different or conflicting. They may be exogenous (to the mensuration activity) and so constrain behaviour, or they may emerge endogenously, due to changes made to the mensuration activity. Thus, if protocols are perceived as institutional rules or conventions coordinating the mensuration process how and why did certain protocols emerge? How did they influence and coordinate the mensuration activity? These are questions of analytical and historical importance in the context of studying the mensuration process.

Standards used within the mensuration process are also measurement 'tools', just as protocols and instruments. What are standards and specifically what are measurement standards? One way of characterizing standards is by the manner in which they are established. *De jure* standards are legal or legally mandated standards, whereas *de facto* standards are those that emerge *ex-post* in a local or customary context.[24] Another term refers to *institutional* standards, which different from *de jure* standards in that they are voluntarily adopted and from *de facto* standards in that they are formally documented.[25] Standards may also be promulgated by standards setting bodies such as International Standards Organization (ISO), American National Standards Institute (ANSI), British Standards Institute (BSI Group), or Bureau International de Poids et Mesures (BIPM). The standards they set may be termed as voluntary consensus standards.[26] Another way of classifying standards is on the basis of their economic functions or characteristics. Accordingly, there are compatibility standards (standards which make a variety of technologies, products, or designs compatible with each other), minimum quality or

[24] D. J. Teece and E. F. Sherry, 'Standards setting and antitrust', *Minnesota Law Review* 87 No. 6 (2003): pp. 1917-20; H. Spruyt, 'The supply and demand of governance in standard-setting: Insights from the past', *Journal of European Public Policy* 8 No. 3: Special Issue (2001): p. 372; C. Antonelli, 'Localized technological change and the evolution of standards as economic institutions', *Information Economics and Policy* 6 No. 3-4 (1994): pp. 196-7.

[25] W. Mattli, 'The politics and economics of international institutional standards', *Journal of European Public Policy* 8 No. 3: Special Issue (2001).

[26] BIPM manages all standards relating to the International System of (Measurement) Units or the SI.

reference standards (standards which function as measure of performance) and variety reduction or rationalizing standards.[27]

Several different kinds of standards are used in the mensuration process. Apart from metrological standards, the process involves the use of technical, design or product standards, depending upon the purpose of the mensuration activity. A set of wire sizes or grain densities could be considered as metrological standards because they employ metrological units and use specific measurement scales.[28] Product grades form part of technical standards, as do measurements used in product designs, such as 'this metal sheet must be 6 millimetre thick' or 'this product must weigh 5 ounces.' The fibre length of cotton staple is both a metrological standard as well as a technical standard for product grading.[29] Similarly, the counts system used for determining the fineness of yarn is also a metrological as well as a technical standard.[30] Metrological units were therefore used both as part of measurement instruments as well as measurement standards.

The historical question is whether these standards helped to make measurements reliable. The analytical issue is whether use of metrological units in mensuration practices helped increase the reliability of measurements? This question may be answered by studying the functions of standards within the mensuration activity. For instance, what reference functions did standards perform in terms of ascertaining quality or monitoring performance? Did standards help to make mensuration practices consistent over time or uniform across geographies? Did they establish compatibility between different practices or activities? In other words, did the use of standards help to standardize mensuration practices?

If standards and standardization can truly reduce transactions costs, eliminate uncertainty, reduce need for regulatory structures, produce physical economies by

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[27] P. Swann et al., 'Standards and trade performance: the UK experience', *The Economic Journal* 106 No. 438 (1996): p. 1298; Antonelli, 'Standards as institutions': p. 197; P. A. David and S. Greenstien, 'The economics of compatibility standards: An introduction to recent research', *Economics of Innovation and New Technology* 1 (1990); Teece and Sherry, 'Standards setting and antitrust'; cf. G. Tassey, 'The role of government in supporting measurement standards for high-technology industries', *Research Policy* 11 (1982), and Spruyt, 'Governance in standard-setting'.

[28] The scales used could be nominal at one extreme – such as numerical quality grades – or they could be ratios – as in the case of numerical estimates of densities. See S. S. Stevens, 'On the Theory of Scales of Measurement', *Science* 103 No. 2684 (1946) for a discussion of the scales used in measurements.

[29] A. H. Garside, *Cotton goes to market : a graphic description of a great industry* (Frederick A. Stokes Company, New York, 1935), p. 68 ff.

[30] Biggs, 'Measuring Yarn'.

enabling repetitive production, facilitate interchangeability, consistency and compatibility, create competitive advantages, etc. as the literature suggests, then we may expect standardization of mensuration practices.[31] This could have been an important strategy that markets adopted to manage measurements and increase their reliability. What does the historical evidence suggest? What was involved in such a standardization process? Who was involved and why? The following section considers some of these issues from a conceptual perspective.

3.4 *Standardization*

Standardization of mensuration practices involves standardizing both the process as well as the tools that were used in the process. To be specific, standardizing observations involves standardizing the property or attribute of the object that is measured in a given context (e.g. quality or quantity, weight or volume, colour, composition, etc.), the recording instruments that are used in making the observations, the method of making observations (e.g. method of stretching cotton staple to observe its length, pouring grain into a measuring vessel from a specific height, measuring the diameter of the wire from the middle of the strand, etc.), and other such activities. Standardizing the comparisons involves making prior decisions about the choice of standard to be used to compare the observations with (metrological standards, product specifications, quality classes and grades, etc.), methods of making the comparisons (sorting, ranking, pair-wise, etc.), the groups or individuals responsible for making these comparisons and conditions under which they are made, etc. Similarly, standardization involves developing prior decision rules for anticipated outcomes of the comparisons (e.g. 'if x, then y, else z' rules), and monitoring mechanisms to ensure their compliance.

To what extent did standardization of mensuration processes involve the development of individual standards, such as metrological standards, product specifications, etc.? In other words, did standardizing mensuration involve standardization of the unit of weight (or volume or length), or a standard set of sizes, or product grades, etc. - i.e. any or all of the several different standards used in the mensuration process? Or did it involve standardizing choices about attributes to be

[31] Antonelli, 'Standards as institutions': pp. 197-98, 200-01; C. Kindelberger, 'Standards as public, collective and private goods', *Kyklos* 36 (1983): p. 377-78, 384; Swann et al., 'Standards and trade': pp. 1298-99; M. Kochsiek and A. Odin, 'Barriers to trade: Towards a global measurement system: Contributions of international organizations', *OIML Bulletin* XLII No. 2 (2001).

measured, methods of making observations and comparisons, etc. - i.e. standardization of protocols? It is possible that although these appear to be analytically separate processes - i.e. standard-setting versus standardizing mensuration - practically they were not. Developing individual standards used in mensuration may have also involved standardizing protocols. On the whole, standardization of mensuration likely involved several aspects such as standard setting and switching processes, technological improvements, emergence of institutional rules, etc.

Literature on the economics of standards describes several approaches to analyze the process of standard-switching or standard-setting. One approach treats the emergence of standards as an outcome of standardization 'clubs', where the emergence of standards is a result of a deliberate decision-making process.[32] Some of this literature argues that apart from *producer* firms, coalitions with or among *users* may prove to be more efficient in standard-setting, although difficult to achieve due to time-inconsistency or free-rider problems; although, coordination failures could be solved through state intervention.[33] Another approach to standardization is based on evolutionary change, which assumes that economic systems are evolutionary in nature, are composed of a variety of alternatives, and where 'rival standards compete for adherence': only those standards that have the greatest likelihood of surviving or propagating become dominant.[34]

An influential historical approach to standardization is the 'accidents of history' approach. W Brian Arthur gives an excellent précis of this view:

> 'When two or more increasing-return technologies compete, then [insignificant events] may by chance give one of them an initial advantage in adoptions. This

[32] Antonelli, 'Standards as institutions': p. 205; Teece and Sherry, 'Standards setting and antitrust': pp. 1934-42, 87; M. A. Cusumano et al., 'Strategic maneuvering and mass-market dynamics: The triumph of VHS over Beta', *Business History Review* 66 No. 1 (1992): p. 65, for the argument that the outcome of the VHS v/s Betamax standards war was the result of the strategic alignment of the producers of the core product.

[33] D. Foray, 'Users, standards and the economics of coalitions and committees', *Information Economics and Policy* 6 No. 3-4 (1994); cf. R. Axelrod et al., 'Coalition formation in standard-setting alliances', *Management Science* 41 No. 9 (1995); Kindelberger, 'Standards': p. 388; K. A. Konrad and M. Thum, 'Fundamental standards and time consistency', *Kyklos* 46 No. 4 (1993), who discuss a formal model of the time inconsistency problem in setting fundamental standards in languages; also Teece and Sherry, 'Standards setting and antitrust';S. Berg, 'The production of compatibility: Technical standards as collective goods', *Kyklos* 42 (1989).

[34] J. S. Metcalfe and I. Miles, 'Standards, selection and variety: An evolutionary approach', *Information Economics and Policy* 6 No. 3-4 (1994); P. Mirowski and K. Somefun, 'Markets as evolving computational entities', *Journal of Evolutionary Economics* 8 (1998).

> technology may then improve more than the others, so it may appeal to a wider proportion of potential adopters. It may therefore become further adopted and further improved. Thus a technology that by chance gains an early lead in adoption may eventually corner the market of potential adopters, with the other technologies becoming locked-out. Of course, under different insignificant events [different] technology might achieve sufficient adoption and improvement to come to dominate.'[35]

The standardization of the keyboard design - QWERTY - is often cited to be the result of such an historical selection process.[36] Another example that is often cited is the emergence of the market for nuclear power reactors using light water technology.[37] These examples stress that the standardization of particular designs or technologies occur in the presence of competing and perhaps more efficient alternatives. Path-dependency has a considerable influence on the standardization process.

A somewhat different analytical approach focuses on the role of gateway technologies to mediate between competing technologies and even influence the emergence of one of them as a *de facto* standard. A gateway technology is an artefact, device, or convention that helps to establish connections between distinct, often disparate, technologies such that the different technologies can be utilized in conjunction, within a larger context or system.[38] There are several examples of such gateway technologies: electrical adaptors, Java programming software; multiband radio transreceivers; rotary converters that convert between alternating and direct electric currents; etc.

The above review suggests that there may be four important elements to consider in a standardization process. First, standardization could be a product of strategic, coordinated, or negotiated efforts between groups or coalitions, who aim to develop standards for a specific purpose. Second, standardization could involve the emergence of standards (technologies, processes, etc.) from among several

[35] W. B. Arthur, 'Competing technologies, increasing returns, and lock-in by historical events', *The Economic Journal* 99 No. 394 (1989): p. 116.

[36] P. A. David, 'Clio and the economics of QWERTY', *The American Economic Review* 75 No. 2 (1985); S. J. Leibowitz and S. E. Margolis, 'The fable of the keys', *Journal of Law and Economics* 33 No. 1 (1990).

[37] R. Cowan, 'Nuclear power reactors: A study in technological lock-in', *The Journal of Economic History* 50 No. 3 (1990).

[38] P. A. David and J. A. Bunn, 'The economics of gateway technologies and network evolution: Lessons from electricity supply history', *Information Economics and Policy* 3 (1988): p. 170.

alternatives through some selection process. Third, standardization is greatly influenced by path-dependency, which may influence the decision of groups or coalitions in terms of selecting some standards over others. The important issue here is that standardization need not result in the dominance of the most efficient standards. Finally, markets develop methods to deal with multiple or non-compatible standards, as suggested by the development of 'gateway' technologies or standards. This implies that a convergence towards a 'one-size-fits-all' standard is not the only outcome of the standardization process. Historically, we notice that multiple standards have existed in many industries and product categories, and continue to do so.

Multiplicity, path-dependency and resistance to standardization are all relevant issues as far as the history of metrology is concerned. Studies of popular protests against uniformity of 'measures' amply demonstrate this. Some of the historical arguments suggest that sources of resistance must be understood in their local or regional contexts and may be closely related to questions of communal memory.[39] The diversity of local measurement units is matched by their persistence in the face of standardized metrology. So great could be the resistance at times and so great a desire to perpetuate local mensuration practices that users would continue to measure commodities, such as grain, in a manner such that 'they were always of the same size and weight as they were before the measure was altered'.[40]

Another source of persistence or resistance to change, as standard-switching inevitably involves change, could be the ideology and cultural symbolism associated with measurement technologies and artefacts. The influence of culture can be understood in terms of symbolic meanings that are relative to specific cultural contexts. For instance, decimal units came to represent progress in the nineteenth-century compared to fractional units, even though some others considered them to be artificial and unnatural (chapter 2). Similarly, fixed, abstract and immutable metrological units based on scientific principles came to symbolize 'objectivity' and 'rationality' in the late eighteenth and nineteenth-century in Britain: in France, the metric units symbolized a break from the 'feudal' units of the *ancien régime*. Symbols

[39] Kula refers to the term *mémoire collectif* used by M. Bloch, who in turn has used Durkheim's terminology to claim that persistence of measures is bound up with questions of communal memory, Kula, *Measures and men*, p. 111.

[40] Sheldon et al., 'Customary corn measures', pp. 34-35, especially the statement by a Wiltshire farmer, Henry Hunt, from the early nineteenth-century.

may form systems of meaning and can become ideologies that exert a powerful influence on (technical) change.[41] Metrological units have historically acted as symbols of culture, identity and ideology that can become powerful sources of resistance.

But path-dependency need not signify persistence only in the sense of stubborn *resistance* to change. Persistence of some standards could also be a result of *inertia* in the sense of a tendency to remain unchanged.[42] Consequently, persistence must be understood in its economic and technological imperatives, as well as in its sociological sense. A useful way to look at inertia as a source of persistence could be to consider the effects of lock-in due to interrelatedness of use. According to this view, if the use of a standard or a dominant technology is based upon compatibility of use (with complementary standards or technologies) or upon its use by a sufficiently large base of users then 'there are benefits to doing what others do.'[43] As this generally strengthens further complementarity of use, eases communication and leads to cost savings due to standardization, switching from this standard to a newer standard would not make sense, or involve high switching costs, to any one user unless all users, or a large majority, switch to the new standard. This phenomenon has been referred to in economics as 'excess inertia', a situation where there is a socially excessive reluctance to switch to a superior new standard. Society could become 'locked-in' on an existing standard even though demonstrably superior standards or technologies may exist (as in the example of QWERTY cited above). Thus, standardization processes may be path-dependent, non-ergodic and may have multiple-stable equilibria i.e. simultaneous presence of several Pareto-optimal outcomes.[44]

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[41] E. Schatzberg, *Wings of wood, wings of metal: Culture and technical choice in American airplane materials, 1914-1945* (Princeton University Press, Princeton, New Jersey, 1999), pp. 11-19; Staudenmaier reminds us that humans repeatedly report feelings of awe, aesthetic delight, or fear as part of their conscious experience of different technologies - suggesting that *technological cognition* is an important aspect of understanding cultural symbols, J. Staudenmaier, 'Problematic stimulation: Historians and sociologists constructing technology studies', in *Social and Philosophical Constructions of Technology*, C. Mitcham. ed. (Jai Press Inc, London, 1995).

[42] Kula, *Measures and men*, pp. 111-13.

[43] J. Farrell and G. Saloner, 'Installed base and compatibility: Innovation, product preannouncements, and predation', *The American Economic Review* 76 No. 5 (1986): p. 940.

[44] David and Greenstien, 'Compatibility standards': pp. 5-9; Farrell and Saloner, 'Installed base and compatibility'; M. L. Katz and C. Shapiro, 'Network Externalities, Competition and Compatibility', *The American Economic Review* 75 No. 3 (1985).

Putting this discussion in the perspective of mensuration practices, the following issues emerge. The path-dependent, non-ergodic nature of the standardization process is likely to have caused tussles between those groups that supported standardization and those groups that did not. How did markets resolve these issues? Did the ability of the market to resolve coordination failures depend upon what was being standardized? Perhaps it is easier for the market to standardize mensuration practices, but harder to develop standardized tools such as metrological standards. Did the state intervene in the setting of metrological standards, but left the standardization of protocols to the market? Understanding the role of the groups in the standardization process is thus important in understanding which parts of the mensuration process were standardized, who wanted them to be standardized, and for what purpose.

Similarly adopting new standards, instruments and protocols involves switching costs, including costs of retooling, retraining, calibration, and contextualizing.[45] Further it involves ensuring that the new standards, etc. were compatible with other existing standards, etc. Consequently standardization requires considerable coordination efforts at all levels. If coordination is important, as the above suggests, then the process of standardizing mensuration practices could be viewed as an institutional change demanding not only that the individual standards be established or altered but also that other components connected to it are established or altered.[46] Institutional change of this nature could be shaped by the coordination between individuals, groups, organizations and institutions at various levels.[47]

Convention theory distinguishes between several modes of coordination by considering a variety of ways in which humans create equivalence between themselves or between things. This includes both cognitive as well as organizational forms to generalize these equivalences. Consequently, coordination forms would depend upon the level of complexity involved in making things (and people) more

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[45] David and Greenstien, 'Compatibility standards': p. 9; Katz and Shapiro, 'Network Externalities, Competition and Compatibility'; Farrell and Saloner, 'Installed base and compatibility'.

[46] C.-F. Helgesson et al., 'Standards as institutions: Problems with creating all-European standards for terminal equipment', in *On economic institutions: Theory and applications*, J. Groenewegen et al. eds. (Edward Elgar, 1995), pp. 165 & 71-72; also Antonelli, 'Standards as institutions': p. 214, who considers standards to be institutions.

[47] North, *Institutions*, pp. 7-8; S. Ogilvie, "Whatever is, is right'? Economic institutions in pre-industrial Europe', *Economic History Review* 60 No. 4 (2007): pp. 668, 674-75.

general across contexts.[48] Diversity in this case becomes non-trivial in that we could rule out the possibility of a single set of rules governing behaviour and coordination.[49]

As a result there need not have existed a single rule or set of rules coordinating mensuration activity. The manner in which it was achieved may have depended entirely on the complexity and the institutional environment in which it occurred. Standards used in mensuration and measurement protocols may have emerged at different levels according to different sets of coordination rules characterized by differing levels of complexity. Also, coordination rules could have emerged endogenously in the process of reducing the complexity and generalizing behaviour or relations.[50]

An important implication of these observations is that standardizing the mensuration activity may not have been the only way in which markets coordinated the use of standards in measurements. A framework that analyzes historical mensuration activity thus needs to be mindful of this fact. Different markets may use different methods to coordinate standard-setting, standard-switching and standard-using in mensuration activities.

3.5 *Analyzing Measurements through Case Studies*

The issues surrounding mensuration, standardization and coordination discussed in the previous sections can be explored in greater depth by considering specific micro economic contexts. In this thesis, I have considered three such micro contexts: the case of the measurements in the delivery of coal, the case of measuring wire sizes, and the case of measurements to grade the quality of wheat.

The case study of the London coal trade c1830 investigates the factors that led to three significant reforms: the abolition of public measurement system, the abolition of the heaped measures, and the switch from using volume measures to weight measures (chapter 4). These reforms were introduced to address a fundamental measurement issue facing this trade: were the measurements regarding quantities

[48] L. Thévenot, 'Organized complexity: Conventions of coordination and the composition of economic arrangements', *European Journal of Social Theory* 4 No. 4 (2001): pp. 406-7.

[49] J. Wilkinson, 'A new paradigm for economic analysis?', *Economy and Society* 26 No. 3 (1997): p. 323.

[50] Ibid.; M. Aoki, 'Endogenizing institutions and institutional changes', *Journal of Institutional Economics* 3 No. 1 (2007): p. 8.

(i.e. amount) used for delivering the product during market exchanges reliable? In other words, could the buyers rely upon measurements used in the trade such that the amount of coal that they received was actually the amount of coal they purchased?

The case of the wire measurements focuses on the incentives facing buyers and sellers of wire products in the nineteenth-century and how these incentives gave rise to different notions of reliable measurements (chapter 5). The case study highlights the struggles to define a standard 'one-size-fits all' gauge to measure wire sizes, which could be legally enforced and would overcome the disputes arising from incompatible and multiple gauges. In other words, it studies the rationalization of multiple measurement standards into a single uniform metrological standard.

The case study of wheat highlights how the measurement of quality became a complex and sophisticated process, involving measurement of numerous product attributes using multiple standards (a standard in this case being an arbitrary reference point to which individual observations were compared). The measurement issue that the trade faced was which 'summary criteria', i.e. a set of product attributes, could capture *ex ante* the important aspects of product quality - in terms of the product's composition, condition and functionality (chapter 6).

Each of the three cases has been chosen to highlight different aspects of the mensuration activity as discussed in previous sections. Chapter 4 discusses the changes that occurred in the measurement protocols as a consequence of the efforts to make measurements in the delivery of coal in London more reliable. Chapter 6 explores the decisions regarding the choice of product attributes to measure and how markets developed solutions to deal with situations when this aspect was not standardized across trade routes. Chapter 5 analyzes standard-switching behaviour, the convergence towards uniform metrological standards, and the development of a standard mensuration instrument. Overall, all three cases explore the correspondence between the different aspects of the mensuration process - observation, comparison, contextualization - and the tools used in the process - instruments, protocols, standards.

The three case studies examine in some detail how people made measurements. The influence of different groups of people on the mensuration activities is analyzed on the basis of the incentives that they faced and the particular interest they had in the measurements. These groups comprised of merchants, traders and middlemen; producers, buyers and consumers; state departments, legislature, and local government authorities; trade and industry associations, commodity exchanges and chambers of commerce; scientific societies and trade journals, etc. The differences in the incentive structures, and the extent to which different groups affected mensuration activities, is specifically highlighted through the cases.

For instance, the case of the coal measurements in London investigates how various groups - local London merchants, producer-merchants in Newcastle and Durham, Corporation of London, Houses of Parliament, state departments (e.g. Treasury), etc. - resolved the measurement problem through lengthy debates on various mensuration issues (chapter 4). The debates raised the following questions. Were public measurements necessary within the trade? Could the inefficiencies of the existing metage system be reformed? Would a switch of standards - from volume to weight - enable the buyers to effectively monitor transaction quantities?

The case of the wire sizes investigates how entrenched interests within buyer and producer groups resulted in a stalemate with neither group willing to accept the other's notion of reliable wire sizes (chapter 5). These interests stemmed from different incentives: the buyers desired sizes that enabled them to use wire products more effectively in their applications, 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.

The case of the wheat trade investigates how the markets addressed the problem of measuring the quality of a highly heterogeneous commodity by selecting different sets of summary criteria for use in different contexts and by different groups (chapter 6). The grading process was a responsive activity: a universal attribute set could not be used across all trade routes, and the grades (and consequently the measurement standards) had to be reviewed periodically. Commodity exchanges developed numerical grades to help manage complex quality measurements using different attribute sets. Even so, not all measurements were made by associations or third party organizations. The buyers often had to rely on their own sets of measurements.

The millers developed specific quality measurement methods and used different sets of measurements to determine product quality.

On the whole, the cases explore how different groups face several factors that are social, economic, political and technological in nature. By exploring how such factors shaped the incentives and decisions of these various groups, the cases analyze how different groups influenced different aspects of mensuration: e.g. selection of attributes to measure (chapter 6), selection of measurement tools (chapter 4), standardization of metrology versus mensuration practices (chapters 4 & 5), etc.

The analysis of the three cases seeks to highlight how different solutions emerged to address the different mensuration issues: metrological standardization (chapters 4 & 5), standardizing protocols (chapters 4 & 6), third party monitoring of measurements (chapters 4 & 6), coordination by trade associations (chapters 5 & 6), etc. For instance, the case of the coal trade shows how standardizing mensuration practices through regulation was a way to solve transparency issues in market transactions. Metrological standardization had not automatically guaranteed reliability. The case of the wire industry investigates how standardizing both the wire sizes (metrological standardization) as well as the wire gauges (measurement instrument) was a solution to make measurements of wire diameters reliable. The efforts of heterogeneous buyers and producers were coordinated through trade associations and in fact the coalition of large manufacturers was able to influence the eventual standards to be fairly close to their desired specifications. The case of wheat trade shows how market institutions and third party monitoring by commodity associations was able to guarantee the reliability of measurements. Standardization of mensuration practices, in this instance, did not involve the rationalization of numerous standards, i.e. decrease the number and variety of standards. In contrast, protocols were developed to make it possible to use several specialized standards.

In all the three cases there was no 'true value' or a universal measurement criterion that measurements had to conform to. There was no true way of measuring grain quality or an ideal wire gauge or the perfect way of measuring the amount of coal delivered. Markets found different solutions to mensuration issues, standardization being one of them. The cases explore the role of market institutions, and demonstrate that a narrow focus on metrology or measurement error cannot uncover how markets managed measurement issues.

Chapter 4

Quantity Measurements in the London Coal Trade: Metrology & Mensuration

"If bread be the staff of life, coals are its clothing" (*The Times*, Mar 28, 1829)

4.1 *Introduction*

The long-distance trade in 'sea-coles' has existed at least since the fourteenth-century: the Company of Woodmongers and Coal Sellers was active in London around c1330.[1] By this time there was a fair amount of traffic in the commodity, which continued to grow steadily until the nineteenth-century. In 1369 the City of London appointed *coal meters* who were city officials responsible for measuring coal. Public measurements of coal was a method devised 'to ensure fair measure for the consumers.'[2] Also, the crown began to levy taxes on coal to finance its activities: a tax in 1362 was levied on coal to help finance the Black Prince's campaign in France.[3] By the nineteenth-century a highly structured and elaborate trade route involving coal, a portfolio of taxes and fiscal charges on this trade, and a public system of 'delegated monitors' to measure the commodity had existed for more than half a millennia - long established institutions in the history of the metropolis.

In this chapter, I explore the links between the trade structure of the London coal trade, the state's fiscal interest in this trade, and the relevant mensuration practices and their changing nature in the early nineteenth-century. The case study investigates the factors that led to three significant reforms c1830: the abolition of the public metage system, the abolition of the heaped measures, and the switch from using volumetric metrological standards to weight standards. In other words, it

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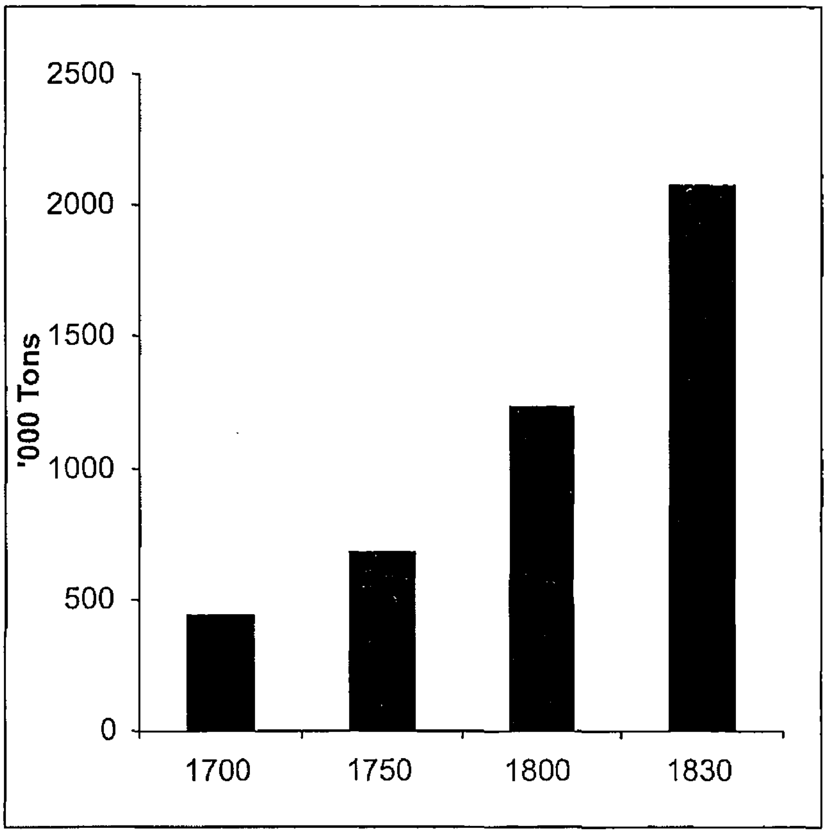
[1] H. B. Dale, *The fellowship of woodmongers: Six centuries of the London coal trade* (Reprinted from the '*Coal Merchant and Shipper*', London, c1922), p. 1.

[2] R. Smith, *Sea-coal for London: History of the coal factors in the London market* (Longhams, London, 1961), p. 2; cf. Dale, *Woodmongers*, p. 1, who claims that the Coal Meters were formed around c1330; also Hatcher, *Coal industry*, p. 25, who cites Dale as his source.

[3] Dale, *Woodmongers*, p. 1; also J. T. Taylor, *The archaeology of the coal trade* (Frank Graham, Newcastle, 1858), p. 13.

Figure 4.1
Quantity of Coal Transported to London (1700-1830)



Source: Based on figures reported in M W Flinn, *The history of the British coal industry (Volume 2: 1700-1830)* (Clarendon Press, Oxford, 1984)., *table 8.1*

analyzes the changes that occurred in the measurement protocols as part of the efforts to make measurements more reliable.

The main argument I make in this chapter is that adopting metrological standards did not automatically guarantee measurement reliability: mensuration practices on the whole required standardizing. This involved making changes in the measurement protocols as well as other measurement tools (instruments & standards), in a process that was mostly coordinated through increased governance. The initiative for change came from the market, and the state's involvement was ensured by the opportunity to solve certain political economy issues. The institutional changes that occurred required overcoming path dependency.

Specifically, the institutional changes involved addressing several basic issues facing the trade. Were the measurements used during product reliable? Could the buyers rely upon measurements used in the trade such that the amount of coal that they received was actually the amount of coal that they purchased? Were public measurements necessary? Did the London trade use the 'wrong' metrological units to measure quantities, i.e. using volumetric standards instead of weight standards? This chapter investigates how markets tried to address these questions and manage measurement and transaction issues in a rapidly expanding trade (figure 4.1).

The London trade faced several governance issues as the traffic in the commodity increased significantly in the early decades of the nineteenth-century. It took nearly a hundred years for the traffic in this trade to double compared to c1700 levels. The same quantum of growth was achieved in only thirty years in the early years of the nineteenth-century. Several institutions regulated the sale and delivery of the commodity in London, including the public measurement system, the various layers of duties and charges, and the 'turn system' that guided the loading and unloading of colliers. With increased traffic, these institutions came under severe strain creating several complications in the governance of the trade. Addressing these complications implied resolving distribution bottlenecks due to increased congestion, improving the port infrastructure and docking facilities, reforming the turn system and restructuring the public measurement or metage system.[4]

The public metage system had traditionally acted as a mechanism to govern and manage the mensuration activity within this trade. It was an important mechanism for monitoring the amount of coal that was exchanged during all trades in the market and determining the fiscal income that would accrue to the government from this trade. The 'measurements' certified by the public measurers (along with other economic 'facts' such as prices) were used as a basis for determining the rights of the sellers, buyers *and* the state. The reformation of the metage system was part of the efforts to strengthen governance within the London trade and in the process to reform or alter a mechanism that was considered by some groups to be inadequate and/or non-transparent.

At a broader level, the trade reforms could also be traced to the changing political economy of British taxation. As was discussed in Chapter 2, the state increasingly sought ways to make the taxable commodities more amenable and conformable to its

[4] Smith, *Sea-coal for London*, pp. 195-229; S. Ville, 'Total factor productivity in the English shipping industry: The north-east coal trade, 1700-1850', *The Economic History Review* 39 No. 3 (1986): p. 364.

system of measurement. As part of its efforts to centralize administrative functions, it had progressively installed a uniform method of gauging taxed goods predominantly at the source of production or distribution.[5] This was achieved for most of the commodities by the eighteenth-century *with the exception of coal*. Fiscal revenues from coal were substantial by the end of the eighteenth-century accounting for more than 3% of the state's total revenue.[6] Nevertheless, the state's capacity to continue taxing this essential commodity, with an inelastic demand, was contested in the early decades of the nineteenth-century. The trade reforms, according to some historians such as Paul Sweezy, T S Ashton and Michael Flinn, represent the 'triumph of [free] trade and rational taxation'.[7]

The issue that lay at the core of the metage reforms was the standardization of quantity, or rather a method of estimating *reliable* quantities. Reliability in this case may be understood both in terms of consistency as well as conformity (see chapter 3 for an explanation of these terms). The state's fiscal, administrative and regulatory functions required a reliable method of accounting for quantity of coal traded: the metage system was originally meant to be a part of that method. Consistency of measurements was an important issue in this case. The market sought reliable measurements to ascertain 'who got what'. Thus, conformity of measurements to some pre-specified value was an important consideration for determining the income and property rights of various economic groups along the value chain (sellers, factors, buyers, etc.). The quantity of coal exchanged during each trade in the London market - and particularly the use of heaped measures using volumetric metrological units to determine that quantity - became the key issue in the early nineteenth-century upon which the reform of the metage system and mensuration practices hinged.

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[5] Ashworth, *Customs and excise*, p. 383.

[6] M. W. Flinn, *The history of the British coal industry (Volume 2: 1700-1830)* (Clarendon Press, Oxford, 1984), p. 284. In 1789 revenues from the coal trade contributed £552,000 of the total state revenue of £16.7 million.

[7] P. M. Sweezy, *Monopoly and competition in the English coal trade: 1550 - 1850* (Harvard University Press, Cambridge, MA, 1938), p. 55. He remarks that the 'cloying fetters of mercantilist trade and fiscal policy were swept away with one stroke'; T. S. Ashton and J. Sykes, *The coal industry of the eighteenth century* (Manchester University Press, Manchester, 1929) make a similar argument stating that the 'remedy for the evils lay not in the increase of state and municipal supervision, but in the abolition of duties, the substitution of weight for measure [and] developments of transport', p. 224-25; also, Flinn, *Coal Industry*, p. 285, who writes that the reforms were symbols of the victory of free trade and the triumph of capitalism and were manifested in the London case by a 'growing willingness on the part of the government to listen to free trade arguments.'

This problem of reliable quantities was not unique to the coal trade around this period. Historically, quantities were mired in the micro-politics of feudal rents, which revolved around the shape of baskets and other measurement artefacts as well as local practices of heaping and striking.[8] Efforts to standardize quantity measurements in the spirits, liquor or salt trades in the eighteenth-century were protracted and involved considerable debate and negotiation between the state and the trade.[9] Standardization of quantity measurements in the grain trade was also attempted throughout the nineteenth-century. This proved notoriously difficult and it was not until the early twentieth century that standardization for wheat and other grains was achieved (chapter 6).[10]

Sidney Pollard had highlighted the significance of the measurement changes and their importance in helping the coal mining industry to standardize quantities. He argued that the increasing complexity of market transactions in the nineteenth-century, both in scale as well as geographical scope, induced owners of coalmines to adopt fewer and standardized metrological units in place of the multiplicity of units that had worked well in the past.[11] I argue that rationalizing the number of measurement units was not sufficient to standardize quantity. In fact, the multiplicity of metrological units *per se* was not the issue upon which the reliability of measurements in this trade revolved. Standard-switching is a path-dependent and non-ergodic process (chapter 3), an aspect that Pollard did not consider in his analysis. Even though the coal merchants may have realized the benefits of switching to uniform measurement standards, coordinating between the collective benefits of uniform measurements and the private benefits of non-standardized or even non-compatible standards may have been anything but straightforward.

However, we cannot ignore the increasing use of standards and standardized measurement tools in the trade. For instance, the coal owners of the northeast had adopted cost and management accounting practices such as discounted cash flow techniques and risk adjusted rates of return on their estates by the turn of the

[8] Scott, *Seeing like a state*, pp. 27-29.

[9] Ashworth, *Customs and excise*.

[10] Hill, *Grain, grades and standards*, pp. 6-12; Dumbell, 'Corn sales'; R. B. Forrester, 'Commodity Exchanges in England', *Annals of the American Academy of Political and Social Science* 155 No. 1 (1931).

[11] Pollard, 'Coal measurements'.

eighteenth-century.[12] The demands for reliability of quantities may have been a reflection of these trends, particularly by the sellers of coal from the northeast.

This raises several questions. Did the standardization – i.e. *rationalization* from many into fewer units - occur when a few dominant coal owners imposed their will on the rest of the industry? To what extent could coal owners, who used the ostensibly more reliable weight standards, impose their preferences on mensuration practices used by the London merchants? Did the switch to weight standards from volume standards make the metage system redundant? Why were the units of weight considered to be more reliable than the units of volume? Answers to such questions must account for the competition and complex negotiations between the different groups of merchants and the various levels within the state (bureaucracy, legislature, local government, etc.), as well as the ability of coal owners to exert their influence on the state and the London market.[13] This case study unearths how the concepts of 'appropriate' metrological standards held by coal merchants at the production end of the trade route 'travelled' and influenced the mensuration practices at a major consumption centre.

The rest of the chapter is organized as follows. The following section describes the structure of the London coal trade around c1830, the interaction between the various groups of merchants involved in the trade and the functioning of the metage system. Measurements used in the trade and the issues of management and the unreliability of measurements is discussed in section 3. It concludes by demonstrating that the measurement problems were largely localized in London, even though both ends of the trade route were using fundamentally different measurement units. Section 4 analyses the reform of the coal trade and reconstructs the events using primary data sources (such as records of the Corporation of London, parliamentary papers, etc.) and summarizes the main changes in the mensuration practices that were brought into effect as a result of the reforms of 1828-1832. The principal implications of these reforms are discussed in the penultimate section. Conclusions and closing observations are offered in the final section.

[12] R. K. Fleischman and R. 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); S. Brackenborough et al., 'The emergence of discounted cash flow analysis in the Tyneside coal industry c1700-1820', *British Accounting Review* 33 (2001).

[13] W. J. Hausman, 'Market power in London coal trade: The limitation of the vend, 1770-1845', *Explorations in Economic History* 21 No. 4 (1984); Sweezy, *Monopoly and competition.*

4.2 *Structure of the London Coal Trade c1800-1830*

London was precocious in its use of coal. Since the Middle Ages the metropolis was supplied by coal from the coalfields of Northumberland and Durham, mainly around the rivers Tyne and the Wear. The abundant outcropping seams of coal and direct water connections favoured this trade route and the traffic along this route grew substantially over the centuries.[14] In the early nineteenth-century, even as the other coal producing regions such as Wales and the Midlands increased their output of coal in proportion to Northumberland, this region dominated the supplies to London. For instance, virtually all of London's coal in the years 1816 and 1817 came from the ports of Newcastle and Sunderland, and more than half of the coal shipped out of these ports was delivered to London.[15] Thus, the Northeast-London (NE-L) coal trade route that dominated the trade in London was as old as the trade in the metropolis.

Table 4.1
Quantity of Coal Delivered to London by Mode of Transportation*

Year	Coastwise (tons)	Inland routes (tons)	Total (tons)
1801	1,289,177	-	1,289,177
1810	1,241,650	8,324	1,249,974
1820	1,492,124	1,128	1,493,252
1827	1,985,969	1,513	1,987,483
1837	2,626,997	2,324	2,629,321
1847	3,280,420	41,967	3,322,387
1861	3,567,002	1,665,080[a]	5,232,082
1866	3,033,193	2,986,989[a]	6,003,089

Sources & Notes: * Excluding foreign imports. Quantities between 1801 and 1827 from PP 1826-27 Vol. XVIII p. 495; for 1837 from PP 1839 Vol. XLVI p. 22; for 1847 from PP 1847-8 Vol. LVIII p. 315; for 1861 and 1866 from PP 1867 Vol. LVIII p. 438; [a] Almost all of this coal was transported by rail. Quantities between 1801 and 1827 reported in London chaldrons (LCh) and converted to tons on the basis of 1 LCh = 25.5 cwt and 20 cwt = 1 ton. Quantities from 1837 onwards are reported in tons

[14] Hatcher, *Coal industry*, p. 25; Smith, *Sea-coal for London*, pp. 5-6.

[15] *PP 1818 Vol. XIV, Account of coals shipped from the ports of Great Britain*, pp. 165-69.

Almost all of the coal that was sold in London until the nineteenth-century was brought via the coastal sea routes. A negligible amount of coal came into London via inland routes. For instance in 1810, out of the 1.25 million tons of coal brought into London, about 1.24 million tons were shipped via coastal routes and only about 8,000 tons was delivered via inland routes, mainly canals (table 4.1). This proportion remained more or less constant until the 1840s when the proportion of deliveries via inland routes increased steadily and by 1866 the proportion delivered by inland routes, primarily by railway routes, was about 50% of the total quantity delivered to London[16]. Thus, before 1840 London's supplies of coal came primarily from the northeast via coastal routes on ships known as colliers.

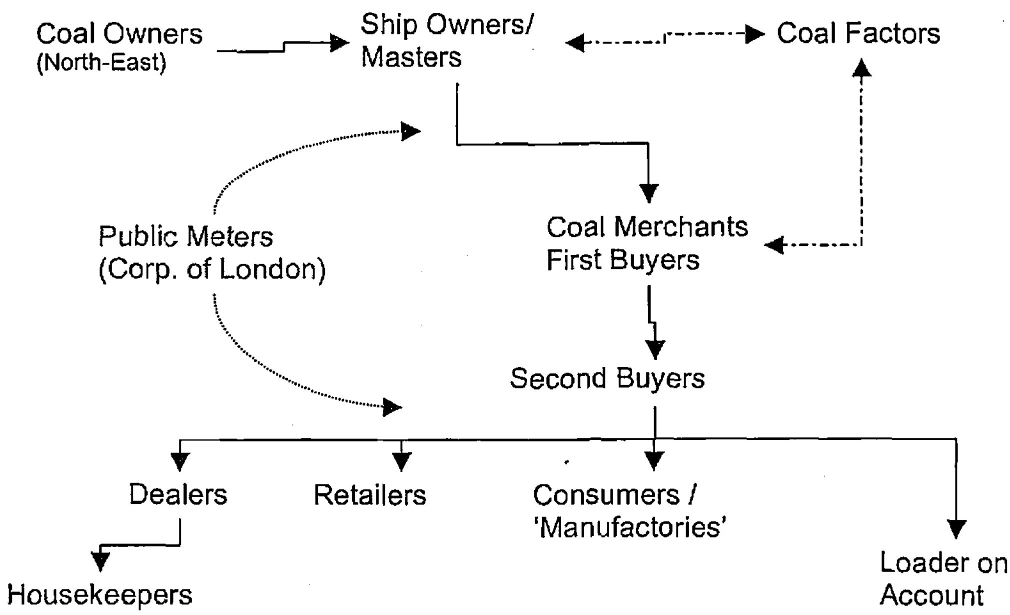
The London trade route consisted of complex structures organized around numerous distinct economic groups (figure 4.2).[17] As the figure shows, the coal passed through several hands before reaching the ultimate consumer. At the NE end of the trade were the *Coal Owners*, who owned or leased estates producing a high quality coal that had a strong demand in London. They were a highly organized group as is evidenced from the fact that since the seventeenth-century they were able to form several combinations that were essentially monopolistic in nature. During the sixteenth and seventeenth centuries, groups of dominant coal owners were organized as the 'Grand Lessees' and later the Company of Hostmen. These groups combined to apportion between themselves the 'Vend' or quantity of coal that would be delivered to the market in each period and there is evidence of such combinations being formed at various times throughout the seventeenth-century.[18] During the seventeenth and early eighteenth-century, the Company of Hostmen also came to include a group of middlemen called the *fitters*. At least three principal combinations were formed between 1700 and 1830 in the Northumberland and Durham region – the Grand Alliance, the Limitation of the Vend and the Joint Durham and

[16] *PP 1867 Vol. LXIV, Account of coals brought coastways and by inland navigation*, p. 642; Of the 6 million tons of coal delivered in 1866 about 3 million were delivered by the coastal routes and nearly 3 million were transported via the railways.

[17] Figure 4.2 and the following account of the supply chain is mostly based on two Reports from the Committee on Coal Trade; see House of Commons Reports (1785-1801) Vol. X 1800.

[18] Sweezy, *Monopoly and competition*, pp. 13-15; F. W. Dendy, ed. *Records of the company of hostmen of Newcastle-upon-Tyne* (The Surtees Society, Durham, 1901); Smith, *Sea-coal for London*, pp. 2-14.

Figure 4.2
Structure of the London Coal Trade (c1830)



Northumberland Coal Owners Association.[19] The intent of most of these combinations was twofold: limit the output of coal and thereby maintain prices and profits.[20] In addition, the owners were also a politically powerful group, well represented in both the houses of the Parliament. Prominent personalities include Sir Matthew Ridley, MP, Lord Durham, and Lord Londonderry, the Marquis of Londonderry.[21]

The role of the *fitters* was to arrange for the coal to be sold to the *shipmasters* of sea-going ships or colliers in return for a commission from the pit owner or lessee. The fitter was also responsible for settling all the customs formalities and obtaining a certificate of loading specifying the price and quantity of coal. The coal would be delivered into the colliers by *keelmen,* who would employ light craft known as keels

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[19] Flinn, *Coal Industry*, pp. 256-67; Sweezy, *Monopoly and competition*, pp. 22-36; also Dendy, ed. *Hostmen*; P. Cromar, 'The coal industry on Tyneside 1771-1800: Oligopoly and spatial change', *Economic Geography* 53 No. 1 (1977), and J. A. Jaffe, 'Competition and the size of firms in the north-east coal trade, 1800-1850', *Northern History* 25 (1989).

[20] Jaffe, 'Competition and size': p. 236; Flinn, *Coal Industry*, p. 256. Small variations in either costs or prices could make substantial differences to the total profits of coalowners.

[21] Lord Durham was the son-in-law of Earl Grey and the owner of an estate of 17,000 acres, with mines connected via a network of private railway; D. Spring, 'The Earls of Durham and the great northern coal field, 1830-1880', *The Canadian Historical Review* 33 No. 3 (1952). Lord Londonderry was the largest coal owner on the wear; Jaffe, 'Competition and size'.

for this purpose.[22] Until the late eighteenth-century the *shipmasters* would transport the coal to London at their own risk - rarely was coal freighted directly to the London market. However, by the 1790s some owners had began consigning cargoes to specific commission agents called *coal factors*.[23]

In the early seventeenth-century, traffic in coal in London increased substantially. In addition, colliers could no longer unload onto the wharves. Consequently, there arose a need for a 'middleman' who could act as a connecting link between the shipper and a) the market and the buyers, b) the customs and city offices for payment of duties and charges, and c) the labour pool who would deliver from the colliers to the wharves. By the 1670s various intermediaries were fulfilling this role, known variously as crimps or brokers.[24] Sometime during the eighteenth-century the *coal factors* emerged as an organized group of intermediaries and by the 1780s were acting as commission agents in London.[25] Gradually, the *factors* had become the first point of contact for the shipmasters arriving with their cargoes into the Port of London. Thomas Gillespy, a coal factor and shipowner in London, stated that in 1800 there were 19 'houses' (comprising of 27 individuals) carrying on the business of coal factors in London.[26] These numbers remained unchanged thirty years later according to the testimony of another coal factor, James Bentley.[27] On arrival of the ship into London the ship's papers were transmitted to one of these factors, who in turn would complete the customs formalities and arrange for the sale of the cargo at the Coal Exchange.

The Coal Exchange in 1800 was a closed market conducted from a building in Billingsgate that was built somewhere around 1769.[28] In this Exchange, the factors would conduct the sale of coal to a group of merchants known as the Coal Buyers or

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[22] The keels and keelmen play an important role in the development of measurement units between the 16th and 19th centuries in the northeast. However, as this is not the main focus of my analysis, I have refrained from discussing it here.

[23] Smith, *Sea-coal for London*, pp. 121-22.

[24] Ibid., pp. 49-50; J. U. Nef, *The rise of the British coal industry, Vol. 2* (George Routledge & Sons, London, 1932), pp. 85-87.

[25] Flinn, *Coal Industry*, pp. 277-78; cf. Smith, *Sea-coal for London*, who reckons that the term 'factor' was being used from the early years of the 17th century, pp. 66-67.

[26] *Report on Coal Trade, 1800*; Gillespy's evidence before the committee, p. 553. However, a subsequent report tabled by the committee's mentions a figure of fourteen instead of nineteen (*Second Report on Coal Trade, 1800*.)

[27] *PP 1830 Vol. VIII*: Bentley's evidence before the committee, p. 149.

[28] Smith, *Sea-coal for London*, p. 85.

First Buyers. Around 1800, there were about 70-75 of these large merchants operating within the Coal Exchange, and although their numbers appear to have increased to about 150 by 1830, only about 50 or so were considered 'first' houses around this time.[29] Thus, the trade was concentrated in the hands of a few individuals who functioned as a conduit for virtually all the coal that entered the London market. Thomas Fletcher, a coal buyer, described the business of the first buyer.

> "The business of the first buyer [is] to purchase entire cargoes of coal from the factors, and to dispose of them afterwards to his customers, of whom there are five sorts, viz. the loader on account; the dealer; the retailer; the consumer, and the housekeeper. The first is a person who loads Coal in his own craft, but has not capital to buy at Billingsgate, where the practice is to purchase whole cargoes, on an average credit from 28 to 30 days. The dealer buys of us to sell principally to housekeepers. The retailer keeps a shed, and sells them out by the bushel; and the consumer is confined to large manufactories[30]."

This heterogeneous group was sometimes also referred to as *second buyers*. According to one contemporary estimate, the second buyers, excluding the housekeepers, purchased roughly five-sixths of the coal from first buyers.[31] This structure of the supply chain within the London market had remained practically unchanged between the late eighteenth and early nineteenth centuries.[32]

Finally, within this supply chain were the *lightermen* (previously known as woodmongers), who kept and operated barges. In the eighteenth-century, the coal factors effectively replaced the lightermen as the middlemen between the seller and the buyer in the London market. By the nineteenth-century, it would appear that the lightermen had turned into a group that would hire out the barges, or lighters, for delivering coal from the colliers to the wharf. They were paid by the buyers, who in turn charged their customers with lighterage as the cost of delivery from the colliers

[29] *Report on Coal Trade, 1800*, p. 553, evidence of Thomas Gillespy; *PP 1830 Vol. VIII*, p. 149, evidence of James Bentley, coal factor.

[30] *Report on Coal Trade, 1800*, evidence given by Thomas Fletcher to the Select Committee, p. 548.

[31] Ibid., p. 553, Gillespy's evidence.

[32] *PP 1830 Vol. VIII*, evidence given by Joseph Holl to the Select Committee, pp. 117-119. A slightly different terminology and arrangement is described by Dale, *Woodmongers*. He mentions ten first buyers who took the whole contents of a ship and sold to the second buyers 'who represented some 60 other firms', and 'beyond these a vast number of brass-plate coal merchants and dealers and retailers who sold by the bushel'(p. 95).

to the wharves.[33] Coal was transferred from the colliers onto these barges by *heavers* or *whippers* who were contracted by an *undertaker* employed by the ship's captain once the colliers entered port.

An important group in the supply chain was the *coal meters,* who were first appointed in the fourteenth-century to 'ensure fair measure for the consumers.'[34] Most probably, as the traffic into the Port of London increased, and duties on coal and other city dues became an essential part of the customs machinery, the meter became an integral part of that institutional infrastructure. By the late eighteenth-century, we perceive two classes of meters; the *sea meters,* those originally employed in the fourteenth-century to measure coal being delivered from the colliers to the lighters; and the *land meters,* who were appointed to conduct measurements on the shore.[35] Once the sale of the coal was arranged on the Coal Exchange, the factor would make an application to the Coal Meters office for an appointment of a sea meter.[36] The duties of the sea meter on board the colliers were to prepare an account of the cargo delivered to the various first buyers on the basis of actual measurements made as the coal was 'heaved up' from the colliers onto the lighters or barges.[37] The land meters were appointed to specific wharves and were expected to 'see all the coal which are sold [was] duly measured, and the due quantity served [and] the whole quantity put into the wagon.'[38]

The meters were employed by the Corporation of London, which charged a metage duty of about 1s 2d per *chaldron* for this 'service'.[39] Fifteen principal sea meters were appointed by the City of London to supervise nearly 150 deputy sea meters. Similarly, two principal meters each for London and Westminster and about four for

[33] *Report on Coal Trade, 1800,* evidence of Thomas Gillespy, pp. 550 and 552; See also Smith, *Sea-coal for London,* pp. 48, 64-6 and 146.

[34] Smith, *Sea-coal for London,* p. 2.

[35] Ibid., p. 52. The Land meters were formed around 1767, when a group of coal merchants successfully petitioned the parliament to secure permission to measure coal 'between the Tower and Limehouse Hole [as] the old Coal Meters of 1330 only operated in the City of London on the river', Dale, *Woodmongers,* p. 82.

[36] *Second Report on Coal Trade, 1800.*

[37] *Report on Coal Trade, 1800,* see evidence by James Dixon (Coal Meter) and Richard Austen (Deputy Coal Meter), p. 558.

[38] *PP 1830 Vol. VIII,* see evidence by John Bumsted (Principal Land Meter), p. 26.

[39] Ibid., pp. 8-9. This was comprised of *8d* per chaldron for the sea metage and *4d* per chaldron for land metage. The chaldron was the customary unit of measurement used in the trade and is discussed in greater detail in the following pages.

the county of Surrey supervised the work of between thirty and forty land meters in each district. The meters were traditionally paid at the discretion of the shipmaster, however, after 1807 the sea meters were paid a fixed amount by the City on the basis of the quantity measured (one penny per chaldron). The land meters were paid a fixed wage per week of up to 28 shillings in London, or less if light work was involved, while those in Surrey were paid between 12 and 20 shillings a week, or less than eight shillings if working occasionally.[40] The metage system effectively performed three vital functions: first, the meters acted as 'delegated monitors' to measure the quantity exchanged between the buyer and the seller; second, these measurements served as a basis for collecting various duties on coal and other city dues; and third, the metage duty was a source of revenue for the City.

However, the functioning of this system was not always smooth. The Corporation of London was faced with the problem of monitoring the coal meters. With over 150 sea meters and nearly an equal amount of land meters, the principal meters had trouble supervising their effort and commitment. The sea-meters had an incentive to collude with the first buyers to provide short measure as they were paid a fixed fee for every chaldron they measured. As far as the land meters are concerned, their earnings were not directly based on how much quantity was measured. However, many of them in fact had other occupations as publicans and small shopkeepers, which explains why so many instances of absenteeism were reported among the meters. One internal memo by principal meters lists several offences reported among the meters including absence from duty, drunkenness, making erroneous returns, giving short measure, etc. Errant meters were disciplined either through prosecution, fines or wage reductions. However, these methods were not always successful and continuing problems with this system were the source of major indignation within the London coal market, as we will see later.[41]

4.3 *Measurements used in the London Coal Trade*

In addition to the numerous groups involved in the delivery of coal from the pits in the north to the end-user in London, a bewildering array of measurement units were in use well into the nineteenth-century. This paper focuses only on those units

[40] Ibid., Appendix Nos. 4(i), 8, 11, 16, 20, & 21; also *Report on Coal Trade, 1800*, see evidence by James Dixon, p. 558.

[41] [C]orporation of [L]ondon [R]ecords [O]ffice COL/CC/CCN/03/012, Papers of the Committee on Coal and Corn Meters, Jan. 1829 - Jul. 1830. Letter by principal meters dated 1 Oct. 1829.

employed in the sale and delivery of coal at the London end of the trade route. The cargo of coal bound for London was loaded on the colliers on the rivers Tyne and Wear using a measure called the Newcastle Chaldron (NCh). This was a *weight* measure, equivalent to 53 *cwt*, eight of which made up a keel load[42]. Once in the Port of London, coal would be sold from the colliers to the First Buyers using a local measurement unit known as the London Chaldron (LCh), which was a *volumetric* measure.[43] This was the measurement practice that had dominated the trade for over half a millennia (figure 4.4). In fact, before the nineteenth-century, a majority of the

Table 4.2
Quantity of Coal shipped Coastwise during 1829 comparing the quantity sold by weight and volume

Quantity shipped to	Weight *(tons)*	Volume *(chaldrons)*
All England and Wales	210,495	2,706,828 (3,451,205)*
London	265	1,548,170 (1,973,916)*

* Equivalent figure in tons assuming 1 chaldron = 25.5 cwt and 20 cwt = 1 ton
Source: Customs Returns, PP 1830 Vol. XXVII p. 131

coal transported around England and Wales by the coastwise trade in sea-going vessels was measured in volumetric units. London alone accounted for more than half of this coastwise trade (figure 4.3 & table 4.2).

Coal was physically delivered from the collier to the barge using a measure known as the vat (also known as *vatts* or *fatts*). Four vats made up the LCh and 9 bushels in turn made up the vat. There was no physical artefact representing the LCh.[44] In

[42] *cwt* is an abbreviation for the *hundredweight* which is equivalent to 112 *lbs* (almost 51*kg*). The quantity measured by this unit had changed considerably since the medieval times roughly increasing by a factor of 2.5 or 3. See Mott, 'London chaldron', pp. 230-35; also B. Dietz, 'The north-east coal trade, 1550-1750: Measures, markets and the metropolis', *Northern History* 22 (1986), pp. 282-86 and Hatcher, *Coal industry*, pp. 561-67; Smith, *Sea-coal for London*, pp. 361-68 contains a useful glossary of similar customary measurement units.

[43] Throughout this thesis I have used the terms 'volume' and 'volumetric' to signify a measure of dimension i.e. capacity. I have generally not used it to signify a numerical quantity, such as sales volume, without expressly stating so – I have preferred to use the term 'quantity' instead. Very often in contemporary quotes the term 'measure' is used to signify a measure of capacity. I have retained this term wherever it is used in quotes, but have used the term 'volume' otherwise.

[44] In the north, no physical artefact represented the NCh. Before the mid-eighteenth century the NCh was estimated using a combination of 'bolls', 'wains' and 'cartload'. After the wooden wagon-ways developed, the NCh came to be estimated using wagons each constructed to hold the equivalent of 53*cwt*. Measurement units such as the boll and *cwt* were legal as well as physical artefacts. *PP 1830 Vol. VIII*, see evidence given by Robert Brandling (Chairman of the Coal Committee at Newcastle), p. 261; see also evidence given by John Buddle (Colliery Expert and Viewer), p. 285. An account of the

contrast, the vat and the bushel, which were used to define the LCh were represented by physical standards in the form of metal vessels. The barges were divided into 'rooms', each holding not more than five chaldrons and one vat (to provide for the 'ingrain' - see below). Merchants purchasing five chaldrons or any multiples thereof would receive the entire quantity of coal in one or more such rooms.[45] Mensuration practices in the London coal trade used legal but local measurement units. The *bushel* used in the trade was different from the more generally used *Winchester bushel* before 1824 and the Imperial bushel that replaced it after 1824. Thus, the LCh and coal *bushel*, which were evidently in use only in this trade and in a particular geographical area (London), and were a result of peculiar trade practices, were contextual measurement units, as we will see later.[46]

How invariable were these measurement standards? Although the LCh was defined as being equivalent to 36 bushels, there is almost no consensus in practice on just exactly how much *quantity* was contained in this measure.[47] Contemporary experts as well as modern historians have been befuddled by the relationships between the various measurement units used by the trade before the nineteenth-century.[48] This issue becomes clearer when we compare the quantity in *gallons* that the LCh was supposed to contain. Estimates of the LCh have ranged from 288 to 396 gallons, although recent research shows that the LCh was historically estimated to be either 384 or 396 gallons.[49] Such variations in the estimates of the LCh are also evident when we compare the estimates of the *weight* of coal contained in one chaldron. One estimate concluded that the LCh attained its "final" level of about 26.5*cwt* in 1530; another ascribed a weight equivalent of 25.7*cwt*, while historical sources seem to

relationship between the NCh and the various units from which it was derived is beyond the scope of this paper. Mott, 'London chaldron'; Dietz, 'Coal Trade'; Hatcher, *Coal industry;* Taylor, *Archaeology of coal trade;* G. Bennett et al., *A fighting trade: Rail transport in Tyne coal. 1600-1800* (Portcullis, Gateshead, County Durham, 1990); etc. discuss the relationships in greater detail.

[45] *PP 1830 Vol. VIII*, see evidence by John Bumstead on March 18, 1830 p. 30.

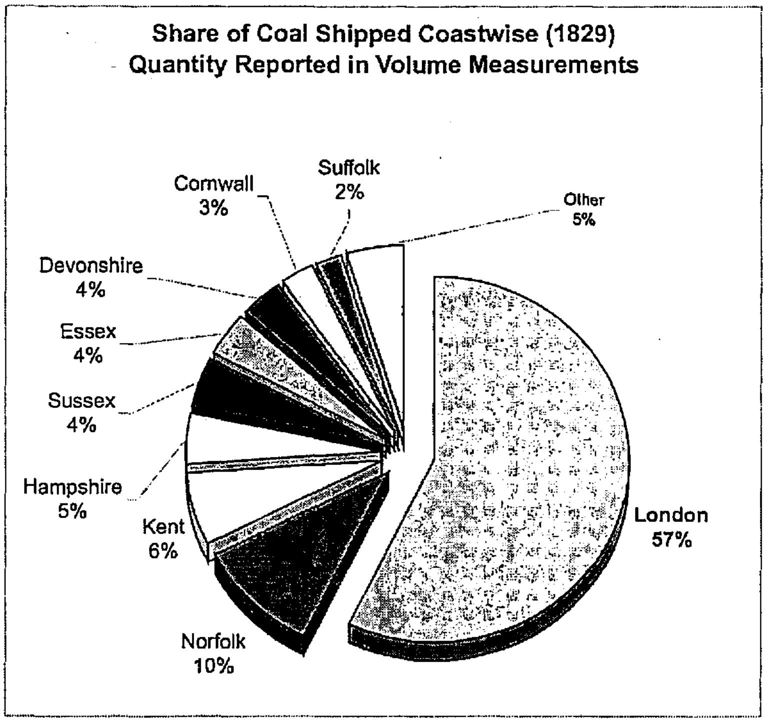
[46] *47 George III, C.68* describes a specific bushel to be used in London for the measurement of coal, that was first defined by *12 Anne Stat. 2 C.17.*

[47] *47 George III, C.68,* para CIX defines the nominal value of the LCh in terms of the coal bushel.

[48] Hatcher, *Coal industry*, p. 557; he remarks that '...immersion in the sources reveals that contemporary experts in the coal trade were at times scarcely less bewildered by the manifold measures in use, and the relationships which they bore to each other, than the historians who followed centuries after'.

[49] Mott, 'London chaldron', pp. 229-30; Dietz, 'Coal Trade': p. 284; the 'gauge' used for this estimate was quite clearly the *Winchester bushel* of 8 gallons and not the coal bushel of 8.5 gallons; Hatcher, *Coal industry*, p. 568.

Figure 4.3



Source: See Table 4.2

suggest that the weight estimates existing between 1793 and 1847 ranged from 26.5*cwt* to 28.46*cwt*.[50]

4.3.1 The Coal Bushel

The *coal bushel* was defined as being equivalent to one Winchester bushel *and* one quart of water[51]. The Winchester bushel itself was supposed to contain 8 gallons or 32 quarts. Thus, the legal coal bushel was slightly larger than the Winchester bushel, 33 quarts instead of 32, and was generally used in the measurement of dry goods. However, the volume of the Winchester bushel itself varied over the years and at some point may have been less than the 8 gallons it was assumed to contain.[52]

There are then two issues here. One, the quantity contained in a single LCh, or its sub-measure the vat, would depend upon which bushel measure was used, legal

[50] Mott, 'London chaldron', p. 230; Dietz, 'Coal Trade': p. 284; Hatcher, *Coal industry*, p. 569; see also Smith, *Sea-coal for London*, pp. 363-64.

[51] *12 Anne Stat. 2 C.17.*

[52] Connor, *English Measures*, pp. 164-66.

coal bushel or equally legal and widely used Winchester bushel. Two, consequently, there was a need to monitor that the correct bushel measure was used to measure out the required quantity. This monitoring system consisted of delegated monitors such as meters who were supposed to ensure that the appropriate bushel measure was used in each instance. Notwithstanding this, the extent of variation as a result of using the wrong bushel was only about 3%, which is almost negligible when compared to the quantities of coal normally traded in London. Furthermore, reports of frauds concerning the bushel measure contain references to an inadequate number of bushels used to measure a given quantity rather than the incorrect artefact.[53]

4.3.2 *Heaped Measures*

Another reason for the variation in the quantity contained in a single LCh was undoubtedly the custom of heaped measurements. The practice of heaping when measuring dry goods dates backs at least to the medieval times, particularly for dry bulky commodities such as grain and coal.[54] The additional quantity in the heap (as compared to the quantity contained within the vessel) appears to have increased over the centuries from one-eight of the quantity contained in the vessel to about one-quarter by the eighteenth-century.[55] By the nineteenth-century, the 36 bushels of coal that nominally constituted the LCh were to be *heaped* bushels and therefore in actuality must have equated to about 48 bushels, if the LCh was equivalent to 396 gallons.[56] Thus, the additional quantity in the heap would be about 1/3[rd] of the quantity contained in a 'stricken' bushel measure. Similarly, the LCh was to contain 4 heaped vats, each vat comprising of 9 heaped bushels.[57]

As a significant quantity was contained in the heap, the state attempted to regulate the size of the heap. For instance, the Act of 1807 states that

> 'All coals shall be duly heaped up in such [coal] bushel in the form of a cone, such cone to be of the height of at least six inches, and the outside of the bushel to

[53] *Report on Coal Trade, 1800*, pp. 600-01, Appendix 34; this variation due to the different type of bushels may be of relevance to the historian attempting to convert historical quantities into modern units. Hatcher, *Coal industry*, appreciated this difference between the two bushels whereas many earlier historians had overlooked this issue.

[54] Connor, *English Measures*, p. 156.

[55] Ibid., p. 156 & 79; also Hatcher, *Coal industry*, p. 567.

[56] 48 bushels (not heaped) x 8.5 gallons of the coal bushel = 396 gallons; equally 48 bushels (not heaped) x 8 gallons of Winchester bushel = 384 gallons.

[57] Smith, *Sea-coal for London*, pp. 367-68; also Connor, *English Measures*, pp. 180-81.

> be the extremity of the base of such a cone; and that each and every chaldron of coals shall consist of thirty-six of such bushels so heaped.'[58]

Given the nature and shape of coal, it was not always possible to form identical cones in subsequent measurement instances, which also led to variability in quantity.[59] Consequently, close monitoring was thought to be necessary to ensure that measurements meted out quantities as close as possible to those intended by both custom and regulation. The metage system, as a monitoring mechanism, were required to use properly stamped or authorised vessels along with triangular gauges to ensure that the size and shape of the cone was as per definition.[60]

4.3.3 *The Ingrain*

Another source of variation was the practice of providing the 'ingrain', i.e. providing about five percent extra quantity for every 20 units of LCh or vats measured. The seller would charge only for twenty units and but deliver a score of twenty-one units, in effect providing a discount of 5% on the price.[61] This customary practice had become a statutory requirement over the years and by 1807 legislation regulated exactly how the ingrain was supposed to be provided.[62]

This raises a couple of issues. First, it was easy for the merchant seller to withhold the additional quantity and thus not provide the quantity discount to the buyer. This practice was called 'loading bare'. Further, it was not too difficult for the merchant seller to deliver less than the twenty chaldrons (or vats) in a score. This could be done easily by adjusting the size of the heap, so that even though the measurements were carried out twenty-one times, the effective quantity could be less than the prescribed amount. There is evidence suggesting this practice was not wholly

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[58] *47 George III, C.68;* by this regulation the quantity contained in the cone of the heap was to be about 30% of that contained within the dimensions of the vessel. This calculation is based on the dimension of the bushel measure along with the cone of the heap shown in the diagram included in the appendix of the Select Committee report of 1830 (*PP 1830 Vol. VIII,* Plate 3 at the end of appendix); The inside diameter is assumed to be 18.5 inches rather than 19.5 inches. See also Smith, *Sea-coal for London,* p. 363. Thus, the volume in the cylindrical bushel measure is assumed to be approximately 1,969 in^3 and the volume of the cone of the heap is assumed to be approximately 603 in^3. Prior to the 1807 act there was no way of estimating exactly how much quantity was to be contained within the heap. The Act of 1713 only mentions heaped measures without any dimensions of the heap.

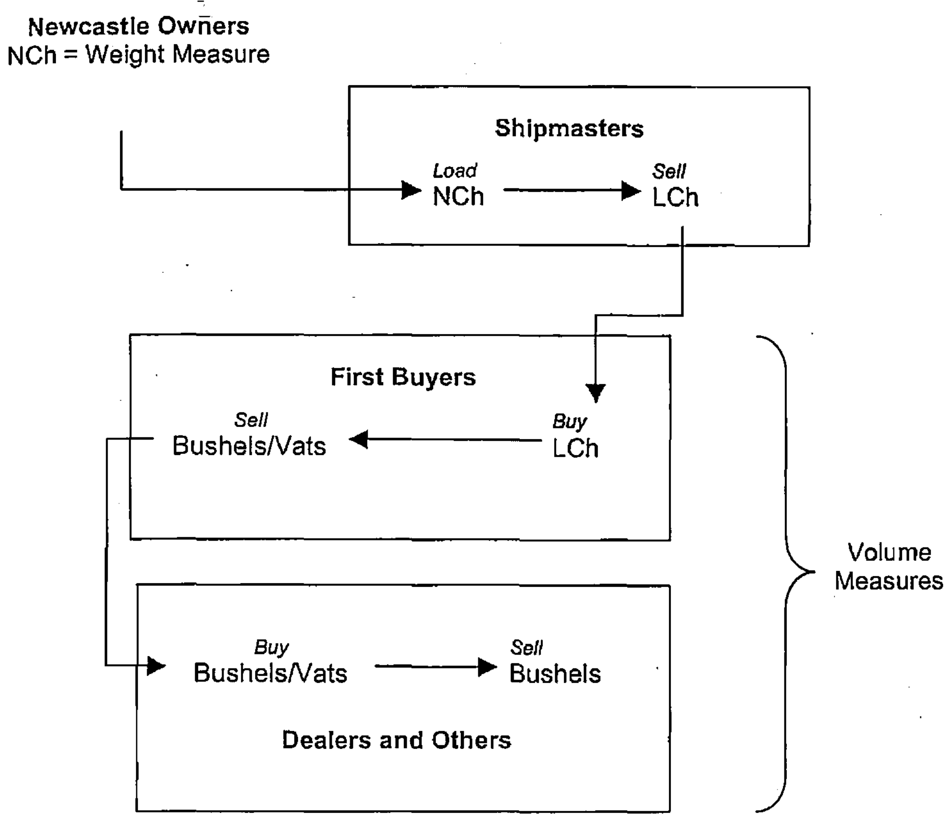
[59] *PP 1830 Vol. VIII,* p. 77.

[60] Ibid., p. 87.

[61] Ibid., p. 361, Appendix 4(h), for an example of deliveries made using the ingrain showing a Ship Meter's delivery bill.

[62] *47 George III, C.68,* para LXII.

Figure 4.4
Measurement Units used in the London Coal Trade (c1830)



NCh = Newcastle Chaldron
LCh = London Chaldron

uncommon.[63] Second, in order to alleviate this problem some effective monitoring system was required. The physical artefacts by themselves were insufficient to ensure that the ingrain was provided. Thus, one of the duties of the meters was to ensure that the proper ingrain was given.

4.3.4 *Weight - Volume Conversions*

In addition to the method of measuring quantity in London, the variation in the LCh was also the result of converting from a weight measure, the NCh, to a volume measure, the LCh (figure 4.4). One obvious requirement was to express the relationship between the two different measures as a stable ratio. However, it appears that there was no fixed or constant conversion ratio between the NCh and the LCh. Several contemporary estimates put the ratio variously at 8:15, 8:17, 11:21,

[63] *Report on Coal Trade, 1800*, pp. 553-54, 56, Appendix 34 & 37, etc.; also *PP 1830 Vol. VIII*, see minutes of evidence.

1:2, etc.[64] This implies that the quantity estimated by the LCh could vary by about six percent compared to the quantity reported by the NCh. This is a pertinent issue, because different types of coal differ in their densities. The density of coal produced from different mines and regions would often vary. Thus, coal known as the Northumberland Wallsend would weigh about 78.97 pounds per cubic foot, whereas another type, the Welsh stone-coal from Milford, would weigh about 89.38 pounds per cubic foot. On the whole, coals of inferior quality tended to be the heaviest.[65] Consequently, a fixed ratio between the two measures would not have worked unless the density of coal was accounted for in this conversion. Considering the numerous varieties of coal traded in the London market, the general consensus amongst local merchants was that 'no two bushels of coal [could] be made to weigh the same'.[66]

Just how large was this variation due to density? John Buddle - a renowned coal expert, consultant and colliery viewer - reported estimates of the variation in density among different types of coal traded in London in the early nineteenth-century.[67] His observations of 77 samples 'indiscriminately' collected from different ships shows that the variability was not as considerable as was alleged in contemporary accounts: an average variation of 3% (table 4.3). An analysis of a subset of this sample containing superior quality coal (Russell's Hetton Wallsend, Lambton's Wallsend, Russell's Wallsend, Northumberland Wallsend, Tanfield Moor, Stewart's Wallsend and Killingsworth) shows that the variance is even less within this subset, with a coefficient of variation of less than 1%.[68]

Thus the variation in quantity, as represented in terms of weight per unit volume, is small enough to have been adjusted within the price mechanism. Different quality of coals, which also differed on the basis of their specific gravity, fetched different

[64] Various Parliamentary Reports; also R. Edington, *Essay on the coal trade* (London, 1803), p. 51; Taylor, *Archeology of coal trade*, p. 24.

[65] *PP 1830 Vol. VIII*, p. 122 & 305.

[66] Ibid.

[67] There is a vast literature on the contributions made by John Buddle to the Coal Industry. An example of his influence can be seen on the adoption of innovative techniques on the collieries, such as the Discounted Cash Flow method of analysis, see Brackenborough et al., 'DCF in Tyneside'.

[68] The selection of this subset is made on the basis of Buddle's own selection where he uses these 7 varieties of coal for further analysis. See Table 4.3 for source.

prices in the London market. The lightest and best quality of coal was the most expensive, whereas the heaviest and the inferior quality of coal was the cheapest.[69]

Density of coal also tended to change depending upon the size and condition of the individual pieces of coal. Some reports claimed that small coals could be about ten percent lighter than larger pieces of merchantable coals, or in other words, small coals occupied ten percent more volume than large coals of the same weight. Other experts were doubtful about the extent to which smaller coal was lighter than heavier coal and claimed that this was true only when very large pieces of coal were broken into marginally smaller ones.[71] Nevertheless, this was sufficient inducement to load large coals in the north and to deliver smaller coals in London, coals having been broken, accidentally or deliberately, during the coastwise voyage.[72]

4.3.5 *Evidence of uncertain quantities*

The uncertainty in the coal measurements was a result of the customary practices in London as well as the measurement artefacts themselves. The likely extent of the

Table 4.3
Specific Gravity Estimates of Coals Sold in London (from John Buddle's sample)

	Main Sample	**Sub-sample of High Quality Coals**
Observations	77	21
Average Specific Gravity (Sp. Gr.)[70]	1,277	1,263
Maximum Sp. Gr.	1,432	1,247
Minimum Sp. Gr.	1,235	1,278
Std. Deviation	37	6.6
Degree of Variation	2.9%	0.53%

Source: PP 1830 Vol. VIII, Appendix nos. 24 & 25

[69] *PP 1830 Vol. VIII;* refer to evidence given by John Buddle.

[70] Specific gravity is a dimensionless quantity, the number representing the density of the substance compared to that of water, which is assumed to be one unit.

[71] C. W. Pasley, *Observations on the expediency and practicability of simplifying and improving the measures, weights and money* (Egerton's Military Library, London, 1834), p. 74;.T. Y. Hall, 'Remarks on the coal trade', *Transactions of the North of England Institute of Mining and Mechanical Engineers* II (1853-54): p. 209.

variation, from the nominal quantities, is presented below, before examining the evidence of actual variation in coal measurements between 1800 and 1830.

Uncertainty due to measurement practices

Heaped measures and the 'ingrain' were the major sources of uncertainty surrounding the quantity measured using the LCh, vat and bushel. Assuming that the measurer used the correct artefacts, the likely extent of variation can be derived as follows.

Suppose q_c to be the quantity delivered in LCh and q_v to be the quantity in vats. Then,

$q_c = q' + q^h$ and,

$q_c = 4q_v$ (by definition)

where q' is the quantity measured by the internal dimensions of the measuring vessel and q^h is the quantity contained within the cone of the heap. Similarly, $q_v = q'_v + q_v^h$ where q'_v is the quantity contained *within* the vat and q_v^h is the quantity within the cone of the heap on *top* of the vat. Now suppose $q_h = 0.3q'$ and $q_v^h = 0.3q'_v$ (as per section 4.3.2). Thus,

$q_c = q' + 0.3q' = 1.3q'$ and

$q_v = q'_v + 0.3q'_v = 1.3q'_v$

Suppose buyer A purchases twenty chaldrons from the seller, a ship owner. According to custom the quantity that is actually delivered from the collier, including the ingrain, into the lighter is $Q_a = 21q_c = 21(4q_v) = 84q_v = 84(1.3q'_v) = 109.2q'_v$ i.e. a quantity that is 109.2 times the volume measured by the dimensions of the vat.

If buyer B, another merchant, purchases 5 chaldrons from buyer A, the quantity that A should deliver to B is

[72] *PP 1830 Vol. VIII*, p. 13. Several witnesses testified to this and claimed that such 'screened' coals resulted in wastage as high as 25-30% of production.

$Q_b = 5q_c + q_v$
$Q_b = 5(4q_v) + q_v$ (by the ingrain given on 20 vats)
$Q_b = 21q_v = 21(1.3q'_v)$
$Q_b = 27.3q'_v$

Thus, the quantity that buyer B should receive is 27.3 times the volume measured by the dimensions of the vat measure, consistent with our earlier result above i.e. one-fourth part of 109.2 units that A purchased. However, A can deliver less $27.3q'_v$ to B in three ways. One, the ingrain is withheld and a score of twenty vats is given instead of the expected twenty-one vats; two, the ingrain is given but the vat is measured 'stricken' and not heaped; and three, the ingrain is withheld and the vat is measured stricken.

If the ingrain is withheld:

$Q_b = 5q_c$
$Q_b = 20q_v = 20(1.3q'_v)$
$Q_b = 26q'_v$

i.e. about **5%** less than the required quantity

If the measure is 'stricken' and not heaped

$Q_b = 5q_c + q_v$
$Q_b = 5(4q_v) + q_v = 21q_v$

But now $q_v = q'_v$ and so

$Q_b = 21q'_v$ i.e. **23%** less than the required quantity

If the measure is not heaped and the ingrain is withheld

$Q_b = 5q_c = 20q'_v$ i.e. about **27%** less than the required quantity

If we consider another scenario where another buyer C purchases a quantity smaller than 5 chaldrons from A. In this case no ingrain is to be provided and the quantity to be delivered then is $Q_c = 4q_c = 4(4q_v) = 16q_v = 16(1.3q'_v) = 20.8q'_v$. If the seller then provides a stricken measure then the maximum amount of short-measure that C will receive will be $16q'_v$ instead of $20.8q'_v$, i.e. **23%** less.

Empirical evidence to confirm this is not easily available. However, instances of measurement frauds reported to the Parliamentary Select Committees in 1800 shows that the extent of short-measure could be as low as five percent to as much as thirty-three percent (appendix 4.1).[73] Thus, assuming that the proper physical artefacts were used to measure the quantity, the merchant sellers could and did provide a substantial short-measure to the buyers.

Variation due to conversion

Variation in quantity as a result of conversion from weight to volume would have been of concern primarily to merchants who sold on the basis of weight (coal owners and shipmasters), if the variation tended to be mostly positive, and to merchants who purchased on the basis of volume (first buyers), if the variation tended to be mostly negative. The extent of variation due to the weight: volume conversion can be examined as follows.

Suppose q_n to be the quantity of coal measured using the NCh and q_l to be the quantity measured using the LCh. The relation between the two units is $q_l = rq_n$ where r is the ratio of conversion between the two units and varies between $0.47 < r < 0.53$ (section 4.3.4)

Suppose q_n^i is the quantity in NCh of a particular type or quality of coal i and d_i is the density in weight per cubic capacity of coal of type i. Since q_n^i is measured in terms of weight, its volume equivalent can be expressed as q_n^i / d_i i.e. weight divided by the density giving volume in cubic capacity units. Expressing this volume quantity in terms of LCh units we then have

$$q_l^i = r(q_n^i / d_i)$$

An error term ε captures the extent of variation in r and d_i from some initial values, say r' and d'_i. Thus,

$$q_l^i = r'(q_n^i / d'_i) + \varepsilon$$

[73] *Report on Coal Trade, 1800*, see Appendix 34 & Appendix 37.

The error term is composed of $\varepsilon = \varepsilon_r + \varepsilon_d$ where ε_r is the variation due to the changing conversion ratio, ε_d is the variation accounted by the density of coal. The density term captures the variation due to the varying specific gravity as well as due to breakages during transportation. Under ideal circumstances the average of these errors should be null or negligible i.e. $\bar{\varepsilon}_r = 0$. An analysis of 22 observations (summarized in appendix 4.2) suggests that the variation in quantity due to conversion i.e. ε_r was very small: a variation of 2 percentage points around the average ratio of 2:1 between the LCh and the NCh.

Table 4.4
Analysis of difference between certified quantity and actual quantity of coal delivered from colliers in the Port of London *(1827-29)*

	Dataset 1	Dataset 2
No. of Ships	10	6
No. of Voyages	28	46
No. of Coal Varieties	4	10
Max. variation by individual ship	7%	5%
Min. variation by individual ship	-5%	-2%
Total Observed Variation	4%	2%

Source: PP 1830 Vol. VIII; Dataset 1 from Appendix 13; Dataset 2 from p. 140

In order to test if $\varepsilon_d = 0$ variation within the same voyage and across different voyages controlling for initial quantity, the type of coal and the individual ship was examined. Data, reported in Appendix 13 and the evidence provided by James Bentley included in the select committee report on the coal trade (PP Vol. VIII, 1830), comprising of 28 and 46 individual voyages respectively were analyzed. The details of individual voyages are included in appendix 4.3 with table 4.4 providing a summary. The overall variation in the first set of 28 voyages was 4% and from the second set of 46 voyages was 2%. As the extent of uncertainty in quantities delivered due to conversion from weight to volume units was relatively modest, it is reasonable to expect the minor variations to be adjusted within the price mechanism, given a tightly controlled market by a small number of merchants.

Thus, the variation resulting from weight to volume conversion was relative minor. Quantity estimates varied mainly due to the customary practice of heaping. Contemporary views about the measurement problems in the London market are succinctly captured in this complaint:

> "I buy all other articles by number, measure or weight, except these coals [is it] too much trouble to obtain satisfaction, that I am supplied with fair measure. I have no faith in the guessing work of the coalmen."[74]

4.4 *Reforming the Coal Trade (1800 – 1830)*

The coal trade, and particularly the trade between the northeast and London, had constantly attracted the attention of the state. For one, since coal was shipped through ports where customs officers were usually present, it became an easily taxable commodity. Secondly, given that London had no alternative sources of fuel, the demand for coal was fairly inelastic. Thirdly, at both ends of the trade route there were politically powerful groups who could demand and get the state's attention in appeals against their opponents. By 1830 there were nearly 200 regulations and Acts of Parliament concerning the coal trade.[75]

By 1800, measurement problems in the London market had become important enough, and embarrassing for the trade, to become the subject of several parliamentary reviews, between 1800 and 1830. The review and reform of the London coal trade actually consisted of two phases, the first between 1800 and 1807, and the second between 1828 and 1832 (figure 4.5 below).[76] On March 12, 1800 a motion was tabled in the House of Commons for an 'inquiry into the present high causes of price in coal.'[77] This call followed disruption in the supply of coal to London and a related increase in the price of the commodity, both of which excited public comment. A parliamentary committee was appointed, to investigate the

[74] Letter to *The Times*, dated 13 Feb. 1824.

[75] Flinn, *Coal Industry*, p. 280.

[76] Another parliamentary review was conducted during 1835-36 that focused almost exclusively on the monopolistic activities of the coal merchants; major concerns regarding measurements appeared to have been addressed by the 1828-31 review.

[77] *The Times*, Mar 12, 1800.

problems in the measurement, carriage and delivery of coal, along with other issues such as the combination amongst coal owners.[78]

The committee's report was tabled after several months of interviewing various people associated with the trade; coal owners and merchants, ship-owners, factors, meters, large purchasers, market clerks and city officials, etc.[79] The committee, after reviewing the 'principal evils' affecting the trade, concluded that the practice of 'loading bare' (i.e. withholding the ingrain amount) and improper heaping were the principal causes of the measurement problems. The report stated that such frauds were committed either due to the inattention or with the connivance of the meter. It further stated that payments to the sea meters were 'optional with the ship owner' and that the payment was often related to how 'satisfactorily' the meter measured the quantity.[80]

The committee also reported the inability of the land meters to properly monitor the wharf measures, and concluded that sacks were often filled without measuring by the bushel or were deliberately filled short of the proper measure of three bushels. On the whole, the report stated that the meter's office was ineffective in detecting offences and monitoring measurement without additional enforcement. The committee even recommended the abolition of land meters and letting the consumers making the measurement during delivery, i.e. self-monitoring instead of

The report made no mention of sale of coal by weight, even though the subject of weight measures was raised during the committee hearings. John Nettlefold, a deputy coal meter, when asked about delivering coal by weight remarked that 'it would be more just that way', but thought that it would be impractical to deliver any more than 40 tons a day given their experience of delivering Scotch coals.[81] John Akenhead, a coal undertaker and ship owner, also thought that 'it would be a more certain method' but he also thought that it was 'not so expeditious or so cheap'.[82] On the other hand, George Russell, a manufacturer and ship owner, stated emphatically

[78] *Report on Coal Trade, 1800*, p. 538.

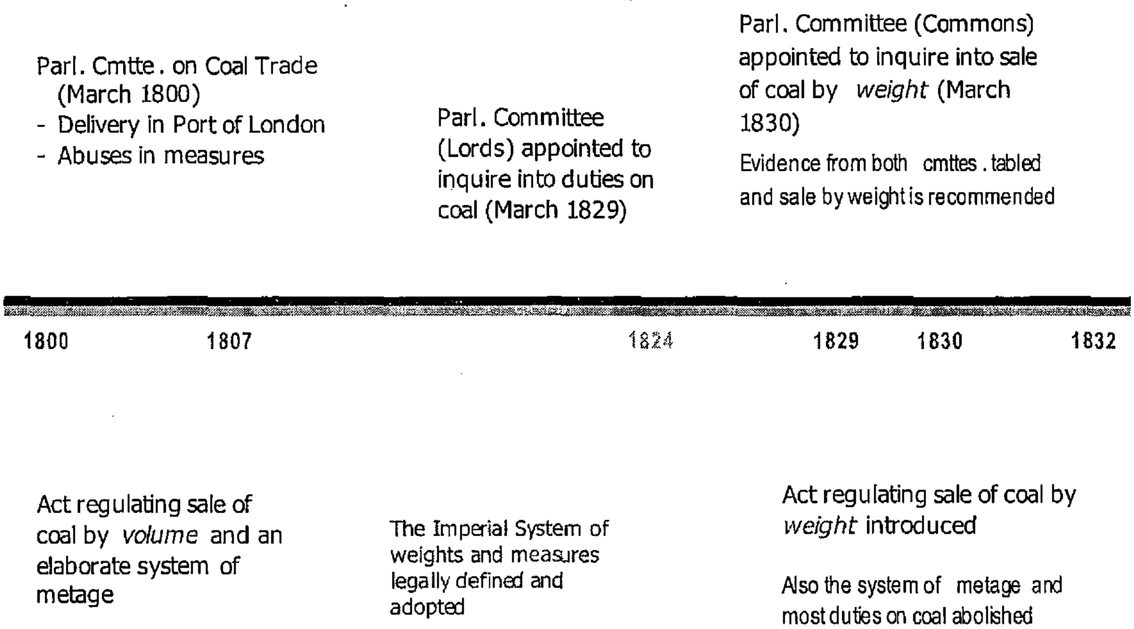
[79] Testimonial evidence from 38 individuals was attached to the appendix of the report, along with at least forty pages of documentary and statistical evidence.

[80] *Second Report on Coal Trade, 1800*, p. 642.

[81] *Report on Coal Trade, 1800*, see evidence by John Nettlefold on April 23, 1800.

[82] Ibid., see evidence by John Akenhead on March 28, 1800.

Figure 4.5
Timeline: Review and Reform of the London Coal Trade (1800-1832)



that weighing coals from 'ship to the lighter [could] be done with as much ease and dispatch, [as] is practised in Ireland.'[83]

Following this review, legislation was introduced in 1807 which intended to iron out the problems of monitoring measurements by specifying the dimensions of the physical artefacts, the rules of custom surrounding their use, regulating the operation of the metage system, the manner of compensation of the meters, etc.[84] For instance, the units of measurement and the artefacts to be used to measure the quantities were specified in paragraphs CVII (dimensions of the sack), CIX (dimensions of the bushel measure) and CX (measurements smaller than the bushel) of the act. The act also stated that coals could be sold either by volume or weight measures (Para CXXIV) and the units used for the measurement by weight were specified in Para CXXII. The legislation also specified the wages and compensation of the meters and regulated the giving of gifts to meters.

The issue of whether this legislation resulted in an institutional change as far as measurements were concerned, as opposed to making administrative changes, is

[83] Ibid., see evidence of George Russell on March 28, 1800.

[84] *47 George III, C.68.*

debatable.[85] The measurement infrastructure of the trade was largely unchanged – the measurement artefacts in use were the same, the monitoring technology in use remained largely unaltered and the rules and customs that were formalized were mostly based on long usage. Further, as the choice of the measurement standard was left to the market, the market continued to use the volume measures in the bulk of the trades.

For nearly two decades after this first review, things lay simmering below the surface. The quantity of coal shipped into London increased by about 45% in the first 25 years of the nineteenth-century (table 4.1).[86] Consequently, the number of ships entering London increased by 2,500 between 1806 and 1824, and added to the congestion in the Port of London.[87] Development of new docking facilities, such as the West India docks (1802), London docks (1805) and the East India docks (1806) attempted to reduce congestion by removing vessels from the river. A series of byelaws regulated the number of colliers permitted into the Pool to 250 ships at a time. The 1807 act had limited the rate of unloading to 42 chaldrons a day. The actual rate of unloading depended upon the availability of the meters, the whippers employed to unload the cargo, and the lighters (small transport crafts) to transport the cargo from the colliers to the wharves. Factoring this in, the turnaround times ventured into days if not weeks. Undertakers, who supplied the whippers to unload the colliers, often demanded 'detention money' from the shipmasters, further increasing the turnaround time and cost of securing release.[88] Often, meters were dispatched to ships that were yet to reach the Port of London. This increased waiting times, as the meter had to unload the ship he had been assigned to before being re-assigned to other ships. The merchants and factors constantly complained about the delays caused in deliveries due to the absence of meters. The Corporation responded to these complaints by increasing the number of land meters in 1824, which failed to alleviate the situation completely.[89]

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85 For instance, Smith, *Sea-coal for London*, considers this process to 'mark the end of one epoch and the beginning of another' (p. 143).

86 *PP Vol. XVIII 1826-27, Number of chaldrons imported into London: 1801-1827*, p. 495.

87 Smith, *Sea-coal for London*, p. 199; Ville, 'Productivity in shipping': p. 364.

88 Smith, *Sea-coal for London*, p. 198.

89 Report in *The Times*, 28 Jan. 1824 that the Court of Common Council, Corporation of London had decided to increase the number of sea meters from 118 to 130.

The retail price of coal also fluctuated considerably between 1800 and 1824. Escalating freight costs as a result of the European war were a primary cause for fluctuating retail prices. The duties, taxes and other charges on coal also increased between 1799 and 1809 before declining to their original levels by 1819 (table 4.5 and appendix 4.4). In 1791, the Greenwich Hospital was paying about 10 shillings per LCh as freight cost on coal shipped from Newcastle, which increased to 22 shillings in 1809 before declining to about 11 shillings in 1827. Unloading and porterage charges and the various duties on coal increased from 15 shillings in 1791 to about 21 shillings in 1809 before declining to 15 shillings in 1827.[90] The real retail price continued to fluctuate even after 1815 and buyers complained of the high-price of coal, continuing shortage of stocks, and measurement frauds.[91]

In March 1826, a petition was made listing several ways in which the meters themselves perpetuated the problems in the measurement and delivery of coal.[92]. This was followed by another petition in 1828 that was on a much broader issue of 'frauds committed against the public under the coal laws'.[93] Around the same time, coal merchants began demanding a fresh review of the recurring problems in the trade, particularly of delivery bottlenecks and high duties. The Society of Owners of Coal Craft[94] together with the London factors, made specific proposals to the Corporation seeking the amendment or preferably the abolition of the metage system. They also suggested remedies to solve the recurring measurement problems, including a recommendation to use "a triangle gauge to determine the cone [of the heap]."[95] The London merchants did not seek an alternation in the existing measurement artefacts and practices, such as a switch to weight measurements.

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[90] W. Beveridge, *Prices and wages in England : from the twelfth to the nineteenth century, Vol. 1* (Longmans, Green and Co., London, 1939); see also, *PP 1830 Vol. VIII*, pp. 9-10; CLRO COL/CC/MIN/01/014 Misc. MSS 241.10 (1/3), Minute book of the committee on charges upon coals, Common Council Committee Papers, 28 May 1828 - 26 Oct. 1831, entry for 28 May 1828. CLRO COL/CC/04/01/007, Minutes of the court of common council, Common Council Reports, 1826-28, report dated 8 July 1828; Flinn, *Coal Industry*, pp. 279-85.

[91] For example see *The Times*, London; 14 Aug. 1802; 5 Nov. 1804; 17 Oct. 1818; 19 & 20 July 1822; 13 Feb. 1824; 17 Feb. 1824, etc.

[92] CLRO COL/CC/04/01/007, entry for March 16, 1826 referring to the petition by Thomas Bradfield. He appears to have had some interest in a ship called Jenny which sank on the Kentish coast on 14th March 1825. The reason why this petition was made is not mentioned.

[93] Ibid., refer entry for January 24, 1828 and February 21, 1828.

[94] This society effectively comprised of the coal merchants of the City of London and is likely to have included most of the first buyers. See Dale, *Woodmongers.*, p. 80 & 96.

[95] CLRO COL/CC/MIN/01/014 Misc. MSS 241.10 (2/3), Papers of the committee on charges upon coals, Common Council Committee Papers, 1828-31; CLRO COL/CC/04/01/008, Minutes of the court of common council, Common Council Reports, 1829-30, entry for 12 Mar. 1829.

Table 4.5
Composition of average price paid by Greenwich Hospital

Year	Newcastle				London				Total Price Paid
	Price at wharf	Loading	Duties and Fees	Insurance	Freight	Un-loading	Porterage	Duties and fees	
1759	7.00	0.86	0.71	0.15	8.50	3.97	1.51	7.91	30.61
1768	7.00	0.88	0.71	0.11	6.75	3.41	1.96	7.90	28.72
1779	7.50	0.86	0.71	0.30	14.00	4.00	2.50	8.32	38.19
1791	7.50	0.90	0.72	0.13	10.00	3.21	2.68	9.02	34.16
1799	11.42	0.56	0.58	0.25	22.06	3.59	3.59	9.55	51.60
1809	16.50	0.52	0.76	0.42	22.06	4.03	4.26	12.99	61.54
1819	17.00	0.34	0.58	0.21	11.50	3.94	4.44	9.74	47.75
1827	15.00	0.34	0.58	0.24	10.75	3.86	4.68	6.49	41.94

Source: William Beveridge, *Prices and wages in England: from the twelfth to the nineteenth century, Vol. 1* (Longmans, Green and Co., London, 1939) 271. Prices in shillings per "bare chaldron" i.e. without the ingrain. The averages are reported weighted by quantities. The years are reported in harvest years. After 1791 the prices paid are for better quality coal

Meanwhile, coal owners had begun to lobby for the reduction of duties on coal sold in London. Increased competition from other coal producing regions, such as south Wales and Lancashire, which had a much lower duty structure compared to the trade from the northeast was the reason behind this lobbying. The 'Richmond shilling', a duty levied exclusively on coal shipped from the northeastern ports was amongst the several other duties that the coal owners wanted abolished.[96] In addition, the City of London was evaluating alternative means of bringing coal to London via inland routes, such as canals and the various railways proposed from Stockton and Yorkshire.[97]

Additionally, the coal owners were keen to avoid any anti-combination legislation targeting them, although previous attempts to curb their monopolistic activities through legislation had remained ineffective.[98] They engaged in a nineteenth-century version of public relations and media campaigning. One newspaper reported:

> "Practices in use in the Port of London [will appear] almost incredible to persons not conversant with the coal trade [especially the] method by which the sworn meters on the Thames make a vessel deliver great or short measure, according to the extent of the fee given to them, [coals] can be heaped in such a manner that the measure shall appear just what it may please the will of the meter [the] consequences of [the substitution of weight for volume] cannot be otherwise than beneficial, since not only will the price of coals in the south be much reduced, but the shipping interest of the north will be benefited, in its relief from a system of fraud and delay, of which it was principally the victim."[99]

Another journal commented that 'were coals sold by weight instead of by measure, the change would produce considerable relief to the consumer, and would suffer the coal-owner to lower the price'[100]. Yet another article bemoaned:

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[96] Sweezy, *Monopoly and competition*, pp. 52-53; Smith, *Sea-coal for London*, pp. 158-62; Flinn, *Coal Industry*, p. 26.

[97] CLRO COL/CHD/DM/05/04/003 Misc. MSS 207.7, Minutes of evidence before Committees, Chamberlain's Department Papers, 19 Nov. 1829, evidence on the Clarence railroad and the possibility of increasing supply from Stockton-upon-Tees; CLRO COL/CC/CCN/03/012, entry for Dec. 1829 relating to the proposed railway between Thurlstone and Smeaton in West Riding, Yorkshire.

[98] Sweezy, *Monopoly and competition*; W. J. Hausman, 'Cheap coals or limitation of the vend? London coal trade, 1770-1845', *The Journal of Economic History* 44 No. 2: The Tasks of Economic History (1984).

[99] Extract from the *Newcastle Courant* as appearing in *The Times*, London, 30 Oct. 1830.

[100] Extract from *The Durham Chronicle* as appearing in *The Times*, London, February 15, 1830, p. 3.

> 'That such a system [i.e. sale by volume] should have been long preserved [is truly astonishing], though the attention of honourable gentlemen has been repeatedly called to the easy method of defrauding [it] does not seem ever to have attracted the smallest portion of their concern. They have continued [to] occupy themselves in stopping up the spigot, while the liquor was running out at the bung-hole'[101].

The London meter had become the trade's favourite flogging horse. The practice of heaping and measuring by volume also came under ridicule, as did those who continued to use such measures.

Facing an inevitable decline in their share of the London trade and the perceived danger of losing their dominant position to other coal producing regions spurred the coal owners into action. On March 24, 1829 the Marquis of Londonderry tabled a motion in the House of Lords to appoint a committee 'to take into consideration the whole state of the coal trade, and to ascertain how far the high prices were affected by the taxes [levied] on coals.'[102] Two days later, on March 26, 1829 a select committee was appointed, which met over the course of that year to gather evidence from prominent coal merchants and experts.[103] The significance of this committee's report is that its members extensively discussed the practicality of selling coal by weight.

Robert Brandling, coal owner and Chairman of the Coal Committee at Newcastle, stated that the 'the way in which [coals] are sold here [i.e. in London], by heaped measure, is a most uncertain mode of ascertaining the quantity of coals sold to the consumer, or the quantity on which government duty is paid; and that the only accurate measure is by weight'.[104] Capt. Cochrane, owner of the Hetton Colliery, was of the opinion that the heap measure used in London was 'fallacious' and that if coal was sold by the ton it would also reduce the spurious increase in quantity due to breakage during transportation.[105] During the testimony of John Buddle, colliery viewer, on May 8, 1829, the following exchange took place:

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[101] 'On the coal trade', *Edinburgh Review* 51 No. 101 (1830): pp. 180-81.

[102] *Parl. Deb.*, Mar 24 1829, 'Debate on Coal Trade'.

[103] Journal of the House of Lords Vol. 61 1829, *Appointment of select committee on coal trade*; Journal of the House of Lords Vol. 61 1829, *Report from the committee on coal trade.*

[104] *Report on Coal Trade, 1800*, see minutes of evidence by Robert Brandling on May 1, 1829.

[105] Ibid., see minutes of evidence by Capt. Cochrane, RN, on May 4, 1829.

> Select Committee (SC): 'Can you suggest any improvement as to the mode of selling the coals – as to selling them by weight or in any other manner?'
>
> John Buddle (JB): 'I have stated it as my opinion that the coal would be sent in a better state to market if it was sold by weight at the place of shipment, rather than by measure, inasmuch as the parties through whose hands the article must pass, between the producer and the consumer, would not be benefited by the breakage of coal'.
>
> SC: 'Do you see any difficulties whatever in establishing the sale of coal by weight; would the revenue suffer in any point?'
>
> JB: 'I should think not. I think in that case the revenue would be better protected than it is at present, [the] duty would be more accurately ascertained by weight than by measure'.
>
> SC: 'Would it not, in your opinion, tend to get rid of a great portion of the fraudulent practices now going on at the Coal Exchange and elsewhere?'
>
> JB: 'I should think it would.'[106]

Sir Cuthbert Sharp, Collector of Customs at Sunderland, commented that 'there could be no possible fraud, if [coals] were taken in weight and delivered by weight'.[107] William Dickson, comptroller of coal duties in the port of London, testified that a majority of the bulk goods arriving in London were charged duties on the basis of weight. This included goods such as sugar, cotton, hemp & wool, etc. He further observed that duties 'taken by weight must of course be taken more accurately than any [duty] taken by heaped measure, as far as accuracy is concerned.'[108]

The state responded to the pressure and began considering several ways to reform the London trade. In early 1828 the Corporation of London was planning to petition the House of Commons to alter and amend the 1807 Act. The proposed amendments included provisions regarding measurements used by the trade as well as those

[106] Ibid., see minutes of evidence by John Buddle on May 8, 1829.

[107] Ibid., see evidence by Sir Cuthbert Sharp on May 4, 1829.

[108] Ibid., see evidence by William Dickson on May 20, 1829.

concerning regulating the duties of meters.[109] In May 1828 the Prime Minister, Arthur Wellesley, Duke of Wellington, asked the Mayor of London to inquire whether duties on coal brought into the Port of London could be reduced.[110] A committee formed to conduct this inquiry swiftly took the matter ahead and within a week held preliminary meetings with several prominent factors and coal merchants.[111] The committee reached the following conclusion regarding the metage system:

> 'By the abolition of the office of the Land Coal Meter, it had been estimated that a direct saving of about four-pence per chaldron, on the whole quantity imported would be effected, but having the fullest reason to believe, that other payments and allowances than those authorized by the Act of Parliament, are made to the labouring land coal Meter, which greatly enhance the amount paid in respect of the said metage, we are convinced that indirectly, a saving of at least six-pence per chaldron would be thereby occasioned'.[112]

They were also convinced that:

> 'The public do not obtain that security in respect of coals either in regard to quantity or quality which they conceive they do in the appointment of Land Sea Coal Meters and in case the same were abolished the public would be better protected against fraud by looking to their own interests than by placing a reliance upon such uncertain and doubtful security.[113]

Thus, it seems that by abolishing the system of land meters, the corporation was hoping to help solve two problems; to seek a reduction in the charges on coal, and to solve the continuing problem of monitoring the meters. That monitoring the 'delegated monitors' was an on-going problem is evident from the various reports of

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109 CLRO COL/CC/04/01/007, refer entry for February 21, 1828 and March 13, 1828. A report by the Coal and Corn committee of the same date (and included in the minute book) states *'The provisions in the Act relating to coals sold by Pool measure, being inadequate to prevent fraud in the delivery of coals, it is expedient that they should be altered and amended and all coals measured by the Bushel'*. Besides these there were 17 other provisions suggested by the report.

110 Ibid., refer entry dated May 23, 1828. The entry suggests that the Mayor was met by the Duke of Wellington along with officials from the Treasury.

111 CLRO COL/CC/MIN/01/014 Misc. MSS 241.10 (1/3) , refer entry for May 28, 1828. Meeting was attended by several prominent Coal Factors and Merchants including Thomas Gillespy and William Horne. In their opinion the Coal Undertakers system could be done away with, reducing the Coal Whippers wages; no comment on the Land Metage system were recorded apart from confirming the charges paid by the trade as metage.

112 CLRO COL/CC/04/01/007.

113 CLRO COL/CC/MIN/01/014 Misc. MSS 241.10 (1/3), refer entry for June 19, 1828 and the committee resolutions passed for that day.

the principal land meters. 'The occurrence of minor offences among the [meters] has of late been so frequent as to produce great inconvenience to the respectable Merchant and not seldom, considerable loss to the Public', complained one memo.[114] It listed several offences including absence from duty, drunkenness, making erroneous returns, giving short-measure, etc.; offences for which, the principals argued, there was no effective remedy. The corporation considered the complete abolition of the land metage system as a serious option, and made this recommendation to the Treasury department[115].

Having made the decision to abolish the land meters, the Corporation began considering options to make the monitoring of measurements more effective by further regulating the existing infrastructure. One of its reports stated that:

> 'In order to afford the Public the means of protecting themselves against fraud [the] sacks to be used should be of one size, the dimensions to be defined as at present, and no sack to be allowed to contain less than 3 bushels. [The] purchaser of the coals, if he should be dissatisfied with the appearance of the coals as to their measure, should be allowed to refuse to receive the same or to have them measured by the Carman or other person having the charge of the Cart or Waggon [sic], in the presence of two credible witnesses, one of whom should be a constable or Police Officer, and for that purpose every cart or waggon should have in some conspicuous part thereof a perfect legal bushel measure, with a triangle to define the proper height of the cone, and that the penalties as may be imposed for sending coals short of their proper measure should be made recoverable before a magistrate...'[116]

However, in early 1830, Thomas Reeve and John Bumstead, the two principal meters of London, claimed that there was "more fraud in the Pool measure than on the Land [wharf] measure" and that "the merchants [were] not sending the whole quantity."[117] On the whole, the wharf-measured coal was more accurately measured than the pool-measured coal, they argued.[118] This implied that all proposals about regulating

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[114] CLRO COL/CC/CCN/03/012, refer entry dated October 1, 1829 that contains the text of the letter to the Sub-Committee of Control over Coal and Corn Meters from the two Principal Land Meters, Thomas Reeve and John Bumstead.

[115] CLRO COL/CC/04/01/007, refer entry dated July 8, 1829, directing that the committee report tabled on that day be sent to 'the Lord Commissioners of His Majesty's Treasury'.

[116] CLRO COL/CC/04/01/008, see report dated March 31, 1829.

[117] CLRO COL/CC/MIN/01/014 Misc. MSS 241.10 (2/3), memorandum dated 19 Feb. 1830.

[118] *PP 1830 Vol. VIII*, see evidence of William Lushington on March 25, 1830, p. 78.

the bushel measure and re-measurement by consumers would be inadequate remedies if uncertain quantities were being sent from the colliers onto the wharves. They further agreed that 'weight measure could be better than the triangular measure' even though 'some coals will absorb more water than others', and recommended this as the preferred method of measurement.[119]

The issue of distorting the weight of coal by wetting them was a concern nursed by several people at the time. William Russell, the expert engineer appointed by the Corporation of London to evaluate the designs received for weighing machines personally preferred the volume measure rather than the weight measure for measuring coal. He claimed that no weighing machine could accurately measure quantity by weight or prevent frauds in measurement due to this basic property of coal.[120] On the contrary, William Horne, while testifying in front of the select committee in March 1830, related the results of an experiment he had conducted regarding the increase in the weight of coal when watered. His experiment, which involved samples of different types of coal that were measured when wet at intervals of one hour, three hours and six hours, showed that the increase in weight was between 1 to 7 per cent.[121] Wetting of coals was a usual practice by the merchants to keep down dust levels, and most witnesses agreed that detecting wet coals was relatively simple and that only very wet coals would retain a substantial amount of water weight.[122]

The Corporation from this point onwards became engaged in switching the trade to weight measurements. A parliamentary committee, appointed in 1830 'to see if another method of selling coals by weight instead of measure, might (be) of advantage to the public' concluded that the issue lay not in effective monitoring of measurements but in the customs and rules surrounding the measurement artefacts. The report stated that 'When coal of all sizes is to be placed in the bushel and piled in

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119 CLRO COL/CC/MIN/01/014 Misc. MSS 241.10 (2/3).

120 CLRO COL/CC/CCN/03/013, Papers of the committee on Coal and Corn Meters, Sep 1830 - Dec 1831, refer to the report submitted by William Russell dated June 9, 1831.

121 *PP 1830 Vol. VIII*, see the evidence given by William Horne on March 30, 1830 and summary of results of the experiment on p. 90. Admittedly the samples did not control for quality of coal and for the size of coal. Also we do not know if the weight of the dry coals was with or without the weight of the sack - as the weight of the wet sack in which the coals were weight after being watered should have been deducted. Nevertheless, this is a useful experiment since it provides the extent of variation in weight due to wetting of coals. .

122 Ibid., evidence of William Turquand (p. 68) and William Lushington (p. 81) on March 25, 1830.

a conical form on the top, it is not easy to define when a bushel is full'. This problem, the report concluded, could be solved if coal were to be delivered by weight, and not by volume.[123] Another select committee of 1829 mirrored this recommendation by stating that 'the selling by weight instead of selling by measure would obviate many of the Temptations to Fraud which at present exist.'[124]

By 1831, the trade in London began preparing itself for the now inevitable switch to the weight standard. Thomas Gillespy, representing the coal factors, stated that they acquiesced with the principle of weighing coals provided it was 'done by quarters as at present'.[125] The merchants, represented by William Horne, delivered a proposition for coals to be weighed into sacks not exceeding *2cwt* at a time in the same vessel that brought them up from the hold and to be lowered into the barge without being emptied. They also submitted a design of a proposed machine for the weighing of coal sacks.[126] Meanwhile, the treasury and the customs offices, anticipating the changes in the coal laws began reporting monthly coal statistics in tons rather than chaldrons.[127] In August 1831, legislation abolishing most of the duties on coal was introduced. The Act for regulating the Vend and Delivery of Coal was introduced in October 1831, which abolished the metage system (Para XXXVIII and LX) and directed that coals had to be sold by weight and not by volume (Para XLIII).[128]

4.5 *Significance of the Reforms*

The review of 1828-1831 resulted in at least three big changes in the London coal trade: the public metage system was abolished; heaped measures became unlawful; and the volumetric metrological standards were replaced with the Imperial weight standards.[129] In other words, the reforms made changes to the protocols and the standards that had formed part of the mensuration practices within the trade.

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[123] Ibid., p. 10.

[124] Ibid.

[125] CLRO COL/CC/MIN/01/014 Misc. MSS 241.10 (1/3), refer to entry for January 21, 1831.

[126] Ibid.

[127] CLRO COL/CC/CCN/03/013, refer letter from Custom House, dated April 21, 1831; refer also to the monthly coal statistics published for July 1831.

[128] *Act to discontinue duties upon coals, 1 & 2 William IV C.16,* 1831 and *Act for regulating delivery of coal,* 1 & 2 William IV C.76, 1831.

[129] Further legislation made heaped measurements unlawful for all dry goods in the country, in addition to coal. *5 & 6 William IV, C.63*. clause VII.

How can we explain these changes? Evidence suggests that the pressure to reform the mensuration practices in London came from the market. The trade's desire to reform stemmed primarily from their dissatisfaction with the functioning of the metage system, and, as far as the coal owners were concerned, the highly unreliable practice of 'heaped' measurements. The unreliability of measurements was also a concern voiced more generally by the London consumers who had seen wide fluctuations in the retail price of coal (in nominal terms). The market's issues with the trade coincided with the state's own reasons for reforming the metage system.

Financially, the revenue collected by the sea meters as metage duty was substantial. After deducting payments to the sea meters and other expenses (maintenance, rent, management costs, etc.), nearly two-thirds of the duty amount could be transferred to the general account of the Corporation of London as revenue (appendix 4.5). In 1829, this surplus sum amounted to more than £17,000 on metage revenues of £26,559. In comparison, the metage charges collected by the land meters just about covered their wages and salaries, and the City was generating very little revenue from this duty. In 1829, the City faced a deficit of £666 on metage revenue of £4,962 collected by the meters within the City of London.[130] Given the problems in monitoring the activities of the meters, and the elaborate infrastructure required to collect the land metage charges, this system was just was not worth it from the City's point of view. The City was keen to hold on to the revenue from sea metage, however, and its recommendation to abolish the metage system only included the land meters and the land metage charges.

The political economy of the price and taxes on coal was also an important reason for the abolition of the metage system. There were two opposing perspectives on the perceived high retail price of coal in London. One view, held by most consumers in London, was that the high price of the commodity was a result of combination and monopolistic practices among the coal owners. The other position, held by the coal owners, was that the high retail price of coal was a result of the numerous duties and charges on the commodity sold in London. Owners also objected to the Richmond shilling, a tax of one shilling per NCh on all coal shipped from the Tyne that "bore unevenly on coal owners [in Northumberland]."[131] As table 4.5 shows, in 1827

[130] *PP 1830 Vol. VIII* Appendix Nos. 8, 10, 11 and 12.

[131] Sweezy, *Monopoly and competition*, p. 49.

consumers (such as the Greenwich Hospital) could expect to pay more than six shillings per LCh as duties and taxes in addition to the eight or nine shillings per LCh as unloading and porterage charges. Although this amount declined almost by half since 1809, it was still considered high for a commodity with a fairly inelastic demand. In contrast the price of coal in Newcastle had increased from 11 shillings in 1799 to 17 shillings in 1819 and declined to 15 shillings in 1827. The coal owners argued that it was the duties and the increase in freight cost that contributed to the rising retail prices rather than any increase in the price of coal in the north.

Historians agree that of the two, the duties and charges on coal were more likely the cause of high retail prices than the monopolistic activities of the coal owners.[132] The coal owners were politically far more powerful than either the London merchants or the consumers. By 1828 they were able to put sufficient pressure on the government to get them to review charges and duties on bringing coal to London. The taxes on coal were fiscally significant, yielding the exchequer over £1,000,000 of the government's total 1820 revenue of £58.1 million. The London trade contributed about half of the government's revenue from coal: in 1828 this amounted to more than £440,000.[133] Nevertheless, the treasury, which was involved throughout the review process, did not resist the attempts to reduce the charges from coal. Along with the other duties on coal, metage duties ended in 1832. In the subsequent years, the average amount that the state generated from the London trade between 1833 and 1835 was about £100,000 to £150,000.[134] The government made the political decision to relinquish a substantial portion of the revenue from the coal trade.

The abolition of the metage duties, and the institution of public measurements for coal, was part of this political-economy process – not part of any pre-meditated metrological reform by the government. This profound change to the measurement protocols had an impact on the other mensuration practices within the trade.

How did this decision affect the measurement issues in London? With public metage due to be abolished, a direct monitoring mechanism would have became unavailable to the trade. This prompted the London merchants and the state to seek alternatives

[132] Ashton and Sykes, *Coal industry*, p. 224; Hausman, 'Cheap coals': p. 327; also, Sweezy, *Monopoly and competition*, pp. 140-45.

[133] Flinn, *Coal Industry*, p. 284; CLRO COL/CC/06/01/0357/1, Papers of the Court of Common Council, Common Council Reports, 1830, petition dated 25 Nov. 1830.

[134] *PP 1836 Vol. XI, Report of the select committee on coal trade*, especially appendix nos. 6, 7, 13, 15, 18, etc.

to the metage system. Early attempts revolved around the bushel measure and involved increased regulation surrounding the heaping practices and the method of providing the ingrain.[135] Impractical as some of these suggestions were, they were initially pursued quite seriously. The coal owners in contrast, had maintained that heaped measures themselves were the main source of unreliable quantities. They argued that the metrological units used in London and the protocols surrounding their use were perpetuating frauds and leading to price increases in the London market. They continued to lobby for a switch in measurement standards to weight units, which they argued were more reliable than the volumetric units. Similar arguments were subsequently taken up within the Corporation of London, where the change of standards was envisioned to solve the problem of unreliable quantities once the public metage was abolished. This cognitive transition, that weight measures were more reliable - and therefore more desirable - compared to volume measures, was an important event in converging towards weight standards. The corporation thus thought they were replacing one method of monitoring measurements, the public metage system, with a method that reduced the degree of personal judgement required.

But what prevented the London merchants from voluntarily switching to weight measurements, if they were indeed more reliable than volume measures?[136] The first buyers benefited from the variability of the volumetric measures as they could give short measure and withhold the ingrain, particularly as the price of coal fluctuated considerably during the early years of the nineteenth-century. Converting from the NCh weight measurement to the LCh volume measurement did not involve significant variations (appendix 4.2). Thus, the metrology worked in their favour as they could 'arbitrage' between the various measurements most effectively. Consequently, they saw no reason to abolish the existing measurement practices. Although the first buyers may have had no incentive to switch standards, other merchants and consumers certainly had an incentive to alter existing mensuration practices. However, switching standards involved overcoming major coordination

[135] *47 George III, C.68*; CLRO COL/CC/MIN/01/014 Misc. MSS 241.10 (2/3), 'Papers of the Committee to Inquire into all Charges upon Coal for the years 1828 to 1831'; one of the recommendations by the London merchants was that a triangle gauge be used to determine the cone of the heap and that the bushel measure should be readily available for inspection by buyers to determine its authenticity.

[136] According to the 1807 act, the choice of using either volume or weight measures was left to the trade. However, only a tiny proportion of coal brought via canals or from Scotland was sold by weight; *47 George III, C.68*.

issues among the merchants. For the switch to be most effective a significant majority (if not all) of the merchants would have had to adopt weight standards. This could be interpreted as a failure of collective action, particularly as smaller merchants lacked the cohesiveness and the political power to insist on a change of standard, and the first buyers had no incentive to switch by themselves.[137]

An important issue to consider here is whether the relevant technology to weigh a bulk commodity such as coal did indeed exist at this time - i.e., was it technically possible to make a switch to weight measurements in London? Did the lack of measurement technology to weigh a bulky commodity create coordination problems for a voluntary switch to weight standards? Numerous methods were used to weigh coal at the origin of the trade route in Newcastle and Sunderland. Apart from outright 'guessing', weight was ascertained by displacement at the time of loading the keels. These light river vessels carried nail marks indicating the degree to which the vessel should submerge each time one NCh, notionally equivalent to 53 *cwt*, was loaded into it. Alternatively, wagons carrying coal from the pits were weighed using "average coal" at the pit's mouth and this weight was marked on the wagon.[138] At the turn of the nineteenth-century and especially after 1830, improvements in port and docking facilities on the Tyne and the Wear meant that coal could be loaded directly on to the colliers without the intervention of the keels. Thus more direct methods of weighing at the production end of the trade route could be adopted in conjunction to the process of loading, either by lowering the tubs or wagons via cranes or by the use of spouts.[139]

However, in London there was no technology available for weighing coals on the colliers before being delivered onto the barges. From the hold of the collier, coal was shovelled into baskets, which were then 'whipped' or jerked on the deck. They were measured here using the vat measure and the basket emptied into a 'room' within the barges. Each room in the barge was supposed to contain the equivalent of five and a quarter chaldrons of coal.[140] In 1830, city officials met with Richard Trevithick to discuss his invention of a portable machine that could weigh coals and deliver

[137] Unlike the first buyers, who were organised into the Society of Owners of Coal Craft, the smaller merchants and consumers do not appear to have been similarly organized.

[138] *PP 1830 Vol. VIII*, evidence of Robert Brandling (261) and John Buddle (285).

[139] Flinn, *Coal Industry*, pp. 169-70; Ville, 'Productivity in shipping': p. 363; F. C. Danvers, *On coal - with reference to its screening, transport, etc.* (W H Allen & Co, London, 1872), p. 56.

[140] *PP 1830 Vol. VIII.*, p. 30; evidence of John Bumstead.

them at the same time. However, this machine, used in some trials conducted in Cornwall, was not in general use at this time.[141] In fact, the corporation advertised a competition in the London newspapers in 1831 promising a reward for a practical design of a portable machine for weighing coals, which elicited an enthusiastic response.[142] Was it costly to acquire such a technology? What was the scale of investment required?

We get an impression of the scale of investment required by examining the expenditure on new machinery and equipment incurred after 1832 by the trade. This included expenditure on weights and scales, beams to support them, shoots (chutes) to deliver the coal from the colliers once they were weighed into the barges, etc. Some modifications to the barges were also necessary as a result. The beams and weights appeared to have cost about £6, 3s a set with an annual maintenance cost of about £35. As far as the shoots were concerned, reports contain varying estimates from tenders submitted by several firms. On an average, larger shoots could cost between £3, 15s and £3, 6s each, whereas smaller shoots could cost approximately £2, 18s each. The annual maintenance costs ranged between £21 and £37 depending upon the number and type of shoots. In February 1833, the total outlay for machinery, new barges and furniture for the previous year amounted to about £2,946 and the expenditure due to wear and tear (depreciation charges provided for) were about £862. By May 1834, the capital stock in terms of barges, shoots, beams, weights, sundry boats and office furniture amounted to £2,312.[143] In comparison, the trade had paid over £ 26,000 annually as metage duty to the Corporation of London c1830.[144] Although lumpiness of investment does not have been a direct source of co-ordination problems, the merchants in London were unwilling or unable to make the switch to weight measurements. It was only with the reforms of the public metage

[141] CLRO COL/CC/MIN/01/014 Misc. MSS 241.10 (1/3), entry for 27 Feb. 1830; the committee also met with other engineers as per entry for 15 Mar. 1830; *PP 1830 Vol. VIII*, p. 202, evidence of Richard Trevithick; Smith, *Sea-coal for London*, p. 288.

[142] CLRO COL/CC/CCN/03/013, copy of advertisement, dated 20 Apr. 1831 and memo dated 26 May 1831; CLRO COL/CC/MIN/01/014 Misc. MSS 241.10 (1/3), entry for 16 April 1831.

[143] The capital and expenditure estimates are from the papers of the Coal Meters Committee held at the Guildhall Library: MS 10162, Reports of the sub-committees - Vol. 1 (1831-1834); specifically, Report of the Subcommittee for superintending weights, etc. dated 26 Jan. 1832, Report of Subcommittee on beams and scales, etc. dated 13 Dec. 1831, Report of the River Committee dated 4 Sep. 1832, Report of the River Committee dated 12 Feb. 1833, Report of the Finance Committee dated 13 May 1834, Reports of the Finance Committee dated, 7 Aug., 6 Nov. and 4 Dec. 1832.

[144] *PP 1833 Vol. XXXIII, Account of duties charged on coals in London.*

system and the pressure from the coal owners that the London merchants finally switched from volume to weight measurements.

Interestingly, even though the first buyers had no incentive to alter measurement standards, they found the mechanism of 'delegated monitoring' useful. For example, immediately following the abolition of the *public* meters in 1831, the first buyers decided that it was indispensable to appoint *private* meters whose cost the factors and the first buyers shared equally.[145] The private meters were employed throughout the nineteenth-century, although their importance diminished gradually as technological improvements made mechanical or instrumental monitoring easier.[146] This desire for private meters at first seems to contradict the first buyers' appeals to end the public metage system. However, evidently these merchants valued fashioning a monitoring mechanism that *they* could control, once the advantages accruing to them from the ambiguous London chaldron were nullified by the switch to weight standards.

Notwithstanding the local trade issues, the conduct of the maritime trade in general also influenced the London coal trade reforms. Expansion of shipping traffic resulted in increased congestion on the Thames from the end of the eighteenth-century onwards. The congestion rendered the 'turn system' - which guided the unloading of the colliers on the Thames - inefficient. Construction of new docks and harbour facilities, such as the West India docks at the initiative of the West India merchants, addressed this paucity of accommodation.[147] However, in addition to improved port facilities, delivery bottlenecks could only be resolved by re-examining the turn system and improving the efficiency of the metage practices. The parliamentary select committees had these objectives in mind when they investigated the public metage system and its measurement issues.[148]

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[145] Coal Meters Committee Papers, Minutes of the coal meters committee, 1831, Guildhall Library MS 30679, minutes for 11 & 15 Oct. 1831, and for meetings between 22 Oct. and 13 Dec.

[146] Smith, *Sea-coal for London*, p. 319. Improved methods included automatic weighing during delivery either by derricks or hydraulic cranes.

[147] W. M. Stern, 'The first London dock boom and the growth of the West India docks', *Economica* 19 No. 73 (1952): p. 59.

[148] Ville, 'Productivity in shipping': p. 364; *PP 1830 Vol. VIII*; *Report on Coal Trade, 1800*; similar changes were occurring at the same time at the origin of the trade route in north-eastern England; see also, A. G. Kenwood, 'Capital investment in docks, harbours, and river improvements in north-eastern England 1825-1850', *The Journal of Transport History* 1 - New Series No. 2 (1971).

Metage reforms did help to improve overall productivity in the coal trade, although historians contest the extent of productivity improvements and its impact on the maritime industry as a whole.[149] Nevertheless, changes in the coal trade provided a benchmark for other commodity trades in several ways. For instance, the parliamentary select committee on the sale of corn turned to the coal merchants in 1834 when they evaluated the possibility of selling all corn by weight measurements. Thomas Gillespy, a coal factor and ship-owner, gave evidence to this committee of how the new system of weighing was 'carried on [completely] to the satisfaction of the trade'. The new machinery installed to deliver coal from the colliers was of particular interest to the corn traders as an example of a cost and time efficient system of weighing and unloading bulky yet loose commodities. While this technology did not exist in the early nineteenth-century, with the introduction of William Cory's derricks (ca. 1860), automatic weighing and delivery of such commodities became generally possible.[150]

4.6 *Conclusions*

This chapter raises some important issues about the universal desirability of invariable measurements. Historically, some groups profited from variable measurements, especially traders and middlemen. Other groups that equated transparency with invariability found it difficult to impose invariability because it was desirable or efficient. The state, too, did not always intervene to impose invariability because it was socially efficient or desirable, or because it was the 'moral' – as in the 'right' - thing to do. On the other hand, reliability of measurements was an important issue that most merchants cared about. The efforts to reform the mensuration practices in the London trade involved making measurements reliable, not only invariable.

This observation reflects the significance of the changes in the measurement protocols that the reforms in the coal trade introduced. The abolition of the public metage system and the heaped measures formed the core of these reforms that

[149] Ville, 'Productivity in shipping'; S. Ville, 'Defending productivity growth in the English coal trade during the eighteenth and nineteenth centuries', *Economic History Review* 40 No. 4 (1987); W. J. Hausman, 'The English coastal coal trade, 1691-1910: How rapid was productivity growth?', *Economic History Review* 40 No. 4 (1987); see also C. K. Harley, 'Coal exports and British shipping, 1850-1913', *Explorations in Economic History* 26 No. 3 (1989).

[150] *PP 1834 Vol. VII, Report from select committee on the sale of corn*, especially the evidence of Thomas Gillespy dated June 26, 1834; Smith, *Sea-coal for London*, pp. 288-93.

changed the mensuration practices. The protocols that had guided the mensuration activity for almost half a millennium were replaced by new protocols. Third party monitoring (i.e. private metage system) was retained by some groups as an important part of the mensuration activity. However, a greater degree of self-monitoring along the principles of *caveat emptor* became an accepted practice.

The changes to the measurement protocols were just as important (if not more so) as the switching of metrological standards from volume to weight. This switch facilitated the abolition of an inefficient institution – the metage system. Switching to weight standards made it possible to claim that monitoring quantities did not require public measurements. This was an important change from a political economy perspective, and, rhetorically, it helped to demonstrate that the larger problems with the coal trade (its high retail price, distribution bottlenecks, etc.) were being addressed.

It is unclear if standard switching would have been possible without the changes in the measurement protocols. It is also unclear if changes in these protocols required standard switching in any way. Nevertheless, changes to the mensuration activity in this instance necessitated changes to both protocols as well as standards. Both these were demanded by the market, albeit by different economic groups. This demonstrates the importance of how managing measurement problems involved a great deal more than switching metrological standards.

We may take a view that changes to the protocols, instruments and metrological standards implied that mensuration activity was standardized in some way. However, there was a greater degree of flexibility in the protocols post-1832, as different parts of the market could monitor measurements in different ways. Thus, while the use of the metrological units and instruments was standardized (via regulation), many of the protocols guiding their use were determined by different groups according to their individual preferences. It would not be incorrect to claim that legislation may have made it mandatory to use certain standards, but it did not completely standardize the mensuration activity.

Finally, even though the changes in the mensuration activity were coordinated through regulation, it is difficult to argue that the 'state' intervened to streamline its administrative functions, or to correct 'market failures'. In fact, the intervention of the legislature was secured by private political interests with strong economic motivations. Even the involvement of local authorities was secured by strong lobbying by the merchants. Regulation appears to be a strategy pursued by politically strong merchants to secure their private interests (see chapter 5 for a similar phenomenon).

Making quantity measurements in the London coal trade more reliable involved changing the mensuration protocols and switching metrological standards. The market initiated these changes, which were coordinated through regulation and legislation.

Appendix 4.1

Reports of Measurement Frauds in London c1800

Report No.	Nominal Quantity Delivered			Shortfall detected			% Shortfall
	LCh	Bushels	Sacks	LCh	Bushels	Sacks	
1	5	180	60			7	12
2	5	180	60			7	12
3	20			1			5
4	5	180	60			7	12
5	20			1.5			8
6	5	180	60			12	20
7	10.5	378		1			10
8	10.5			1			10
9	7			2			29
10	5	180	60			7	12
11	1	36	12		6		17
12	1	36	12		6		17
13	20			4			20
16	10			1.5			15
17	20			1			5
19	5			1			20
21	2.5	90	30		30		33
22	2.5	90	30			7	23

Source: PP 1800, Vol. X, *First Report of the Committee on Coal Trade*, Appendix 34.

Appendix 4.2

Estimate of ratios used to convert quantities of coal from Newcastle Chaldron (NCh) to London Chaldron (LCh)

Name of Ship	Quantity in Newcastle Chaldrons	Quantity in London Chaldrons		Ratio
		Certified	*Delivered*	*LCh:NCh*
Kate	107	220	225.75	2.06
Kate	108	216	228.75	2.00
Kate	108	216	225.50	2.00
Kate	108	216	229.75	2.00
Kate	107	216	237.50	2.02
Kate	108	216	231.00	2.00
Malta	120	240	270.75	2.00
Malta	114	224	247.75	1.96
Malta	116	232	246.00	2.00
Malta	116	230	248.50	1.98
Malta	116	232	249.75	2.00
Percy	132	272	286.25	2.06
Percy	132	272	288.00	2.06
Percy	132	272	285.75	2.06
Perseverance	85	176	190.00	2.07
Perseverance	85	176	172.75	2.07
Perseverance	85	174	186.00	2.05
Recovery	123	260	270.25	2.11
Recovery	125	256	276.25	2.05
Recovery	125	256	275.50	2.05
Recovery	126	256	269.30	2.03
Recovery	125	256	271.25	2.05

Note: All voyages are c1827-29 carrying the variety known as Pelaw Main
Source: PP 1830 Vol. VIII, p. 12, and Appendix no. 13.

Appendix 4.3

Details of dataset 1 to compare converted and measured quantities
(see page 104 of main text)

Quantity Converted from NCh into LCh						
Name of the Ship	Variety of Coal				Total	No. of Voyages
	Browns	Harraton	Pelaw	Springwell		
Alexy	832				832	4
Ann				220	220	2
Britannia			360		360	2
Joanna				288	288	2
Kate			1,080		1,080	5
Lady Durham		540			540	2
Malta			464		464	2
Percy			816		816	3
Perseverance			352		352	2
Recovery			1,024		1,024	4
Converted Quantity	*832*	*540*	*4,096*	*508*	*5,976*	*28*

Quantity Measured in LCh						
Name of the Ship	Variety of Coal				Total	% Variation across Ships
	Browns	Harraton	Pelaw	Springwell		
Alexy	836.5				836.5	1
Ann				209.75	209.75	-5
Britannia			383.75		383.75	7
Joanna				301.5	301.5	5
Kate			1,152.5		1,152.5	7
Lady Durham		528.5			528.5	-2
Malta			495.75		495.75	7
Percy			860		860	5
Perseverance			362.75		362.75	3
Recovery			1,092.3		1,092.3	7
Delivered Quantity	*836.5*	*528.5*	*4,347.05*	*511.25*	*6,223.3*	
% Variation across Coal Variety	1	-2	6	1		4%

Source: PP Vol. VIII, 1830, Appendix 13.

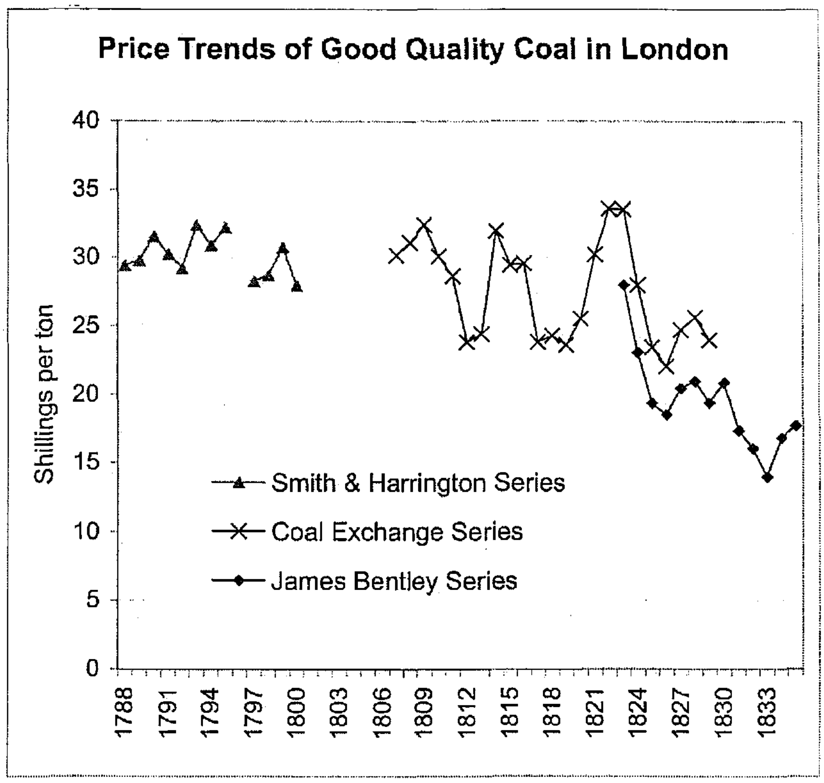
Details of dataset 2 to compare converted and measured quantities
(see page 104 of main text)

Quantity Converted from NCh into LCh							
	Name of the Ship						
Variety of Coal	Amity	Edward	Hannah More	Henry & Harriet	John	Ocean	Total
Bells Robson	768						768
Burdon	1,008						1,008
Clarks					500		500
Heaton			750				750
Heaton Wallsend			496				496
Killingworth		432					432
Newmarch	504	1,080				1,760	3,344
Northumberland					500		500
Pelaw				536			536
Perkins		648		2,144			2,792
Converted Quantity	*2,280*	*2,160*	*1,246*	*2,680*	*1,000*	*1,760*	*11,126*
No. of Voyages	9	10	5	10	4	8	46

Quantity Measured in LCh							
	Name of the Ship						
Variety of Coal	Amity	Edward	Hannah More	Henry & Harriet	John	Ocean	Total
Bells Robson	774.75						774.75
Burdon	1,022						1,022
Clarks					537.25		537.25
Heaton			778.25				778.25
Heaton Wallsend			504				504
Killingworth		437.25					437.25
Newmarch	523.25	1,084.25				1,731.75	3,339.25
Northumberland					512.5		512.5
Pelaw				560			560
Perkins		646.75		2,224			2,870.75
Delivered Quantity	*2,320*	*2,168.25*	*1,282.25*	*2,784*	*1,049.75*	*1,731.75*	*11,336*
% Variation across Ships	2	0	3	4	5	-2	2

Source: PP Vol. VIII, 1830, p. 140, data reported by James Bentley.

Appendix 4.4



The price series have been constructed as follows:

Smith & Harrington series was constructed using data on the quantity of coal consumed at the Smith and Harrington Corn Distillery in Old Brentford, Middlesex. Prices reported in shillings per LCh. (Appendix No. 16, Report from the committee on coal trade, 1800, p. 589)

The Coal Exchange series was constructed using retail prices of coal (in shillings per LCh) for the 1st day of each month from January 1807 to May 1829 on the Coal Exchange. Where possible the published prices for the Russell Wallsend variety of coal have been used (Appendix No. 7, PP 1830 Vol. VIII, p. 184-274)

The James Bentley series has been constructed using the prices reported by James Bentley, coal factor, as evidence before two parliamentary committees. The series is based on the average monthly price of Stewarts Wallsend on the Coal Exchange between January 1823 and December 1837. The prices between 1823 and 1831 were reported in shillings per LCh and after 1832 in shillings per ton. All conversions from LCh to tons are at the rate of 25.5 cwt per LCh. (prices from January 1823 to December 1835 from PP 1836 Vol. XI, p. 65; between January 1836 and December 1837 from PP 1837-8 Vol. XV, p. 76)

To deflate the nominal prices, the Phelps Brown-Hopkins price index for consumables was used and the base year was adjusted to 1875=100; E. H. Phelps Brown & Sheila V. Hopkins, "Seven centuries of the prices of consumables, compared with builders' wage rates," *Economica* 23 (1956): 313-14.

Appendix 4.5

City of London Metage Accounts

	Sea Meters			Land Meters[a]		
	Revenue	Expenditure	Surplus	Revenue	Expenditure	Surplus/ Deficit
1810	18754	6174	12580	4222	4167	55
1811	18698	6074	12624	4215	4189	26
1812	18015	6079	11936	3936	4023	-87
1813	16280	5579	10701	3512	3911	-399
1814	19062	6476	12586	4017	3934	83
1815	18720	6350	12370	4089	3923	166
1816	20356	6765	13591	4313	3890	423
1817	19052	6452	12600	4162	3844	318
1818	20146	6697	13449	4183	3836	347
1819	19834	6937	12897	4102	3976	126
1820	21987	7144	14843	4539	4246	293
1821	21297	7396	13901	4313	4187	126
1822	21020	7818	13202	4083	4191	-108
1823	23954	8059	15895	4398	4246	152
1824	25910	9080	16830	4254	4260	-6
1825	24638	9038	15600	4020	4311	-291
1826	26624	9613	17011	4301	4102	199
1827	24367	9108	15259	4779	4540	239
1828	25893	9166	16727	4891	4990	-99
1829	26559	9499	17060	4962	5628	-666

Note: All figures in Sterling £'s. [a] These accounts do not include the figures for land meters employed in Westminster and Surrey districts.

Source: PP Vol. VIII 1830, *Report of the select committee on coal trade*, Appendix Nos. 8 & 10.

Chapter 5

Uniformity of Wire Sizes: Standards & Mensuration

> Where there is so much confusion order would be welcome for its own sake, but if it can be secured without any violent disruption of existing rules, it is clearly to the interest of everybody to contribute towards the attainment of the general good. (*The Ironmonger*, Feb 14, 1880)

5.1 *Introduction*

The wire industry uses a system of standard numbers to express the thickness of wires that are used in hundreds of applications – wire ropes in suspension bridges, electrical conductors and telecommunication cables, precision scientific instruments such as telescopes, hypodermic needles, etc. Before the wire numbers were standardized in Britain 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 the thickness when measured in *inches*. At first glance this appears simply to be a matter of using more precise instruments to minimize measurement errors. But, making measurements of wire diameters reliable involved standardizing the system of wire numbers (design or technical standards), methods of measuring individual wire sizes (metrological standards and measurement protocols) as well as the wire gauges (measurement instruments).

Theoretically, there were 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. Problems erupted 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 groups within the market. The adoption of decimal units, rather than using fractional units, could not and did not make existing sets of sizes more reliable. Standardization therefore implied synchronizing the various sets of 'desired' wire sizes that various groups of buyers and producers were keen on. No notion of true, accurate or ideal values, based on abstract, scientific or natural principles could dominate the practical and economic principles by which the various groups evaluated rival proposals.

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.

This chapter highlights the struggles between the various groups - buyers, dominant producers, smaller and medium scale wire makers, etc. - to define a standard 'one-size-fits all' wire gauge. The market sought to address two basic information areas. How to produce wire of a particular specification (conformity)? Could the wire of a particular number do what it was expected to do (quality)? Standardization in this context implied a rationalization of wire gauges, i.e. from many standards to one uniform standard. The chapter studies how the preferences of heterogeneous groups were aligned (buyer-producer, producer-producer, etc.) through trade associations. Uniformity, coordination and rationalization were important aspects in standardizing mensuration activity within this industry.

The case of uniform wire sizes highlights how apparently straightforward measurements can become strategic issues that threaten the competitiveness of entrenched or dominant producers, how dominant producers preferred to cooperate if faced with the threat of enforcement of a 'wrong' industry standard, how path-dependency can significantly impact the choice of the standard that emerges, and how buyers could initiate a convergence towards uniformity.

The issue of uniform wire sizes is analysed on the basis of three broad questions. Why was it necessary to standardize wire sizes according to a single uniform wire gauge? How did institutions reconcile the differing notions of reliability held by various groups of buyers and producers, and get the groups to agree and accept one uniform wire gauge? Why did the dominant producers consider the wire sizes proposed by the chambers of commerce to be the 'wrong' industry standards?

Standardization of wire sizes must be considered in the context of the emergence of engineering and manufacturing standards from the late eighteenth-century onwards. Historically, a baffling variety of standards were in use before the nineteenth-century. Each workshop had its own standard for producing parts such as screws, wires, rivets, bolts, and early forms of tools and machine parts.[1] By the nineteenth-century there was a definite move towards mass manufacturing and interchangeable parts production that involved 'making things the same'.[2] 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.[3] Technological convergence helped in standardizing processes such as cutting metal into precise shapes; the result being that machine types and machine tools became standardized.[4] Emergence of British engineering standards must 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 and the manufacturing standards that they used.[5]

At the same time, standardization in manufacturing often implied deskilling of labour when, for instance, limit gauges began to be used for measuring the grinding of machine parts. Gauging had become 'a mechanical affair [not requiring] the same skill or the same knowledge on the part of the workman'.[6] However, machine precision did not entirely replace artisan skills, at least not initially. Instead, mechanical methods depended both upon the traditional as well as newer skills,

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[1] B. Sinclair, 'At the turn of the screw: William Sellers, the Franklin Institute, and a standard American thread', *Technology and Culture* 10 No. 1 (1969); J. Whitworth, *Papers on mechanical subjects* (E&F N Spon, London, 1882).

[2] Alder, 'Making things same'.

[3] K. Alder, 'Innovation and amnesia: Engineering rationality and the fate of interchangeable parts manufacturing in France', *Technology and Culture* 38 No. 2 (1997); D. A. Hounshell, *From the American system to mass production 1800-1932 : the development of manufacturing technology in the United States.* (John Hopkins University Press, Baltimore; London, 1984).

[4] Rosenberg, 'Technological change'.

[5] Allen, 'Iron and Steel'; Floud, 'American engineering competition'; Saul, 'Engineering industries, 1860-1914'; also D. S. Landes, 'Watchmaking: A case study in enterprise and change', *Business History Review* 53 No. 1 (1979).

[6] Speech by Sir R T Glazebrook at a meeting of the Physical Society of London at Imperial College, London on Mar. 28, 1919.

making this combination the limiting condition determining the nature and extent of standardization.[7] The objectivity and the form of nineteenth-century standards was influenced as much by social factors as it was by technological convergence and competition.

Standardization in the nineteenth-century must also be placed firmly in the context of the Victorian markets, which were far from being the 'neutral arena for competitive exchange'. Many Victorians considered the 'untrammelled market forces' to be dangerous unless linked to a source of 'unquestioned authority' that adjudicated when 'morality clashed with market principles'.[8] This view of the market has important implications for any standardization story, and for understanding the role of the state in overcoming issues of coordination between the various groups involved (chapter 2).

Standardization more generally had become an integral part of the overall Victorian landscape. Apart from standardized engineering products (e.g. machine tools, screws, cylindrical gauges, etc.), this included scientific and technological standards (e.g. the *ohm* and the voltmeter), measurement standards (e.g. accounting, weights and measures), standards used in trade (e.g. commercial contracts, commodity grades), etc.[9] 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. The role of institutions and industry/professional associations in standardization is an important backdrop against which uniform wire sizes have to be considered.

Based on these reflections, the rest of the chapter is structured as follows. Section 2 reviews the wire industry in Britain. This is followed by section 3 on the technology

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[7] Gordon, 'Mechanical ideal and reality'; Alder, 'Making things same'.

[8] P. Johnson, 'Market Disciplines', in *Liberty and Authority in Victorian Britain*, P. Mandler. ed. (Oxford University Press, Oxford, 2006); G. R. Searle, *Morality and the market in Victorian Britain* (Clarendon Press, Oxford, 1998), p. 256; cf. A. Gambles, *Protection and politics: conservative economic discourse 1815-1852* (The Royal Historical Society, 1999).

[9] B. J. Hunt, 'The ohm is where the art is: British telegraph engineers and development of electrical standards', *Osiris* 9 (1994); G. J. N. Gooday, 'The morals of energy metering: Constructing and deconstructing the precision of the Victorian electrical engineer's ammeter and voltmeter', in *The values of precision*, M. N. Wise. ed. (Princeton University Press, Princeton, NJ, 1995); Brackenborough et al., 'DCF in Tyneside'; Fleischman and Macve, 'Management accounting'; Connor, *English Measures;* Forrester, 'Commodity Exchanges'; R. B. Ferguson, 'The adjudication of commercial disputes and the legal system in modern England', *British Journal of Law and Society* 7 No. 2 (1980); C. Chattaway, 'Arbitration in the Foreign Corn Trade in London', *The Economic Journal* 17 No. 67 (1907).

and process of wire making and the importance of gauges in the production process. The aim of this section is to demonstrate the problems facing various groups of buyers and producers stemming from unreliable wire sizes by focussing on the multiplicity of gauges. The section highlights the interrelatedness that existed between the gauges and the production process. The following section 4 examines some of the early attempts at standardizing wire sizes followed by a discussion on the emergence of the legal standard in 1883 and the role of the state and industry associations in this process. Section 5 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 their own preferred industry standard. The following section 6 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 7 puts these events into perspective and draws general conclusions

5.2 *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 became an important centre for wire making activity, encouraged by engineering workshops that became located in this region. For example, Peter Stubs, the Warrington toolmaker, became involved in the wire trade initially as a large buyer of pinion wire, but eventually the firm he founded became one of the important wire producers in the country.[10] 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. 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

[10] E. S. Dane, *Peter Stubs and the Lancashire hand tool industry* (John Sherratt & Son, 1973).

and about 40 wire weavers in 1875; their numbers had increased from 5 in 1800 and 35 in 1866.[11]

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.[12] 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, on an average, less than 150 people.[13]

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.[14] 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

[11] F. White, *Commercial and trades directory of Birmingham, Vol. 2* (Birmingham, 1875); W. C. Aitken, 'Brass and brass manufactures', in *The resources, products and industrial history of Birmingham and the Midland hardware district*, S. Timmins. ed. (Robert Hardwicke, London, 1866), p. 359.

[12] J. B. Smith, *Wire, its manufacture and uses* (John Wiley & Sons, Inc., London & New York, 1891), pp. 93-98.

[13] F. Carnevali, "Crooks, thieves and receivers': transaction costs in nineteenth-century industrial Birmingham', *Economic History Review* 57 No. 3 (2004): p. 539.

[14] Smith, *Wire, its manufacture and uses*, p. 5.

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. 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. In and around Birmingham, jewellers and brass and metal works used fine wire made from gold, silver, nickel, copper and brass.[15]

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.[16] 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.[17]

Unsurprisingly, Yorkshire, Lancashire and West Midland together employed about three-quarters of the wire drawers in England (table 5.1). The number of persons engaged in wire drawing or wire making increased during the nineteenth-century indicating growth in wire making activity in these locations.[18] 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 drawer's weekly wage could be between £3 and £5 in Sheffield; wire workers wages were reportedly higher than those of skilled ironworkers in 1873.[19] Nevertheless, wire drawers

[15] White, *Birmingham trades directory;* Dane, *Peter Stubs;* Landes, 'Watchmaking'; T. Hughes, *The English Wire Gauge* (London, 1879); *Ironmonger and Metal Trades Advertiser* (hereafter *Ironmonger*), Feb. 26, 1881, p. 261

[16] Cited in B. C. Blake-Coleman, *Copper wire and electrical conductors - The shaping of a technology* (Harwood Academic Publishers, Reading, 1992), p. 157.

[17] M. Seth-Smith, *Two hundred years of Richard Johnson & Nephew* (Richard Johnson & Nephew Limited, Manchester, 1973), p. 75; Smith, *Wire, its manufacture and uses.*

[18] C. Lean, 'Wire drawing and steel wire, and its uses', in *The resources, products and industrial history of Birmingham and the Midland hardware district*, S. Timmins. ed. (Robert Hardwicke, London, 1866).

[19] A. Bullen, *Drawn together: One hundred and fifty years of wire workers' trade unionism* (1992), pp. 7-8; this varied considerably by location, see Lean, 'Wire drawing'; *Ironmonger*, Jan 11, 1879, p. 51-2.

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.[20] 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 considerable wage reductions in the 1880s.[21]

Table 5.1
Distribution of Wire Workers in England and Wales

	1871		1881		1891	
Total (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
Note: Figures in parentheses represent proportions to total numbers.

Estimates of market size in terms of output are difficult to locate. One tentative estimate stated that about half a million tons a year was the probable domestic production. Another estimate put it between 40,000 and 80,000 tons, although this may have been an underestimate.[22] The first UK Census of Manufactures estimates

[20] Seth-Smith, *Richard Johnson & Nephew*, p. 81.

[21] Bullen, *Drawn together*, pp. 14-15.

[22] L. Bell, *The iron trade of United Kingdom* (British Iron Trade Association, London, 1886), p. 23; L. Thomas, *The development of wire rod production* (London, 1949), p. 10.

the net domestic production of iron and steel wire c1907 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 around this time was approximately 17,000.[23] Using these figures, per person output in 1907 appears to be about 13 tons per annum. Later estimates for sales of wire products between 1920 and 1922 suggest that per person output per annum was between 16 and 20 tons.[24]

Table 5.2
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%

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

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 significantly. Making a broad assumption that output per person between 1870 and 1890 was likely to be 13-15 tons, domestic wire 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 5.2). 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

[23] Final Report on the First Census of Production of the United Kingdom (1907), 1912, pp. 113-117.

[24] F. Stones, *The British Ferrous Wire Industry* (J W Northend Limited, Sheffield, 1977), see illustrations between p. 12 & 13.

respectively.[25] In comparison, exports of wire from the UK around 1907 were 55,000 tons or about 25 percent of the total domestic production.

The German wire industry – UK largest competitor during this period – had increased production from 179,000 tons in 1878 to 250,000 tons in 1881, and further to 378,000 tons in 1882.[26] The German manufacturers exported around 30 percent of their production in 1878, which increased to about 60 percent by 1881-82. In terms of 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.[27] 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.[28]

Following this snapshot of the industry in the late nineteenth-century, the next section describes the process of wire manufacturing. It discusses the significance of wire sizes and gauges in the production and commercial activities in the industry and highlights some of the problems that resulted from the use of multiple wire gauges.

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

[26] *Ironmonger*, Apr 9, 1881, p. 510; Bell, *UK Iron Trade*, p. 23; France, Belgium and the United States were also important wire making countries.

[27] U. Wengenroth, *Enterprise and technology: The German and British steel industries, 1865-1895* (Cambridge University Press, 1994), pp. 139-41, see tables 15 & 17, also p. 186.

[28] Smith, *Wire, its manufacture and uses*, p. 97.

5.3 Wire Drawing: Process, Sizes And Gauges

5.3.1 Wire Sizes

Wire was produced from wire rods (approximately 1/4th inch in diameter), which were drawn or pulled by wire drawers through perforated surface 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 50 for finer wires - the increasing numbers signified smaller wire diameters.[29] 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 than thicker wire.[30] 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 made to manufacture wire of a required diameter.[31] A skilled wire drawer knew what intermediate holes could be avoided, and this form of remuneration may actually have encouraged this practice. On the other hand, wire reduced more than two sizes in one draw was usually not of good quality, a fact easily assessed by visual inspection. This most likely discouraged the practice of 'jumping holes'.[32] There was a strong economic and technical interrelatedness between the technique of drawing wire, the wire drawers' wage, and the overall cost of production.

In any case, there was a particular sequence of holes through which wire had to be drawn in order to maintain quality. Such sequences were established empirically through long usage. The skill of the wire drawer was to know such sequences. For example, if iron wire of No. 4 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, presuming the metal wire were tough enough to withstand the strain, it would be found irregular in thickness, ellipse here, fluted there, and flat further on, instead of being smooth and equal diameter throughout'.[33]

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[29] Sizes greater then No. 1 referred to wire rods.

[30] Stones, *Wire Industry*, see price list from 1884 between p. 12 & 13.

[31] Annealing is a process of softening the metal to make drawing easier.

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

[33] *Ironmonger*, Feb 26, 1881, p. 259-61.

The same source gives us another example. Suppose iron wire of No. 5 size was required.

> 'The drawer [took] No. 1 annealed rod, [reduced] it, first hole to No. 3, second hole to No. 4, and third hole to No. 5 [making] three draws. Were the wire annealed each draw the reduction to No. 5 could be accomplished in two draws, but it would not be 'finished' wire fit for the market, and the cost of repeated annealings would ruin the manufacturer.'[34]

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 9/64ths 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, he could produce wire of almost any diameter that was required. Wire drawing involved a considerable degree of tacit knowledge, and a wire drawer could make wire without drawing it through the drawplate. 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, instead of the drawplates, to do this.[35]

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. Steam power was used to draw longer pieces of wire by the 1840s. 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. Around the same time, the German manufacturers were also making improvements to rod rolling technology. By 1878, German wire makers

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[34] *Ironmonger*, Feb 26, 1881, p. 259-61; a contrary view held that this was true only of certain sizes and not generally, Hughes, *Wire Gauge*.

[35] *Ironmonger*, Feb 26, 1881, p. 259-61.

could cut capital and labour costs by making some changes to the manner in which rods were rolled in the rolling mill.[36]

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 eighteenth-century. In contrast, the output of rod rolling mills increased by a factor of almost fifty.[37] In order to increase the efficiency of wire drawing, the technique of combining several blocks of wire drawing machines was introduced in the late nineteenth-century. In 1871, the Woods brothers from Manchester patented a continuous wiredrawing machine, which made it possible to pass wire through four drawplates in a series.[38] Nevertheless, continuous wire drawing technology was relatively new and not generally adopted within the British industry in the 1870s. 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. In fact, the technique was reported as a new innovation even in the 1880s hinting that that trade was largely unfamiliar with such technology:

> 'An ingenious machine has lately been introduced here for expediting the work, the wire passing through a succession of plates pierced by holes of diminishing gauges, [and] the wire is drawn down three sizes at once, at a great saving of time, labor and cost'[39]

It was only by the late 1880s that wire could practically be drawn from say No. 34 to 48 in one continuous operation.[40]

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[36] Thomas, *Wire rod production*, p. 15; Seth-Smith, *Richard Johnson & Nephew*; 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*, pp. 23-4.

[37] Blake-Coleman, *Copper wire*, p. 83; N. K. Laman, 'The Development of the wire-drawing industry', *Metallurgist* 3 No. 6 (1959): p. 268.

[38] Thomas, *Wire rod production*, p. 15; Laman, 'Wire-drawing': p. 269.

[39] *Ironmonger*, Apr 10, 1880, p. 494.

[40] Bullen, *Drawn together*, p. 12; Smith, *Wire, its manufacture and uses*, pp. 84-89.

Figure 5.1
Picture of The Board of Trade Standard Wire Gauge (1884) kept at the City of Liverpool

Photo courtesy Terry Sears (2008)

5.3.2 *Wire Gauges*

The origin of the slot gauges used in nineteenth-century Britain is uncertain. They were likely introduced into England from Germany in the sixteenth-century. The sizes were initially divided into vulgar fractions of the English inch. As the number of sizes increased and became cumbersome to denote in terms of fractions they were collected into a series of numbers.[41] The perforations on the drawplate corresponded with the sizes of wire as measured by the wire 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 (figure 5.1). The wire gauges in use before c1880 were empirically derived i.e. based upon long experience of wire drawing. Some engineers claimed that there was a definite mathematical relationship between the breaking strength of each wire and the opposition provided by the drawplate while drawing wire.[42] This created a degree of interrelatedness between the drawplates and the gauges. The progressive sequence of holes on the drawplate was empirically derived based on the observation of the breaking strength of wire of different metals.

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[41] H. W. Dickinson and H. Rogers, 'Origin of gauges for wire, sheets and strip', *Transactions of the Newcomen Society* 21 (1943); Hughes, *Wire Gauge.*

[42] L. Clark, 'On the Birmingham wire gauge (Paper presented to the British Association in 1869)', *Journal of the Society of Telegraph Engineers* 7 (1878): p. 338.

The original gauges were based upon these sequences of holes, which varied by the metal used to make wire, the workshop, the geographic region and the use-context of a given wire product. In turn, the gauges themselves were used both as a verification tool to ensure that the wire drawn was of the expected diameter, as well as a template to replicate new drawplates once the older ones became worn out due to repeated use. Historically, virtually every workshop had its own wire gauge that was devised according to its experience of drawing wire and 'guarded with great care [and] transmitted almost as heirlooms from father to son'.[43]

Minor variations in the sizes of wire inevitably crept into this practice of making wire gauges.[44] Thomas Hughes narrates the following experience.

> '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'.[45]

Very likely, this resulted in the profusion of wire gauges as each workshop or region developed their own gauge. 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 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 (in fractional inches) and gauge numbers differed significantly.

Consider two different wire gauges used in Warrington and Birmingham around 1879.[46] Comparing these gauges, we discover, for example, 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

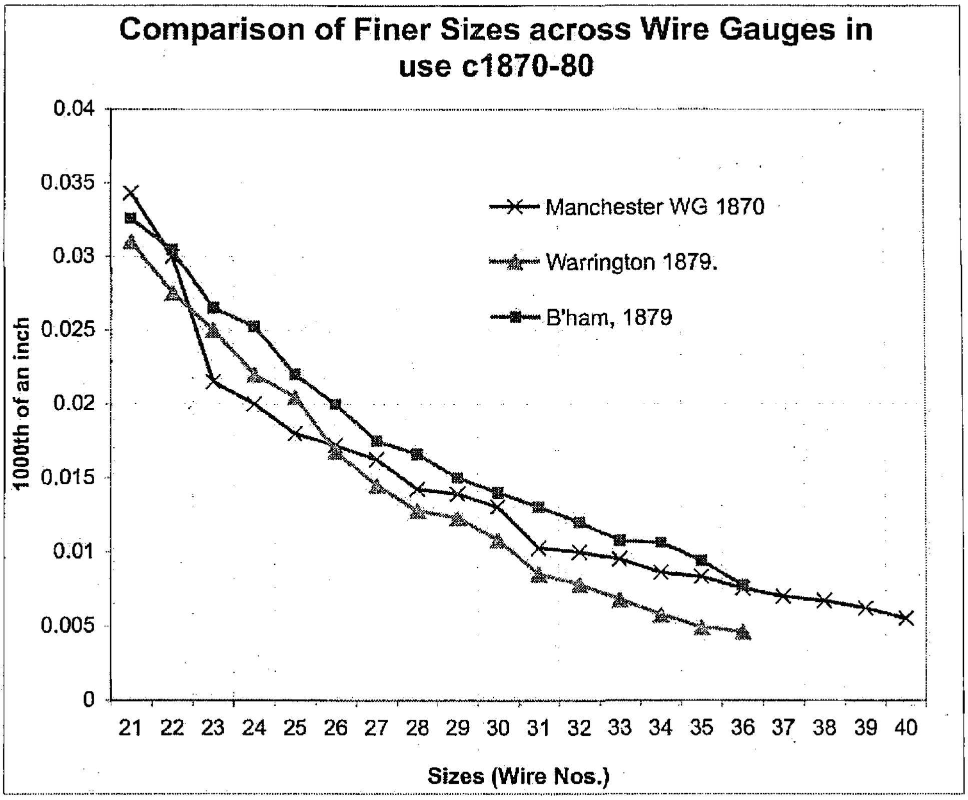
[43] Smith, *Wire, its manufacture and uses*, p. 55; Dickinson and Rogers, 'Origin of gauges': p. 88.

[44] Hughes, *Wire Gauge*; Clark, 'Birmingham gauge, 1869': p. 337 & 341.

[45] Hughes, *Wire Gauge*.

[46] Ibid.

Figure 5.2



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

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 5.2)

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. 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 mnemotechnic.

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.[47] 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. (see appendix 5.1).

Wire makers did not exclusively use such slot-wire gauges, 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, and was reported to be very precise and in trials 'gauge boys [could] very easily be taught to read the thousandth of an inch'.[48] However, the micrometer gauge was not generally used in Britain as its use by workmen was considered to be 'liable to errors of unobserved movement'.[49]

The foregoing discussion about wire sizes, numbers and gauges is significant in that we can identify various sources of transaction problems arising as a result of the different gauges in use. 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 about £8,000 to the contract value. The solution was to specify both the gauge number as well as the diameter of the wire, which only proved the 'uselessness of the present system'.[50] 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

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

[48] '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'.

[49] Smith, *Wire, its manufacture and uses*, p. 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.

[50] Clark, 'Birmingham gauge, 1867': p. 226.

> [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'.[51]

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.'[52]

Further, wire manufacturers reportedly secured orders through underselling; however, this was the effect of supplying a thicker wire for a given 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. 21½ in Warrington, Liverpool, or Staffordshire, making it cheaper outside Birmingham by £4 or £5 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.[53] Hughes narrates the following anecdote.

> 'A maker [of wire gauges] told me that when a customer used certain sizes [frequently], the gauge made for him had those sizes made smaller [i.e. a lower size number] than they should be, to enable him to purchase wire cheaper. A case in point shortly after came under my observation. 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.'[54]

In contrast, 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. That is, a No. 100 wire in this system was 10 millimetres in diameter, a No. 55 wire was 5.5 millimetres in diameter, and a No. 2 wire was 0.2 millimetres in diameter. The wire

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[51] Hughes, *Wire Gauge.*

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

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

[54] Hughes, *Wire Gauge.*

numbers thus decreased progressively as the wire diameters reduced, in contrast to the English gauges where the numbers increased as the diameters decreased. German wire-makers 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'. By 1881, the German wire makers, like the French manufacturers, were using the millimetre gauge to express wire sizes.[55]

> 'Formerly, neither the French nor Germans had a standard wire gauge. 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 millimeters, on the reverse. The Germans long discussed a standard wire gauge, ultimately deciding upon one similar to the French'.[56]

Large buyers purchasing wire 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. On one hand, there were distinct advantages in making standard sizes uniform. Equally, there were advantages to some groups in maintaining an 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 divisions of the inch in addition to the gauge numbers. Wire manufacturers had begun printing lists of wire sizes specifying the diameters (in decimal inches) for each gauge number.[57] Nevertheless, between 1878 and 1883, the industry attempted to define a uniform wire gauge, which they hoped would alleviate problems arising from multiple gauges.

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[55] *Ironmonger*, Feb 14, 1880, editorial notes, p. 209; Ibid.

[56] *Ironmonger*, Feb 12, 1881, pp. 206-211.

[57] 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.

5.4 *Standardizing Wire Sizes*

5.4.1 *Early Attempts*

The early attempts at defining an industry standard gauge can be dated back to 1824. However, the first real proposal was that of Charles Holtzapffel in 1847.[58] He remarked that 'some irregularity thence exists amongst the gages [sic] in common use, notwithstanding that they may be nominally alike'. Consequently, he proposed an

> 'easy and exact system of gages [where] the nomenclature should be so completely associated with the actual measures, as to convey to the mind [a] very close idea of [the] thickness of sizes.'[59]

Holtzapffel intended to remove the

> 'arbitrary incongruous system of gages now used [by using the decimal divisions of the inch so that] there could be no more difficulty in constructing the gages of customary forms, with notches made to systematic and defined measures, that may easily be arrived at or tested, than with their present unsystematical and arbitrary measures, which do not admit of verification.'[60]

Holtzapffel's proposal was published in a textbook on mechanical engineering, wherein he outlined his views with reference to the Stub's or Lancashire wire gauge.

A few years earlier, Joseph Whitworth had become involved in the standardization of the screw threads and cylindrical gauges based on the decimal subdivisions of the inch.[61] In the 1850s, he claimed that in the wire making industry

> 'There [was] no standard of appeal; and the different wire and other gauges differ so considerably that the [customer had] to send a sample of what he wants [to the manufacturer], there being no means of correctly expressing its size'.[62]

This prompted him to propose the use of decimal units in the measurement of wire sizes by illustrating the precision with which wire diameters could be measured

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[58] Dickinson and Rogers, 'Origin of gauges'.

[59] C. Holtzapffel, *Turning and mechanical manipulation - Vol. 2* (London, 1847).

[60] Ibid.; emphasis in their original.

[61] Whitworth, *Papers on mechanical subjects*, paper to the Institution of Civil Engineers, 1841.

[62] Ibid., Paper to Institution of Mechanical Engineers, 1856.

using the decimal system, a scheme remarkably similar to the one the German manufacturers were to adopt nearly two decades later.[63]

Another engineer who wrote about the standardization of wire size was Latimer Clark, the telegraph expert. Between 1867 and 1869, Clark presented two papers to the British Association on the need to standardize the Birmingham Wire Gauge (BWG). He 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 alternatively the weight of the wire increased by about 25 percent.[64]

Holtzapffel, Whitworth and Clark were primarily concerned with measuring the wire diameters as *precisely* as possible. They believed that making precise measurements, i.e. using decimal units to measure diameters rather than fractional units, would help to eliminate the problems that arose from multiple gauges. Holtzapffel wrote that 'quantities expressed decimally would be more easily written down, and more exactly defined than the compound fractions such as 3/8ths and 1/16th of an inch.'[65] He claimed that

> 'When certain objects are required to be so proportional as to constitute a series, the intervals between the decimal measures would be far more easily arranged and appreciated, than those of vulgar fractions.'[66]

Similarly, Whitworth wrote that 'there can be no doubt of the beneficial results that would follow the passing of [decimal weights and measures]'. He further wrote that 'small accurate standards of length, of the decimal parts of an inch, would be of much service to some trades [such as wire making].'[67] Clark stressed that

> 'For obviating the inconvenience arising from this great confusion among gauges in common use [I] approve of the system of measurement in decimal fraction of an inch.'[68]

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[63] Ibid., Proceedings of Institution of Mechanical Engineers, 1857. It is interesting to compare Whitworth 1857 decimal wire sizes to the German gauge described by Thomas Hughes in 1879; Hughes, *Wire Gauge*.

[64] Clark, 'Birmingham gauge, 1867': p. 153.

[65] Holtzapffel, *Turning (Vol. 2)*.

[66] Ibid.

[67] Whitworth, *Papers on mechanical subjects*, paper to Institution of Mechanical Engineers, 1856.

[68] Clark, 'Birmingham gauge, 1867'.

All these proposals involved replacing existing production methods, either in terms of using decimal measurements or fundamentally changing the relationship between the wire numbers and wire sizes. Whitworth's proposal involved altering the existing system of gauge numbers completely by reversing their order, that is, the smaller sizes had lower wire numbers and the other way around. Clark's proposed sizes involved a constant decrement in sizes, contrary to many of the existing gauges, which that had no recognizable or regular pattern in the arrangement of wire sizes. This meant that some of his thicker wire sizes were actually larger than those practically in use. Both Clark's and Holtzapffel's proposal were virtually identical to the gauge known as the Stub's gauge, which was only *one* of the several gauges in use at the time.

We lack any clear evidence as to how the industry reacted to the early proposals to standardize the wire gauge using decimal divisions of the inch and based on abstract principles of regular or scientifically derived increments in wire sizes. As the use of multiple wire gauges persisted until the 1880s, we can assume that the industry simply chose to ignore the various suggestions to standardize around a uniform series of wire sizes. However, bucking the general trend of resisting metrication and decimalization of measurements, by the late 1870s the wire industry had begun to use decimal divisions of the inch to express wire sizes. Hughes wrote:

> 'Of late, wire manufacturers are adopting the plan of sending to their customers [printed] list of sizes of wire [with] diameters of the wire, expressed in decimal parts of an inch, opposite to the number of the gauge.'[69]

A trade report from 1881 claimed that 'during the last few months merchants have begun to order wires to decimal fractions of an inch.'[70] A decimal measuring machine was also introduced claiming usefulness to 'manufacturers of wire, copper, brass or charcoal sheets, small arms, sewing machines and others working on the interchangeable system and requiring great accuracy in measuring'.[71] The industry thus did begin using decimal measurements, but did not converge towards a uniform 'one-size-fits-all' standard for wire size.

5.4.2 *Competing Proposals & Standardization of Wire Sizes: 1878-1883*

[69] Hughes, *Wire Gauge*.

[70] *Ironmonger*, Jan 1, 1881, p. 18-21, 2nd article on Wire Gauges.

[71] *Ironmonger*, Jan 8, 1881, p. 43.

In contrast to this rather lacklustre response 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 made several attempts to establish a standard wire gauge. Telegraph cable companies had become large and sophisticated purchasers of wire products, particularly of copper wire. One contract for a submarine cable specified the core to be made of seven No. 22 BWG copper wires with a total diameter equal to No. 14 BWG weighing 107 *pounds* per nautical mile.[72] Other buyers, such as pin manufacturers, demanded greater consistency 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. 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. According to Latimer Clark, 'pin makers and others have really to resort to small divisions [and] it is most desirable [that a gauge be defined] so that it can be measured on a machine'.[73] Hughes echoed this by writing:

> 'Much wire is in these days ordered quarter sizes, and even greater divisions, and is worked up by self-acting machines - such as screws, pins, rivets etc. Unless the wire is accurately drawn, the machine either makes an imperfect article or spoils it.'[74]

In fact, some contracts required wire makers to manufacture wire not only to a specified diameter but also to a specified weight per gauge and length. Many contract specifications included wire diameters expressed in ten-thousandths of an inch, or in hundredths of a millimetre. 'The wire manufacturers ingenuity [was] being strained to meet the [specialized] demand for wires of given diameters', wrote one trade journal.[75] Wire used in fine woven gauzes also had to be made to fairly exacting and *consistent* standards: some of the gauzes were so finely woven that they contained nearly 40,000 meshes of wire per square inch.[76] The users and retailers of

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[72] Blake-Coleman, *Copper wire*, p. 157.

[73] TNA, BT 101/124, notes on conference dated Dec 27, 1882.

[74] Hughes, *Wire Gauge*.

[75] *Ironmonger*, Jan 1, 1881, pp. 18-21.

[76] Smith, *Wire, its manufacture and uses*, pp. 6-26; H. I. Dutton and S. R. H. Jones, 'Invention and innovation in the British pin industry, 1790-1850', *Business History Review* 57 No. 2 (1983): p. 190; *Ironmonger*, Jan. 1, 1881 p. 18.

wire were urged to demand an industry standard with one trade journal writing that 'it is from these classes that the pressure for a standard uniform gauge must come'.[77]

In 1872, telegraph engineers proposed a uniform wire gauge based upon a mass-length standard. They argued that as copper wire 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.[78] 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, 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.[79] The committee, consisted mainly of telegraph engineers (Latimer Clark, H Mallock, W H Preece, C V Walker, etc.), but also included J Thewlis Johnson of Richard Johnson and Nephew, who provided the manufacturer's perspective.[80] The committee's report, published in the society's journal in 1879, acknowledged that any uniform wire gauge 'should not vary materially from the present gauges now in use [as] these gauges have been based on long practice and experience and [are] well adapted to the practical requirements of trade'[81]. Nevertheless, the gauge proposed by the committee as the British Standard Gauge (BSG) was basically Latimer Clark's geometric gauge of 1867. Although, the BSG was 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'.[82]

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[77] *Ironmonger*, Dec 18, 1990, editorial.

[78] H. Mallock and W. H. Preece, 'On a new telegraph wire gauge', *Journal of the Society of Telegraph Engineers* 1 (1872): p. 81.

[79] Society of Telegraph Engineers (STE), Council Papers, Minutes of Council Meetings, Institution of Engineering and Technology Archives IET/ORG/2/1/2, entry for May 23, 1878.

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

[81] Report on the BWG, STE Journal, 1879, p.476.

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

In October 1878, 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.[83] After corresponding with the other chambers of commerce, the BCC council decided to write to Joseph Whitworth asking for assistance in 'furtherance of a scheme to establish an uniform wire and metal gauge'.[84] 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. Latimer Clark and Joseph Whitworth both attended his first meeting 'by special invitation'.[85] 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'.[86]

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

[83] TNA, BT 101/114, Report of the Associated Chambers of Commerce (hereafter ACC) on Wire Gauge; Birmingham Chamber of Commerce, Council Minutes Books, Birmingham City Archives MS 2299 Acc2000/127 Box4, entries for Oct. 23, Nov 20 and Dec 18, 1878.

[84] Birmingham Chamber of Commerce minutes, entry for Dec 18, 1878.

[85] ACC Executive Council Minutes: Vol. 3, Council Papers, Aug 1876 - Aug 1883, Guildhall Library Ms 14476/3, entry for Oct 29, 1878.

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

and 'theoretically imperfect'. Nevertheless, in March 1882, the ACC adopted Harding's proposal as the basis for their standard wire gauge.[87] 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.[88]

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, 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.[89] 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 (figure 5.3 and appendix 5.2).

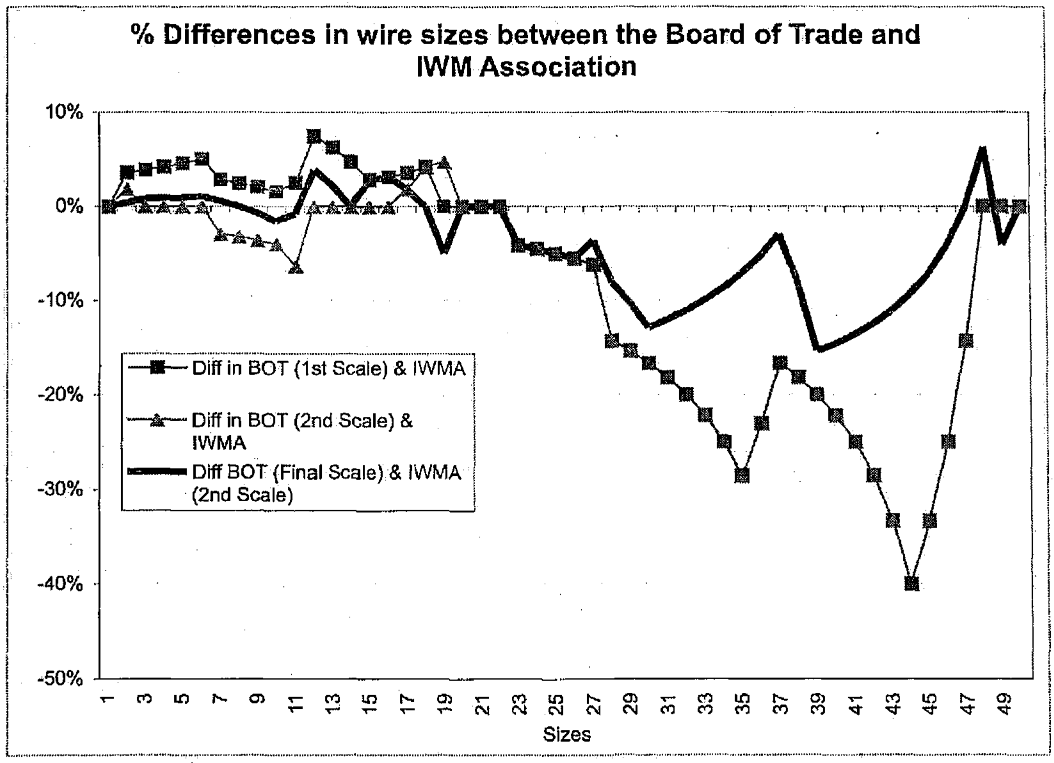
The ISWMA did not represent the opinion of all wire makers. One irate correspondent, presumably a small wire maker from Birmingham, wrote:

[87] *Ironmonger*, Feb. 25, 1881, p. 281; ACC Executive Council Minutes, entry dated Mar. 1, 1882; TNA, BT 101/114.

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

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

Figure 5.3



Source: The National Archives, BT 101/119, 101/124, 101/133 (BoT proposals); BT 101/116, 101/123 (IWMA proposals)

> '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?'[90]

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.[91]

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

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

[91] Stones, *Wire Industry*, p. 1.

proposal also, and the BoT had to propose a further modified scale in February 1883.[92] 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!'[93]

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.[94] 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' (see figure 5.3 for comparison of the different proposals).[95]

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 in 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

[92] TNA, BT 101/119, memo dated Jul 28, 1882; BT 101/123, letter dated Jan 5, 1883; BT 101/124; Ibid., p. 4.

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

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

[95] *Ironmonger*, Mar 17, 1883, editorial p. 386, and letter by Thomas Hughes p. 392; Stones, *Wire Industry*, p. 4.

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

Table 5.3
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

unchanged. The BoT's final proposal in February 1883, which would become the SWG, made significant changes over their 1882 proposals (figure 5.3). The size differences between the BoT and ISWMA proposals were decreased considerably by this scale, however, the differences in the finer sizes – especially between No. 27 & 34 – persisted. Appendix 5.2 shows the differences between the SWG and the ACC and ISWMA proposals.

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. 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.

5.5 *Competition, Coordination & 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; 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. It is only after BoT's decision to introduce the ACC proposal as the legal standard that the dominant wire producers cooperated to suggest their own standard gauge in 1882. Why did ISWMA oppose the ACC proposal? Why did the dominant manufacturers cooperate in the first place to form the ISWMA?

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. In contrast growth in British production and exports was quite modest (table 5.3). By the 1880s, German wire was outselling British wire in the international markets by a factor of two to one. 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. US duties on British iron wire increased from 9s 4d plus 15% *ad valorem* in 1860 to 18s 8d plus 15% *ad valorem* in 1880. Similarly, duties on steel wire increased from 11s 8d plus 15% *ad valorem* in 1860 to 14s plus 20% *ad valorem* in 1880.[96] '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.[97]

German wire was also being imported into Britain during this time: 'the great influx of German wire in England is beginning at last to tell upon the trade'.[98] Even the British government placed an order for 1,000 tons of 'strand' wire with a German firm 'due to its cheapness'. Trade reports around this time continually lamented about how domestic demand for German wire was beginning to tell upon the English wire industry. 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 rod-making firms such as Pearson & Knowles found it difficult to compete with German firms. At least five other wire-rods mills closed down due to excessive German

[96] *Ironmonger*, Jan 28, 1882 & Sep 7, 1878; also Blake-Coleman, *Copper wire*, p. 212.

[97] Seth-Smith, *Richard Johnson & Nephew*, p. p. 83.

[98] *Ironmonger*, Jan 3, 1880, p. 28.

competition. Also, pin makers, netting weavers, rope makers, etc. were purchasing German wire in preference over English wire.[99]

There were several sources of Germany's competitiveness in wire manufacturing. German heavy industry was protected by tariffs and was dumping iron and steel products, such as wire and rails, in international markets. 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 contributed to low steel prices. Also, German efficiency in iron and steel manufacturing increased relative to Britain 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.[100] Additionally, railway freight rates in Britain were more than twice those of Germany, Holland and Belgium. For example, cost of transporting one ton of packed wire by railway from Birmingham to London was 24s, while according to German, Belgium and Dutch tariff rates the same journey would have cost 10-11s, 8s 11d and 8s 2d respectively. In fact, Belgian wire was available at lower prices in London than wire from the Midlands.[101]

Also, German firms were operating at or near full capacity compared to English firms whose domestic capacity had increased faster than demand. In addition, German labour productivity was higher compared to British manufacturers. 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 differentials.[102] When Thewlis Johnson and George Bedson (of Richard Johnson and Nephew) visited 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

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[99] H. Janes, *Rylands of Warrington: 1805-1955* (Harley Publishing Co., 1956), p. 63; *Ironmonger*, Sep 7, 1878, p. 929-30; June 7, 1879, p. 763; Jan 3, 1880, p. 28; Oct 23, 1880, p. 489; Nov 3, 1883, p. 651.

[100] Wengenroth, *Enterprise and technology;* Allen, 'Iron and Steel': pp. 920, 28-29 and Table 8.

[101] Bell, *UK Iron Trade*, p. 108; *Ironmonger*, June.7, 1879, p763, cost of Belgian wire calculated on the Thames on f.o.b. basis.

[102] *Ironmonger*, Oct 4, 1878, p. 514; Nov 4, 1882, p. 635; May 5, 1883, p. 626.

and reported that labour costs were about 40 to 50 percent lower in Germany.[103] The overall picture of the British wire trade that emerges is one of 'slackening demand and increasing competition [and] the wire trade relapsing into [a] state of depression'.[104]

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. 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. 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.'[105] 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.[106]

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

[103] Seth-Smith, *Richard Johnson & Nephew*, p. 78; *Ironmonger*, Apr 27, 1878, p. 305.

[104] *Ironmonger*, Jul 31, 1880.

[105] Seth-Smith, *Richard Johnson & Nephew*, pp. 79-80; Stones, *Wire Industry*, p. 5; Bullen, *Drawn together*, pp. 14-16; Ironmonger, Apr 1880; May 24, 1884, p. 711.

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

Horsfall - in addition to making steel wire for ropes, cables, picture cords, etc.[107] 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.[108] Apart from individual firm strategies, co-operative action by manufacturers was actually limited. 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, or the US industry in 1894-95 or even those that were formed in related British industries, such as pin manufacturing.[109] There is no evidence of any industry association during this period until the ISWMA was formed in 1882, primarily to deal with the issue of the standard wire gauge. There is also little evidence that technological improvement, such as continuous wire drawing, newer methods of cleaning, annealing and treating wire, etc. helped to improve British competitiveness.[110] Continuous wire drawing, for example, was relatively new and does appears to be in limited use. 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 the wire numbers. For instance, switching from a Lancashire gauge to the ACC gauge implied changing the numbers in thirteen of the fourteen sizes between Nos. 6 and 18. 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. As a considerable proportion of thick wire was drawn according to the Lancashire gauge the result of switching to the ACC gauge would have been costly for the manufacturers in a highly competitive environment (table 5.4).

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

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

[109] Seth-Smith, *Richard Johnson & Nephew*, p. 83; S. R. H. Jones, 'Price Associations and Competition in the British Pin Industry, 1814-40', *The Economic History Review* 26 No. 2 (1973); Warner, John Dewitt, *Steel & Wire*, Letters, No. 12, New England Free Trade League. There is mention of an association attempted in the 1860s in Stones, *Wire Industry*, p. 1; also, Bullen, *Drawn together*, p. 14 mentions an industry organization dealing with export prices around 1867. It is unclear how these associations operated and the purposes for which they were formed.

[110] Seth-Smith, *Richard Johnson & Nephew*, p. 82.

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.[111]

Table 5.4
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 reproduced in Frank Stones, *The British Ferrous Wire Industry*. Sheffield: J W Northend Limited, 1977, illustrations between pages 12 & 13.

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 would have increased the number of draws and

111 Price of copper wire from Blake-Coleman, *Copper wire*, pp. 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.

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'.[112] 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.[113] Thus, the switchover was likely to result in a short as well as a long-term impact on the competitiveness of the British manufacturers. Consequently, the ISWMA proposed an alternative gauge, which was different from the ACC gauge. BoT's 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 (figure 5.3).

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.[114] 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.

But why did the large manufacturers cooperate to form the ISWMA in the first instance? 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

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

[113] *Ironmonger*, Dec 2, 1882, p. 749; see note 105.

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

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.

5.6 *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, use gauges to express sizes rather than measurements such as inches or millimetres.[115] The legalization of the SWG (Standard Wire Gauge) was intended to remove the confusion surrounding the wire sizes. The industry largely discontinued the use of older gauges such as the BWG. Vestiges of the old gauges survived 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. 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

[115] J. S. Pöll, 'The story of the gauge', *Anaesthesia* 54 No. 6 (1999).

LSG (Legal Standard Gauge). Notwithstanding this, the legal gauge defined in 1883 was the gauge that was 'generally used in the wire trade'.[116]

Table 5.5:
Comparison of Wire Exports from UK, Germany & US (1870-1906)

<table>
<tr><th></th><th>UK</th><th>Germany (wire)</th><th>Germany (rods)</th><th>US</th></tr>
<tr><td>1870</td><td>21</td><td></td><td></td><td></td></tr>
<tr><td>1877</td><td>51</td><td colspan="2">32[a]</td><td></td></tr>
<tr><td>1878</td><td>44</td><td colspan="2">57</td><td></td></tr>
<tr><td>1879</td><td>37</td><td colspan="2">77</td><td></td></tr>
<tr><td>1880</td><td>59</td><td colspan="2">102</td><td></td></tr>
<tr><td>1881</td><td>75</td><td colspan="2">156</td><td></td></tr>
<tr><td>1882</td><td>87</td><td colspan="2">223</td><td></td></tr>
<tr><td>1883</td><td>63</td><td>176</td><td>28</td><td></td></tr>
<tr><td>1890</td><td>62</td><td>49</td><td>83</td><td></td></tr>
<tr><td>1894</td><td>34</td><td>85</td><td>122</td><td>20</td></tr>
<tr><td>1895</td><td>42</td><td>87</td><td>114</td><td>27</td></tr>
<tr><td>1900</td><td>38</td><td>74</td><td>92</td><td>78</td></tr>
<tr><td>1906</td><td>95</td><td>174</td><td>146</td><td>174</td></tr>
</table>

[a] Separate estimates for wire and rod exports between 1877 and 1882 are not reported in the source; Leslie Thomas. *The development of wire rod production*. London, 1949.

Did the adoption of uniform wire sizes assist the British industry to regain its dominant market position after 1883? Table 5.5 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 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 overtake 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 continued to be dominated by drawn wire and have a much smaller proportion of wire rods (figures not included in the table). British exports, shown here, are primarily

[116] TNA, BT 101/537; BT 101/538; BT 101/943, letter from the Deputy Warden of Standards.

comprised of drawn wire. Uniformity in wire sizes do 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 dominant wire manufacturers, both internationally as well as domestically, well into the twentieth century

Following the standardization of wire gauges, other trades attempted to standardize gauges. For instance, in 1893 the Needle and Fish Hooks Trade Association unsuccessfully tried to standardize a gauge for needles.[117] In a move to standardize an international gauge for 'flats and rounds', the American Society of Mechanical Engineers proposed a collaborative association with the BoT in 1894; no such gauge is known to have emerged from this.[118] The American industry, in fact, continued to use a variety of wire gauges until the early decades of the twentieth century.[119]

5.7 *Conclusion*

This chapter has shown that, as far as the market was concerned, there was no one superior or obvious way of determining a uniform set of wire sizes. If uniformity of sizes and conformity to them led to reliable wire measurements, then these aspects had to be negotiated, not mapped to some abstract principle. The process involved reconciling different notions of desirable sizes that different market groups held. The process was institutional in nature, not technologically deterministic.

The process of making wire sizes uniform involved establishing a host of standards to be used in the mensuration activity: a single set of wire sizes that all groups agreed to; a single set of nominal numbers that served as a mnemotechnic for wire sizes; a one-to-one correspondence between the sizes and numbers; the use of decimal sub-divisions of the inch to express the wire sizes; the protocols that established the use of a particular (physical) form of wire gauge; protocols specifying the use of a single gauge, sizes, and numbers for all metal wires, etc. Thus, many different parts of the mensuration activity had to be made uniform.

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[117] TNA, BT 101/346.

[118] TNA, BT 101/ 386.

[119] C. A. Adams, 'Industrial Standardization', in *The Annals of the American Academy of Political & Social Science: Industries in Readjustment*, (Philadelphia, 1919), p. 292.

While various groups of buyers and producers were involved in making wire sizes uniform, the role of institutions was important in reconciling differences, coordinating efforts and aligning preferences. Industry associations served as lobby groups, but also helped to settle internal debates between members. The state was 'invited' by market groups to settle a deadlock at a micro-level. The events leading up to the introduction of the uniform sizes are actually evidence of market processes at work and not coordination failures. The various market institutions did lead to a resolution and convergence towards uniformity. There is no evidence to suggest that the state would eventually have intervened to correct market or coordination failures.

Regarding standardization, it is interesting to think about why oligopolistic manufacturers sought uniformity when they dominated virtually all of the domestic market. A defensive strategy to prevent lock-in on the 'wrong' standards emerges as a possible explanation. Notwithstanding this, the fact that large manufacturers were prepared to lock-in on any single standard suggests the desirability of a commitment mechanism of some sort.

Appendix 5.1

Comparison of Sizes of Various Wire Gauges *(sizes expressed in 1000th of an inch)*

Sizes	Stubs Gauge[1]	BWG[1]	Rylands Gauge (RG) [1]	Cocker Steel Gauge (CSG) [2]	South Stafford-shire Gauge (SSG) [2]	Variation as compared to the Stub gauge (%)			
						BWG	RG	CGS	SSG
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 known versions...' (1905) British Library 1882.d.2 fo. 126.

Appendix 5.2

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

Notes & Sources: The measurements above, including the differences, are reported in 1000th of an inch. The SWG gauge of Aug 1833 is taken from The National Archives, BT 101/133; the ACC gauge of Mar 1882 from BT 101/114; the ISWMA gauge of Jul 1882 from BT 101/116.

Chapter 6

Quality Measurements in the British Wheat Trade: Institutions, Standards & Mensuration

6.1 *Introduction*

During the nineteenth-century the sources of grain for the British markets changed significantly. An increasing quantum of wheat was imported after the repeal of the Corn Laws c1840; by c1860 more wheat was imported than was being sold in the domestic markets. Simultaneously, other changes occurred in the trade: some groups involved in the trade became specialized in particular activities whereas other groups integrated other commercial activities; there was an increase in the wheat varieties that were available in British markets; demand for whiter bread increased causing an increase in demand for particular types of wheat (and flour); the milling industry became more professionalized and underwent rapid technological transformation; etc. Organizational changes, changes in technology (transportation, port infrastructure, etc.), expansion of international trade routes (both in scale and scope), and the changing nature of the commodity put the spotlight on the quality assessment practices within the trade. The issue that the trade faced was which set of product attributes could capture *ex-ante* the important aspects of wheat quality. This chapter focuses on how the process of quality management became a complex process within the British wheat trade. By studying its evolution from historical market practices to specialized control procedures, the case study traces how 'who measures' and 'what was measured' in the context of wheat quality changed during the nineteenth-century.

Generally, assessing quality for heterogeneous products is considered to be difficult, as it is not practical to delineate all product attributes completely and acquire information about them.[1] But, quality is a relative concept rather than an absolute one: it can have different meanings depending upon who is conducting the measurement. There is quality 'in the eyes of producers', but there is also quality 'in the eyes of the consumers'.[2] To someone responsible for producing or inspecting a

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[1] Barzel, 'Measurement cost': pp. 28-29; Pirrong, 'Commodity Exchanges'.

[2] P. Bowbrick, *The economics of quality, grades and brands* (Routledge, London and New York, 1992), pp. 2-11.

product, quality can be defined narrowly or absolutely. In contrast, to the user of that product, quality is a relative concept, to be compared with other similar or substitute products. Theoretically, this implies that quality will be measured, by any given economic group, on the basis of 'summary criteria', i.e. on a set of product attributes that a particular group will choose to proxy for the product's quality. This set of attributes is most likely to differ amongst groups if each group has a different notion of product quality.[3]

How can quality be managed in such a context? The answer to this depends upon *what* we perceive is being managed. Managing quality could mean sharing information about the product, its production process, etc. between groups who would otherwise have only partial access to such information.[4] In other words, managing quality could involve managing 'facts' about the product and how 'well' they travel between different groups along a value chain. One way of making this happen is for all groups to make quality measurements using similar criteria using similar measurement artefacts and consistent practices, i.e. quality standards.[5] From our perspective, this implies standardizing the attributes for measuring quality, developing standards to compare observations of selected attributes, establishing rules to sort products into different categories based on quality measurements, developing institutional rules and organizational structures to monitor the process, etc. The historical question is whether this is what occurred in the wheat markets of the nineteenth-century and whether there is any evidence to support this view.

Prima facie evidence suggests that different groups developed their own individual criteria for evaluating the quality of produce. Historically, samples of wheat would be assessed on the basis of numerous criteria, the assessment requiring a high degree of tacit knowledge and reliance on tactile senses (touch, smell, etc.).[6] Literature suggests that with the advent of formal grading by commodity exchanges and trade

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[3] Barzel, 'Measurement cost': pp. 28-32, for a discussion of how buyers and sellers could sort commodities into multiple classes; Ponte and Gibbon, 'Quality standards': p. 7, for a discussion of quality from the perspective of 'convention theory'. They stress that 'there is no universal understanding of quality' and that 'quality is cognitively evaluated in different ways'; also, B. Daviron, 'Small farm production and the standardization of tropical products', *Journal of Agrarian Change* 2 No. 2 (2002).

[4] Ponte and Gibbon, 'Quality standards': pp. 2-3.

[5] O. Favereau et al., 'Where do markets come from? From (quality) conventions!', in *Conventions and structures in economic organization*, O. Favereau and E. Lazega. eds. (Edward Elgar, Cheltenham, UK, 2002), p. 243.

[6] Dumbell, 'Corn sales': p. 144.

associations in the latter half of the nineteenth-century, the management of quality through product grading became the dominant way of managing wheat quality.[7] Even though the literature highlights that different attribute sets were used to grade wheat, primarily according to source, grading is considered to be an efficient way of economizing measurement costs.

The historical issue here is were these grades used primarily by the trading groups i.e. corn merchants and middlemen, or were they used more generally by the other market groups, such as millers, who were large buyers of imported wheat? Did the buyers use product grades as the only criteria for assessing the quality of wheat they bought? What other quality measurements did they depend on, if any? What measurements were used for product grading, and why? What role did the institutions play in managing the mensuration activity apart from developing quality grades?

As this case study shows there was no universal set of attributes that the markets used to measure quality even by the end of the nineteenth-century. It demonstrates how quality assessment along the commodity chain involved the measurement of different sets of product attributes by different groups as the organization, technology and trade routes transformed and the number of 'standards' used to measure quality increased. It shows how markets developed different solutions to the measurement problem, as product attributes measured were not standardized within the trade. The chapter demonstrates that standardization of mensuration practices did not involve a rationalization of standards. In fact, protocols were developed to make it possible to use several specialized standards within the mensuration activity.

The rest of the chapter is structured as follows. Section 2 examines the composition, structure and the changing nature of the British wheat trade during the nineteenth-century. It also highlights some of the problems in measuring quality of the commodity and traces the important changes in who measured quality of the commodity during this period. Section 3 examines in detail how the trade assessed the quality of grain and traces the important changes in the mechanics of quality assessment. Section 4 provides the problems in measuring quality from the buyer's

[7] Pirrong, 'Commodity Exchanges': p. 233; also Daviron, 'Standardization of tropical products', for standardization of grades as a strategy to manage quality, although he admits that this is only 'one amongst a series of possible modes' to manage information asymmetry.

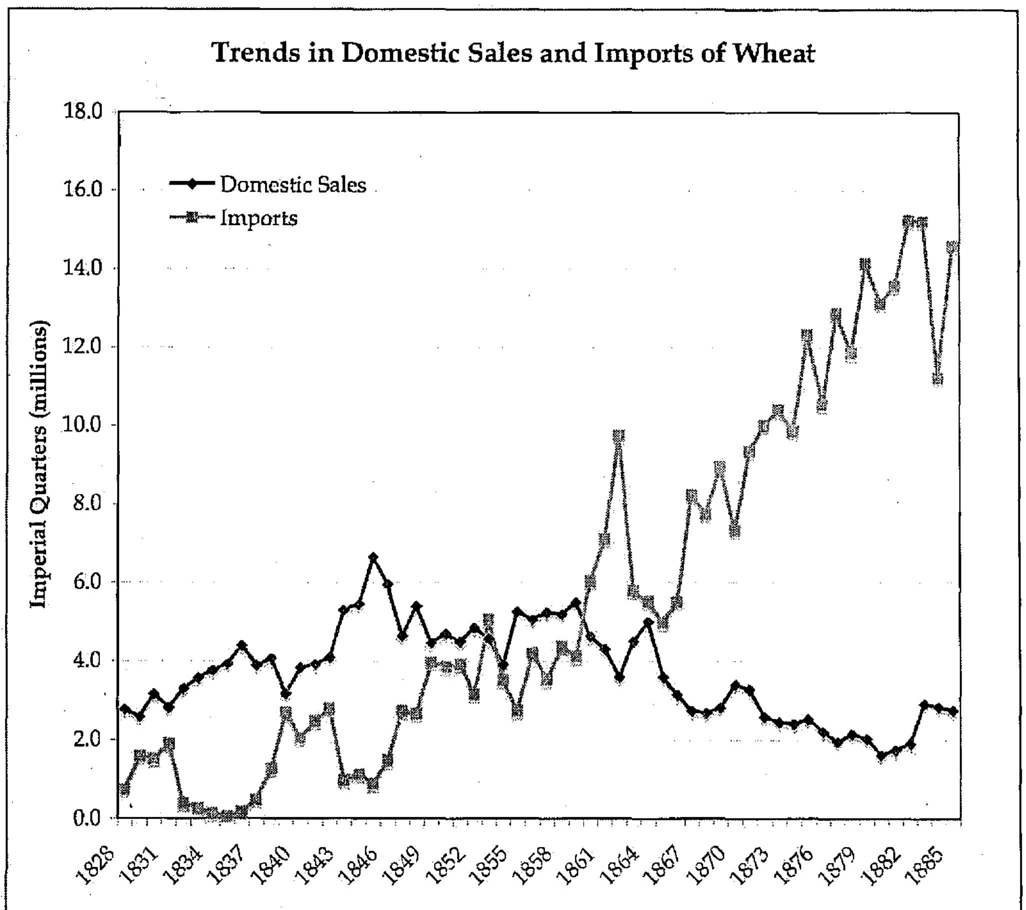
perspective. The example used in this chapter is the millers, a large and important group of wheat buyers. This section traces how increased professionalization of the milling industry had important implications on how grain quality was perceived. Section 5 examines the case of the natural weight measurements, which as I argue, is reflective of the problems in standardizing quality measurements. The analysis of how natural weight measurements declined in importance suggests broader changes occurring in the measurement infrastructure and mechanisms, which are explored in greater depth in section 6. This section also examines the standardization of quantity measurements and demonstrates how the separation of the processes of quality assessment and distribution of wheat led to different sets of standardized measurements. Section 7 provides some concluding remarks.

6.2 *British Wheat Trade of the 19th Century*

An overview of the wheat trade in the nineteenth-century presents some major trends discernable during this period. The composition of the trade was changing in terms of the sources of grain (domestic versus foreign), the different groups involved in the trade and their specialization, the enormous heterogeneity of wheat varieties available in British markets, the issues in quality measurement, etc. This influenced the measurement of quality in terms of who measured it, at what stage of the value chain it was measured, and how it was measured after c1860.

In the first half of the nineteenth-century, domestic wheat sales showed a slow steady growth, growing roughly fives times in quantity between 1815 and 1850. With the repeal of the Corn Laws, which had restricted the import of foreign corn between 1815 and 1846, imports of wheat increased nearly tenfold between 1830 and 1885. This slowed the growth in domestic wheat sales, which eventually declined in terms of the quantum sold domestically. By the 1860s, more wheat was imported than was being sold in the domestic markets. The commodity was imported from several sources, the main sources being the US and Russia in the late nineteenth-century. However, wheat was also imported from Argentina, Australia, India and several other locations in Europe. In addition to wheat, these markets supplied the UK with other grain and cereals, such as barley, malt, rye, etc. The US imports became the single most important overseas source of grain for the UK in the last two decades of the nineteenth-century. On an average, imports of wheat from the US accounted for

Figure 6.1



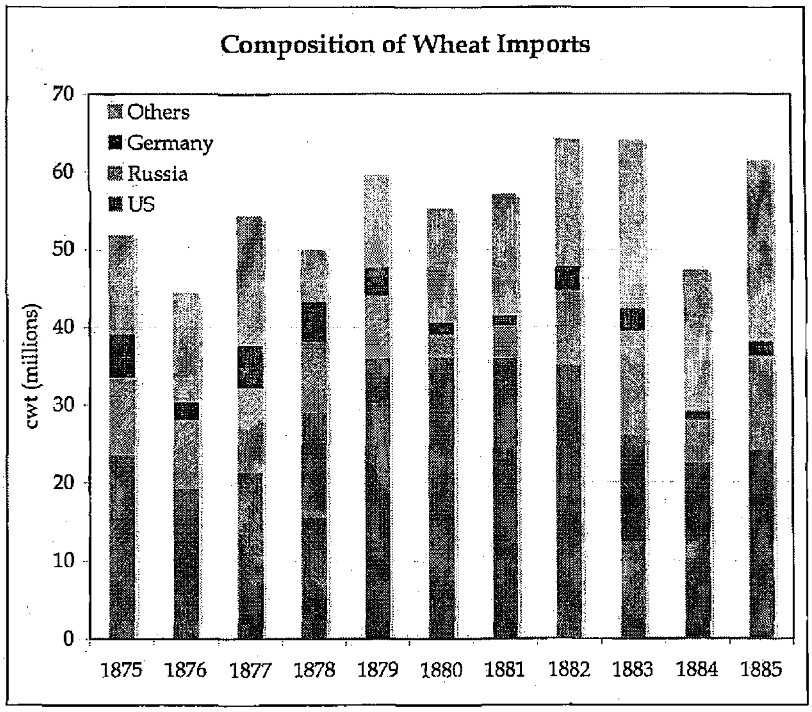
Source: Data on domestic sales from PP 1889 Vol. LX p. 23; data on imports from PP 1886 Vol. LX p. 405.

nearly half of the annual wheat import into the UK between 1875 and 1885 (see figures 6.1 & 6.2).[8]

The proportion of British population consuming wheat (and wheaten bread) increased throughout the nineteenth-century compared to consumption of other cereals. Whereas in 1800 about two thirds of the population of Great Britain were estimated to have been consuming wheat, by 1900 wheat consumption had become nearly universal, while the consumption of oats and barley declined. These shifts were a result of several factors, such as the decreasing price differentials of the various cereals, the high cross-price-income elasticity of wheat, degree of

[8] *PP 1886 Vol. LX, Return of total quantity of various kinds of grain and flour imported into the UK in each year from 1828*, p. 405; *PP 1889 Vol. LXIII, Quantities and average price of wheat as sold in the towns of England and Wales between 1815 and 1888*, p. 423; Statistical Abstracts Nos. 37 & 38.

Figure 6.2



Source: Statistical Abstracts Nos. 37 & 38.

urbanization, the emergence of professional bakers and millers, technological improvements in milling, changing eating habits, etc. Thus, per capita consumption of wheat is thought to have increased during the mid-nineteenth-century from 5.1 bushels to 5.5 bushels.[9]

The structure of the trade had evolved since the eighteenth-century and by the end of the nineteenth-century involved a fairly complex organizational structure, characterized by layers of interrelated firms and organized commodity markets (figure 6.3).[10] Historically, corn was supplied to London by a class of middlemen known as the *mealman* who purchased and milled the grain (or got it milled from millers) and subsequently sold the flour directly to the bakers or on the open market.[11] Sometime during the eighteenth-century, the functions of the *miller* and the mealman began to merge, as the millers integrated several related activities: corn

[9] E. J. T. Collins, 'Dietary change and cereal consumption in Britain in the nineteenth century', *Agricultural History Review* 23 (1975): pp. 114-15.

[10] Rothstein, 'Multinationals'.

[11] F. J. Fisher, 'The Development of the London Food Market, 1540-1640', *The Economic History Review* 5 No. 2 (1935): p. 61.

buying, grinding, dealing in meal and flour, etc. Up until then, the mealman had been responsible for 'mealing', or mixing of flour, a function now taken over by the millers. Some bakers had begun to integrate backwards combining the functions of the baker, miller and mealman. Nevertheless, we find the millers and bakers as distinct groups in the nineteenth-century, suggesting that not all bakers had integrated backwards.[12]

Concomitantly, a powerful group of *corn factors,* known as 'hoymen' had emerged by the early eighteenth-century. They sold corn in London markets, such as the one at Bear Key, on commission basis on behalf of the farmers. In these markets, wheat was mainly sold to the miller, while other corn was purchased by 'a galaxy of corn dealers [and other middlemen], many of whom were engaged in "dealings" or speculative activities alongside their basic trades.'[13] Initially, private bargaining had characterized the trade, with open or regulated market trades being insignificant. By the mid-eighteenth-century, the Corn Exchange was set up in Mark Lane in London signalling the beginnings of an organized or terminal market for wheat and other grains. Supplies to this market came from the home counties of Kent, Essex and Suffolk as well as from foreign destinations. Very few farmers sold directly at Mark Lane and wheat was sold through the factors to millers or to shipping factors for re-shipment. Wheat that was not sent to London was sold to country millers, although it was not unusual for country millers to obtain wheat from London based factors.[14]

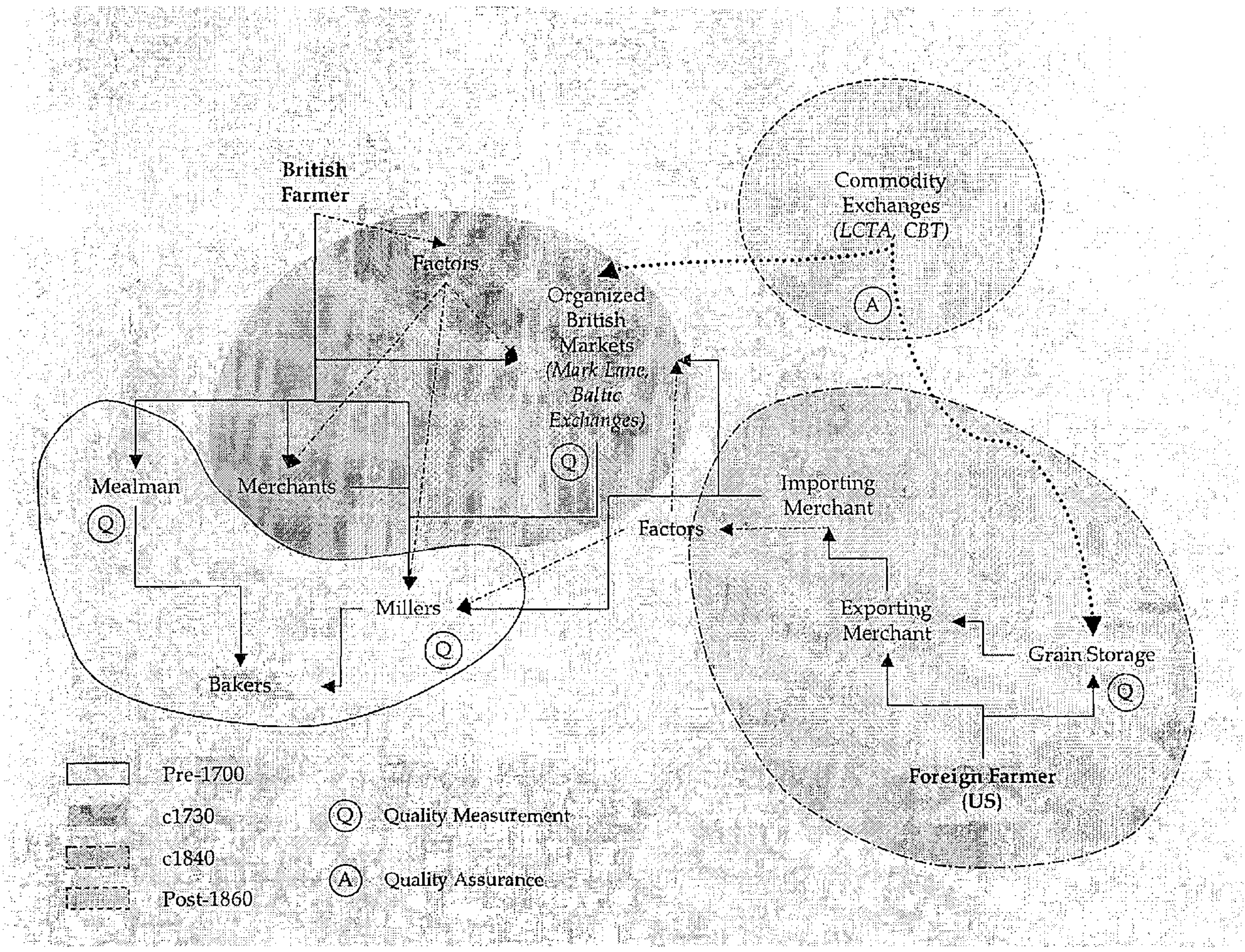
By the end of the eighteenth-century, a parallel structure had emerged as increasing amounts of imported wheat began reaching British markets, such as supplies of Irish corn sold in Liverpool. The *importing merchant* became an important member in this chain, although it was the factor that remained a conduit for the trade buyers of wheat, i.e. the millers. The Baltic Exchange, that had its origins in the Virginia and Baltick Coffee House of Threadneedle Street in London, was primarily a place where merchants involved in the international trade would meet. Later it would serve as the 'headquarters' of the London Corn Trade Association; practically all London grain dealers were members of both the Baltic Exchange as well as the Corn

[12] D. Baker, 'The marketing of corn in the first half of the eighteenth century: North-east Kent', *Agricultural History Review* 18 No. 2 (1970): pp. 142-43.

[13] Ibid.: p. 136.

[14] Fay, 'London corn market': pp. 72-73; Baker, 'Corn marketing': p. 138.

Figure 6.3



Source: See text

Association.[15] The members included importing merchants, as well as foreign merchants and shippers. In the auction room, oil and tallow were offered for sale initially, and after the repeal of the corn laws, wheat and other grain were auctioned.[16]

As imports of wheat grew dramatically after c1860, the structure of the trade at the exporting country became significant, particularly from the perspective of quality measurements, as we will see later on. Broadly speaking, wheat sold by the farmer to the *exporting merchant* for reshipment to Britain would normally arrive in sacks at the importing port, which could be identified with the original seller. If grain was mixed

[15] Forrester, 'Commodity Exchanges': p. 200; J. G. Smith, *Organised produce markets* (Longmans, Green and Co, New York, 1922), p. 30.

[16] H. Barty-King, *The Baltic story : Baltic coffee house to Baltic Exchange, 1744-1994* (Quiller Press, London, 1994) ; Forrester, 'Commodity Exchanges': pp. 200-01.

it was done by the importing merchant at the port of import. The most important exception to this was North American corn, which was sold to the operators of the grain elevators. Here the grain would be mixed with other grain of similar quality, the farmer receiving the price according to the quality. The operators would sell this mixed grain, of 'standard' quality either at the trade exchanges or to the exporting or commission merchants at the large primary markets, such as Milwaukee or Chicago.[17]

The trade dealt with numerous varieties of wheat grains, based upon botanical distinction as well as distinct characteristics of each botanical variety. By 1840 several new wheat varieties were added to the existing Red Lammas type of low yielding British varieties. At least 16 different domestic wheat types were available for sale in English grain markets in the 1850s, each differing not only in gluten content – the chemical substance which determines the bread-making ability of wheat - but also in terms of yield (i.e. quantity of grain per acre).[18] In addition to the domestic varieties, wheat imports greatly increased the total number of varieties available for sale in British markets. An analysis of English and foreign wheat available in 1884 listed more than 25 domestic varieties (including distinct grain types as well as grains of different quality) and about 40 foreign ones. The foreign varieties were used mainly in the manufacture of flour, particularly in South England.[19]

The heterogeneity of variety was not unique to wheat or grain. The variety and quality of imported cotton differed according to the region from which they were sourced. For example, in the eighteenth-century 'fine varieties' of West Indian cotton such as Cayenne, Surinam, Issequibo, Demerara, Tobago, Guadeloupe, Grenada and Martinico, were available with other 'dirty' varieties such as Barbados, Tortola, St. Vincents, St. Kitts, Montserrat, Anguilla, Nevis and Antigua.[20] By the early twentieth century, American cotton, although limited to one botanical variety, the upland cotton, was further divided into distinct classes, which in turn could be further divided into sub-classes. Thus, on the basis of 'grade' (i.e. presence of foreign

[17] *Miller* (London) April 5, 1880, p 99; Rothstein, 'Multinationals'.

[18] J. R. Walton, 'Varietal innovation and the competitiveness of the British cereals sector, 1760-1930', *Agricultural History Review* 47 No. 1 (1999): pp. 45-48.

[19] W. Jago and W. C. Jago, *The technology of bread-making* (Kent & Co., London, 1911), pp. 272-79.

[20] John Slack, Remarks on Cotton, (Liverpool, 1817), cited in S. Dumbell, 'Early Liverpool cotton imports and the organization of the cotton market in the eighteenth century', *The Economic Journal* 33 No. 131 (1923): p. 370.

material and the physical condition of the fibres), its colour and the staple length, American cotton could be classed into more than 1200 possible varieties.[21] Agricultural products could not be standardized by simple and controllable processes. They were affected by several natural factors, and quality variations within the same variety or breed could occur in an unpredictable fashion. This made assessing their quality a particularly difficult process.[22]

An important issue here is at what stage in a long value chain was the quality of wheat measured and who measured it? Figure 6.3 indicates the different nodes at which quality was measured as the structure of the trade evolved during the eighteenth and nineteenth centuries. Traditionally, it was in the interest of the mealman, who mixed different grades of wheat, to assess the quality of grain he bought, as there was often a substantial price differential between the best and inferior quality wheats.[23] When the millers integrated the functions of the mealman by the eighteenth-century, the mixing of different grain quality, and therefore the assessment of quality, was done by them. With the establishment of the organized markets, such as Mark Lane or other regional markets, the assessment of quality was done at these nodes. This coincided with the rise in the practice of selling by sample. The buyer and the seller would agree on a price upon inspection of the sample and the delivery by the seller would have to conform to the quality of the assessed sample.[24] When foreign grain was imported in large quantities after c1860, the inspection and sampling issues became particularly important to assess the quality of grain being imported, although their significance in earlier periods, especially for Irish imports, should not be underestimated.[25] After c1860, grain imported from North America, especially from the Midwest area of the US, was shipped according to distinct quality grades. The grain elevator operators did the grading, particularly since grain from different producers was being mixed during storage and prior to transportation.

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[21] Cox, 'Cotton price': p. 543; Garside, *Cotton markets.*

[22] W. A. Sherman, 'Standardizing production - what has been done and what can be done', *Annals of the American Academy of Political and Social Science* 142 (1929): p. 419.

[23] C. Petersen, *Bread and the British economy, c1770-1870* (Solar Press, Aldershot, England, 1995), pp. 158-9; *PP 1805 Vol. III, Report of Select Committee on Import and Export of Corn,* p. 195, evidence of Peter Giles to the select committee stating that the price of good quality wheat could be double that of inferior quality.

[24] Baker, 'Corn marketing': p. 138; *PP 1834 Vol. XLIX* p. 259.

[25] Dumbell, 'Corn sales'.

Broadly speaking, the nodes at which quality was measured (mensuration activity) changed and varied as the structure of the trade changed between the eighteenth and nineteenth centuries. Measurements were made some of the times at the exporting end, and at other times at the importing end of the trade. Why did these changes occur? What determined the node at which quality was measured? To what extent, and why, did the attributes measured differ? These issues are explored in more detail in the following sections.

6.3 *Mechanics of Assessing Quality: A Perspective from the Supply Chain*

Historically, buyers developed their own individual criteria for evaluating the quality of produce and the degree to which it matched their requirements. Varieties were identified according to their geographical origin. However, quality according to this criterion varied considerably and was not always consistent.[26] Samples of wheat sold in important markets such as London or Liverpool were submitted for inspection and the *natural weight* of the grain (i.e. its weight per cubic capacity), its colour, dryness, presence of impurities and other physical characteristics were important attributes on which quality was assessed. The extent to which tacit knowledge was used to assess quality was high as 'the eye, nose and hand were necessary [in] judging the value of grain and dealers could determine its specific gravity by "merely taking up and poising a small quantity of it in their hands"'.[27] Grain quality was assessed on the basis of such attributes before the advent of systematic grading by commodity exchanges after c1860. Prime, medium, and inferior reds and whites existed alongside English, French, Chicago, Milwaukee and New Orleans varieties of grain and most millers made their selection of grain with 'care and deliberation'.[28]

While the distinction between different wheat qualities was important to the buyers and the trade, British wheat farmers were mainly concerned with the 'harvest index' of the crop. This index referred to the proportion of total shoot weight accounted for by the grain, the balance being the weight of the stalk (figure 6.4). To the farmer, both

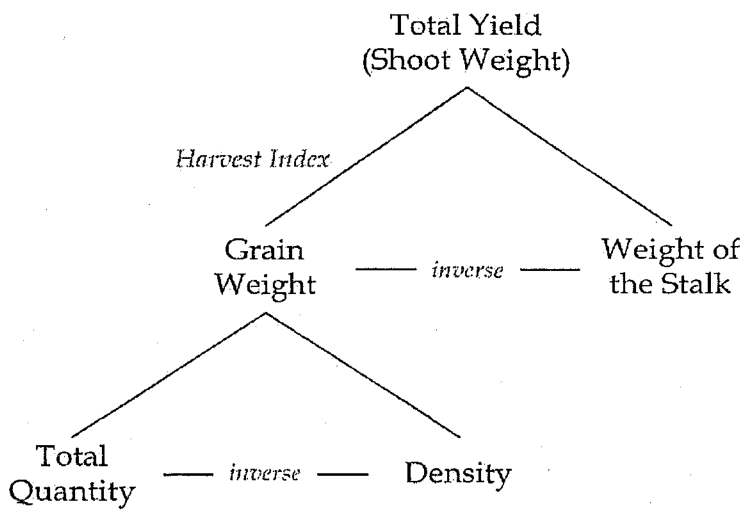
[26] Daviron, 'Standardization of tropical products': p. 169.

[27] Dumbell, 'Corn sales': p. 144. It is important to consider the difference between *specific gravity* and *natural weight* in this context. Specific gravity measurements usually refer to the density of individual wheat grains. However, as will become clear later in the chapter, due to the manner in which natural weight measurements were made, they included the 'density' of empty spaces (or air) in addition to the density of the individual grain.

[28] Ibid.

Figure 6.4

Components of Yield in 19th Century Grain Varieties



Source: Based on Figure 1 in Walton, "British cereals," 39-40 & 48.

the grain as well as the stalk were of value, particularly in the high farming systems where the stalk provided valuable livestock fodder. In addition, there was an inverse relationship between the quantity of grain produced (yield) as opposed to its natural weight or density. Generally, varieties that had higher yields, in terms of volume per acre, had lower densities. Also, there was no single variety available that could produce heavy stalk yield and a large volume of grain at high densities preferred by the baking trade.[29]

Grain yield was a multi-faceted concept to the farmer who had to balance all the three aspects of the harvest, i.e. the weight of the stalk, the weight of the grain and the total amount of grain produced. The application of high fertilizer doses in the nineteenth-century, while increasing the overall yield of the crop, changed the character of the crop in one of two ways. If, the harvest index was reduced, that is the proportion of stalk to grain went up, this increased the density of the individual grains, while reducing its yield in terms of the total quantity of grain produced. But, if the overall quantity of the grain increased, i.e. the harvest index increased, it

[29] Walton, 'British cereals': pp. 39-40.

resulted in decreased density of the grains.[30] This quest for greater yield gradually resulted in a varietal shift of wheat available in domestic markets, as farmers preferred the high volumetric yielding varieties, but with lower density. These varieties of soft wheat began to replace the harder, lower volumetric, higher density yielding varieties previously grown.[31]

For example, Talavera (originally introduced from Spain), a variety that offered a high flour extraction percentage and good quality flour, had a comparatively lower volumetric yield than another variety, such as Spalding, which had lower bushel weight and higher volume yields. By the 1860s, Talavera was largely abandoned by farmers, whereas Spalding, 'a farmer's wheat than a miller's', was extensively grown.[32] Thus, we see a dissonance between the preference of the farmers and large buyers of wheat: millers complained that they could no longer find suitable domestic wheats for bread making. This varietal shift implied that the softer high yielding wheat increasingly grown in Britain after c1860 were unsuited to the rolling mill technology introduced in the 1880s and millers had to import hard wheats that were more suited for this new technology, as we shall see later.

In several domestic markets, selling on the basis of natural weight or density emerged as a common method of assessing the quality of produce. This method guaranteed that the contracted volume of grain, say one-*bushel* measure, would weigh a specified amount, say 60 *lbs*. If the actual weight was more or less than the guaranteed weight per volume, the contract price was adjusted proportionately.[33] For example, a contract for wheat from c1830, guaranteeing delivery weight to be 18 *stone* per *quarter*, specified price and terms as 54s 6d 'pay or be paid' i.e. the farmer was to make a 'proportionate allowance' to the merchant in case the net weight on delivery was under 18 *stone* 4 *lbs*, and conversely the farmer was to receive an allowance from the merchant in case the net weight on delivery was found to exceed 18 *stone* 4 *lbs*.[34] In another example from Sheffield, weight per *load* was mentioned by the seller as confirmation of quality and could vary from 12 *stone* 19 *lbs* to 13 *stone* 10

[30] Ibid. pp. 39-40 & 48.

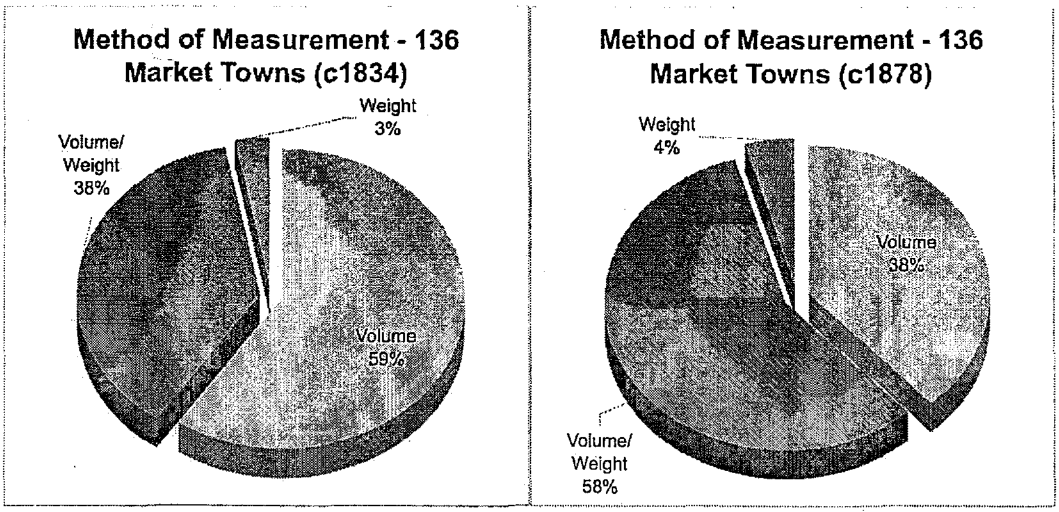
[31] Ibid. pp. 48-50.

[32] Ibid. pp. 48-51.

[33] The other methods of selling grain in domestic markets were on the basis of volume-only or weight-only measures. *PP 1834 Vol. VII*. Also, *PP 1878-79 Vol. LXV, Summary of returns by corn inspectors.*

[34] *PP 1834 Vol. XLIX*, p. 259; 1 *stone* equals 14 *lbs* and 6.35 *kgs*.

Figure 6.5



Source: Data for c1834 from PP 1834 Vol. XLIX; data for c1878 from PP 1878-79 Vol. LXV

lbs according to the quality of wheat. Also, wheat brought into this market from Gainsborough and Lynn was sold by the *quarter* weighing 504 *lbs,* whereas wheat from Hull was to be delivered at 480 *lbs* per *quarter.*[35] In the market town of Lewes, if the wheat purchased did not weigh the quantity stated by the seller per cubic capacity, 'a diminution in price agreed upon [was] made' and when the grain exceeded the weight stated, 'the price [was] advanced'.[36] There are similar examples from other market towns such as Lincoln, Stamford, York, Leeds, Wakefield, Hull, Whitby, Malton, Durham, Stockton, Darlington, Newcastle-upon-Tyne, Whitehaven, etc.

Returns from corn inspectors from 136 market towns in 1834 suggest that two-fifths of these towns were already selling wheat on the basis of their natural weights.[37] Comparing the same 136 towns in 1878 suggests that the number of market towns selling grain on the basis of the natural weight had increased to more than half during the nineteenth-century (figure 6.5). Of the top twenty towns accounting for about 60% of the corn sold in domestic markets in 1880, eleven markets were reported to be using natural weight measurements as a basis for wheat sales. These

[35] Ibid. p. 262.

[36] Ibid. letter by John Bartlett, Aug 27, 1833.

[37] *PP 1834 Vol. XLIX,* p. 256; in addition more than half the towns reported that the basis for selling corn was by volume-only measurements, and the rest of the towns using weight-only measurements.

included towns such as Norwich (10%), London (4%), Boston (3.5%) and Northampton (3%).[38]

The use of natural weights to assess the quality of wheat was not unique to Britain. French bakers regularly used this method to distinguish between a *setier* of good wheat and average quality wheat. Although 'artful and meticulous bakers' could assess quality of grain through sensory examination, by itself this was not considered to be a sufficient guarantee of quality; the most reliable test of goodness was weight.[39] As weight of wheat brought into Paris would vary sharply from year to year, a 'three-quality-range' had emerged in the mid eighteenth-century. The *setier*, the Parisian measure of volume, was equated to either 240, 230 or 220 *pounds* for a normal year, the highest weight representing the best quality wheat. In an exceptionally good year, the weight of the *setier* could be set as high as 250 *pounds*. The three-quality-range could vary: in 1769, the range was set at 241, 236 and 233 pounds in Etampes, whereas in Pontoise it was set at 229, 223 and 220 pounds respectively.

Such natural weight measurements did not capture information about the *condition* of the grain, such as the presence of impurities, dryness or moisture content, texture, etc. - attributes that were equally important to the miller and the baker in addition to the density of the grain. Historically, information about the condition of the grain could be verified through sampling and visual inspection. However, even inspecting samples could prove to be problematic. Samples could hide the extent of variation in the quality of a given stock. They were also liable to damage due to exposure or handling and therefore could not represent the actual quality of the entire stock. For example, after selling on the basis of samples became common practice in the mid-eighteenth-century, there were complaints against corn factors that they exposed only a selection of their samples so that the buyers did not get a complete picture of the actual quality of stock they represented. Similarly, American grain inspectors sampling wheat from railway wagons faced similar problems in the early twentieth century. Sampling from fully loaded wagons, particularly those loaded to the roof, was fraught with difficulties in terms of the reliability of the samples extracted.

[38] *PP 1881 Vol. LXXXIII, Return showing total quantity for wheat in 1880.*; the figures in parentheses represents the proportion of grain sold in that market town compared to the total grain reported as sold for that year.

[39] Kaplan, *Provisioning Paris*, pp. 52-3.

Sampling was also problematic in other commodity trades. Cotton sellers in Liverpool often accused brokers of carelessly handling samples, which 'prejudiced the sale of the whole lot and often put the seller to the expense of re-sampling'.[40]

From the mid-nineteenth-century onwards, commodity exchanges, such as the London Corn Trade Association (LCTA) or the Chicago Board of Trade (CBT), began to develop detailed mechanisms to measure and grade these complex goods.[41] Developing grades involved selecting a finite set of characteristics, or 'summary criteria', such that the commodity could be graded into a manageable number of classes. This was important given the plethora of wheat varieties available, and the incredibly large number of ways in which it could be classified. Criteria used to determine the commercial grade of grain from the samples submitted for inspection included moisture content, natural weight, freedom from foreign material (cleanliness), condition and texture of the kernels, general condition (whether the grain is cool and sweet or it is musty, sour, heating or hot), etc.[42] Previously, grain traders had adopted a distinct vocabulary to describe quality characteristics. This included several terms such as sound, bright, common, extra, choice, merchantable, clean, fair, hot, unsound, etc.[43] Many of these terms were used to describe the grades that the commodity exchanges developed.

Commodity exchanges initially found it difficult to fix numerical grading standards. When product attributes could not be graded absolutely or quantitatively, these exchanges provided an alternative by creating dispute resolution or arbitration mechanisms.[44] For the London and Liverpool Corn Trade Associations, the cash market measurement and arbitration systems were more important than fungible instruments adopted for the futures market. The commodity exchanges therefore functioned as quality *assurance* or *guaranteeing* centres, and not only institutions that coordinated the mensuration and grading activity.

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[40] Daviron, 'Standardization of tropical products': p. 169; Hill, *Grain, grades and standards,* p. 6; Fay, 'London corn market': p. 73; J. C. F. Merrill, 'Classification of grain into grades', *Annals of the American Academy of Political and Social Science* 38 No. 2 (1911): p. 63; T. Ellison, *The cotton trade of Great Britain : including a history of the Liverpool cotton market and of the Liverpool cotton brokers' association* (E Wilson, London, 1886), p. 177.

[41] Pirrong, 'Commodity Exchanges': p. 234.

[42] L. S. Tenny, 'Standardization of farm products', *Annals of the American Academy of Political and Social Science* 137 (1928): p. 209.

[43] Hill, *Grain, grades and standards,* pp. 13-14.

[44] Pirrong, 'Commodity Exchanges': p. 235.

The British exchanges, such as the LCTA and the Liverpool Corn Trade Association were primarily concerned with grading imported wheats, not domestic ones: there is no evidence that either of these exchanges developed formal grades for the domestic trade. This is perhaps not surprising, as by the time these exchanges began developing formal grades c1880 or thereabouts, the quantum of foreign imports was roughly eight times that of domestic sales (figure 6.1).[45] By the end of the nineteenth-century, guaranteeing quality of imported wheat traded in the London market involved four distinct grading methods: certificate final, sealed sample, fair average, and fair average quality (FAQ).

Certificate final referred to grades that were certified by an authority in the originating country, such as the CBT in the US. These grades functioned as classes or standards, ranking the quality of the produce based on descriptions of certain attributes, and which British merchants could accept as guarantee of quality. In the fair average method, a standard was issued by an authority in the producing country based upon samples from the produce in a given period from the growing regions in that country. These standards could change depending upon the quality of produce in a given year.. In contrast, sealed sample and FAQ methods involved inspection of samples once the produce had reached the UK ports. These differed according to the methods of sampling and the basis on which the samples were used, either for sorting the grain into grades or for resolving disputes relating to the quality of the product.

The FAQ method was the one that was most commonly adopted in London. Under this method, samples of all grain imported into UK, including several ports in Europe, were periodically collected by LCTA who would then arrive at the grades for any given year. The actual mechanism or methods used to describe the grades could not be determined from the archival records. It is difficult to establish whether the FAQ grades were standards - as in a reference point that establishes conformity or deviation - or as ranked categories into which the different samples could be sorted. Since the grades were developed on a responsive basis, i.e. based on annual samples collected, it is likely they functioned as ranked categories rather than as standards.

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[45] In 1880, foreign wheat imports amounted to 55 million tons as opposed to 6.7 million tons reported in domestic returns; *PP 1889 Vol. LX, Statistical Tables of Corn Averages*, p. 423; *PP 1886 Vol. LX, Report of Grain Imported into the UK*, p. 405.

When the LCTA began grading grain on the FAQ basis, the description of quality depended upon the source of the produce. For instance, when Indian grain was graded on FAQ terms, allowance was made for dirt and other impurities (such as non-farinaceous seeds). While drawing up the standards for Indian wheat for the 1889 season the East India Grain Committee of the LCTA defined the standard for No. 1 Club Bombay Wheat as containing

> '[Not over] 3% of impurities of which 1(1/2)% may be dirt for shipments to the 30th June, and 3(1/2)% [impurities], of which 2% may be dirt, for the remainder of the seasons shipments'[46]

Similarly, standards for New Zealand wheat were made separately for round berried and long berried wheat.[47] North American grain was gradually accepted on the basis of 'official certificate of inspection to be final as to quality', i.e. according to the quality guaranteed by the official inspection certificates issued in the US. Even so, LCTA would sometimes inspect the samples prior to accepting the grades.[48]

While making the FAQ grades, the LCTA would take into account the differences in the natural weight of the grain from Argentina, Australia, California or other locations. For example, while fixing the standard for Australian wheat in 1894, the LCTA fixed an average weight of 63 *lbs* per bushel for the seasons wheat. On the other hand, the average weight of Californian White was assumed to be 60.5 *lbs* per bushel, while fixing the standards for 1895. Similarly, for grain imported from the Black Sea ports, the committee had developed rules to account for the natural weight, especially for rye and barley.[49] In Liverpool, natural weight was used to grade American milling wheat specified as spring wheat (weighing 60*lbs* per bushel), soft winter (of 61*lbs* per bushel) and hard winter (of 60½*lbs* per bushel). The North and South Argentine wheats too were graded according to their natural weight at 59½ and 60½*lbs* per bushel respectively and the Australian wheat was specified at

[46] London Corn Trade Association (hereafter LCTA), Minutes of East India grain committee: Vol. 1 (1888-96), Guildhall Library MS 23186/1, entry for 8th Aug 1889.

[47] LCTA, Minutes of American and Australian grain committee: Vol. 1 (1882-96), Guildhall Library MS 23177, entry for 9th April 1891; Smith, *Organised produce markets*, pp. 24-25.

[48] LCTA, American Grain Committee, entry for 1st Jan 1891; Pirrong, 'Commodity Exchanges': p. 236; LCTA, Subcommittee to examine rules of arbitration, Guildhall Library MS 23175, suggested alteration of Contract Forms 1898 proposed by the Liverpool Corn Trade Association on 8th Nov 1897 and accepted by committee.

[49] LCTA, American Grain Committee, Sep 24, 1895; Feb 20, 1894, etc.; also LCTA, Minutes of Black Sea Grain Committee: Vol. 1 (1890-1901), Guildhall Library MS 23183, especially the comparative table for the regulation of the natural weight of rye; also, Forrester, 'Commodity Exchanges': p. 202.

60½lbs per bushel. No wheat weighing more than one pound per bushel 'under basis' was accepted within these grades.[50]

LCTA had to periodically review the samples of on FAQ basis to determine the acceptable average natural weights of the different varieties and did not use a defined unchanging numerical standard. The association also used other criteria, such as cleanliness and colour, to establish its grades. As we have seen earlier, the proportion of impurities was an important criterion for assessing the quality of grain from India, presumably more so than the variation in natural weights.

The use of natural weights is also evident in of US wheat grades. In 1858, the Board of Trade of the City of Chicago (CBT) began classifying grades of grain according to descriptions of colour, quality and general condition and at the same time certifying to those grades.[51] Four basic grades for spring wheat, for instance, were established: Club wheat, No. 1 Spring, No. 2 Spring, and Rejected.[52] When this system of grading attracted opposition, because it lacked uniformity and 'responsible inspectors', the CBT continued to refine these grades; there were allegations that inspectors had too much discretion based upon their 'own judgement of quality and grade'.[53] In 1859, CBT added 'test weight' i.e. natural weight, as a grading factor for wheat. The following minimum test weights (pounds per bushel) were introduced: Club, 60 *lbs*; No. 1, 56 *lbs*; Standard, 50 *lbs*; Rejected, 40 *lbs*. These did not always work, as in 1859 when grain less than 45 *lbs* per bushel but of Standard grade or better was delivered. As a result, CBT revised the grades and the minimum test weights as follows: No. 1, 56 *lbs*; Standard, 50 *lbs*; No. 2, 45 *lbs* and Rejected, 40 *lbs*. Even these 'standardized' natural weights failed to gain approval by the trade. The CBT consequently left the specification of the test weight to the discretion of the grain inspectors when ascertaining grade.[54]

By the turn of the century, a numerical system of grading the various varieties of red, white, winter and spring wheat had emerged. For instance, No. 1 white winter wheat was defined as that which was pure white, sound, plump and well cleaned. No. 3

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[50] Forrester, 'Commodity Exchanges': p. 204.

[51] Merrill, 'Grain grades': p. 58.

[52] Hill, *Grain, grades and standards*, p. 15.

[53] Ibid.

[54] Ibid. pp. 13-16.

was defined as not clean and plump enough for No. 2 but which weighed not less than fifty-four *pounds* to the measured bushel. The Board of Railroad and Warehouse Commissioners had developed this system of rules for inspection in order to 'establish a proper number and standard of grades for inspection of grain'.[55] These rules took into account the natural weight of grains such as wheat, barley and oats to define certain grades in addition to other attributes.

Nevertheless, the numerical grades in the US were not entirely based upon *quantitative* measurements of quality. Quantification of quality attributes continued to remain problematic and elusive. When the US Grain Dealers National Association adopted inspection rules in 1908, their Grade 1 specified moisture content to be 15%, impurities (dirt, broken grains, etc.) to be 1%. Yet in c1914, numerical grades continued to be based upon descriptions such as sound, dry, reasonably clean, sweet, mature, plump, etc.[56] Studies conducted by USDA after 1909 to identify 'tangible factors' influencing the 'intrinsic value' of corn considered weight per bushel as an important factor (apart from moisture, breakage, cleanliness, etc.). When the US Department of Agriculture (USDA) promulgated official grades for commercial corn in 1914, six distinct numerical grades were defined on the basis of moisture, damage to the kernels (due to heat or presence of broken corn, etc.) and presence of foreign material.[57] Natural weight continued to remain an important test factor for quality, but it was not one of the attributes that defined the numerical grades.

The foregoing discussion raises several issues regarding the measurement and management of quality in the British wheat trade. The first set of issues relates to the multiplicity of criteria used to define and measure the quality of wheat. Broadly speaking the density of wheat was considered as an important indicator of the bread-making ability of a given variety of wheat. This aspect was only vaguely understood before the latter half of the nineteenth-century and advances in the chemistry of wheat would later reveal why this should be so. This is discussed in more detail in a following section. Apart from density, other criteria were just as important in assessing the condition of the grain. Also, the set of attributes used to measure quality differed according to the trade route and sources of imported wheat.

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[55] Chicago Board of Trade 1905, *The forty-seventh annual report of the trade and commerce of Chicago.*, 30-33.

[56] Hill, *Grain, grades and standards*, p. 76, table 3 comparing grades specified by USDA and those used in three major grain markets of New York, Chicago and Minneapolis.

[57] Ibid. pp. 18-19 & 71-73.

The second set of issues relate to the difficulty in arriving at numerical standards of quality. In its extreme sense, we can question the very possibility of quantifying quality measurements. Could the bread-making ability of wheat - an important test of grain quality of from a miller's (and a baker's) perspective - be quantified? What criteria should be included in this quantified measure? Could characteristics such as colour and texture be quantified, just as density of the wheat grain could be? To what extent were quantified measurements reliable as predictors of quality? Understanding these issues would help us uncover the various elements of the mensuration practices.

The third set of issues relates to the nodes at which such measurements were made. For instance, why were quality measurements of American wheat, made in the exporting country? Why were they acceptable in British markets? Why was wheat imported from other sources checked for quality in British ports? These issues are explored in detail in the following sections.

6.4 *Millers, Milling and Quality of Wheat: The Buyer's Perspective*

While important changes were occurring in the British wheat trade in the latter half of the nineteenth-century, there were corresponding and equally significant changes in the milling industry around the same time. Being the largest buyers of wheat, these changes cannot be merely coincidental and are likely to be intimately connected. The important question here is what role did the milling industry play in the standardization of quality measurements. How did the millers assess wheat quality and what problems did they face in measuring or quantifying quality.

After c1870, we discern a 'professionalization' of skills required in the milling industry as the process of milling became highly specialized and technically sophisticated. This is evidenced by at least two developments that have a direct relevance to the issues discussed in this chapter. First, in this period we witness some radical changes in the methods, locations and reorganization of the milling industry that stem primarily from revolutionary technological advances made after c1870. Second, we also see the emergence of some institutions in this period that further engineered the professionalization of the trade. These institutions included technical and trade journals, and industry associations that sought to overcome the knowledge and skills deficit within the industry. The structural reorganization and institutions helped to modernize the milling industry.[58]

The milling technology in use around c1870 had remained unchanged since the late eighteenth-century when steam milling had reduced the industry's dependence on wind and water. Millstones continued to be used for grinding wheat, the replacement of wooden gear wheels with iron ones being the only improvement of note in the intervening period.[59] This 'sudden-death' grinding method ensured that the wheat grains were ground thoroughly and as quickly as possible. The consequence of this method was that the flour obtained contained a significant proportion of bran, although the extraction rate of flour from the wheat grain was as high as 80%.[60] New developments in milling technology, particularly in Hungary and the US, involved improvement and perfection of roller milling techniques.[61] Rolling produced whiter flour although the extraction rate reduced to about 72% of the wheat grain.[62] The main advantage of this new technology was that it improved the quality and the whiteness of flour obtained for the same proportion of grains used to produce the coarse 'household' grade flour using the older grinding technology.[63]

The speed and extent of adoption of roller milling was shaped by at least three important factors: increasing domestic demand for white flour, unsuitability of softer domestic wheat varieties to the technology, and increase in the imports of foreign flour and hard wheat varieties. The causal links between all these factors is not entirely clear. However, it is likely that the increasing demand for white flour had to be satisfied either by importing better quality foreign flour or by increasing the domestic production of white flour using the new technology. The increase in the import of wheat grains (figure 6.1), which gradually outsold domestic wheat by a

[58] H. Macrosty, 'The grainmilling industry: A study in Organization', *The Economic Journal* 13 No. 51 (1903); G. Jones, *The millers: A story of technological endeavour and industrial success, 1870-2001* (Carnegie Publishing Limited, Lancaster, 2001), especially Chap. 1; R. Perren, 'Structural change and market growth in the food industry: Flour milling in Britain, Europe and America, 1850-1914', *The Economic History Review* 43 No. 3 (1990); J. Tann and G. Jones, 'Technology and transformation: The diffusion of the roller mill in the British flour milling industry, 1870-1907', *Technology and Culture* 37 No. 1 (1996).

[59] Perren, 'Flour milling': p. 424.

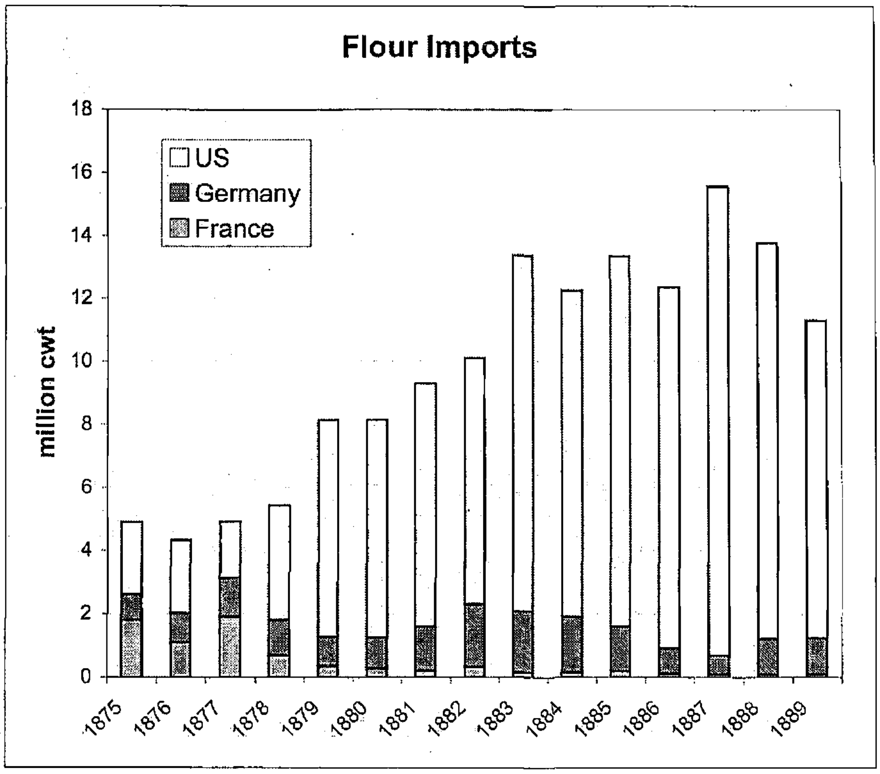
[60] Jones, *The millers*, p. 22; Tann and Jones, 'Technology and transformation': p. 60.

[61] Tann and Jones, 'Technology and transformation': pp. 41-43.

[62] Jones, *The millers*, pp. 23-25.

[63] Perren, 'Flour milling': p. 423.

Figure 6.6



Source: Statistical Abstracts Nos. 37 & 38

factor of eight, were of direct relevance to the adoption of roller milling as well as to the changing structure of the industry. The roller milling technology was more effective with the harder wheats, which had been edged out of domestic markets when domestic wheat varieties gradually shifted towards the softer 'farmer's wheat' of the high yielding varieties, as we have seen earlier.[64]

The import of foreign hard wheats after c1860 certainly aided the diffusion of the new technology. Imports of milled flour too increased during this period. Within a decade from 1875, the quantum of flour imports had nearly trebled, and most of it was sourced from the US (figure 6.6). The imported flour constituted nearly a fifth of the national consumption by the end of the 1880s, almost double compared to the

[64] Tann and Jones, 'Technology and transformation'; Perren, 'Flour milling'.

previous decade.[65] The impact on domestic wheat and flour prices, and profitability, concerned not only the millers but also the corn trade in general.[66]

The take-up of roller milling technology was slow and uneven. Similarly, the industry structure and demand profile displayed uneven contours. There was a polarization of the industry into a few large firms, serving regional and national markets, and hundreds of small country mills serving mainly local demand. The small firms formed about 95 percent of the mills in the UK in the late 1880s, but produced about 35 percent of the domestic flour. By 1910, five of the largest roller milling firms (from a total of more than 800 firms) accounted for about one-fifth of the total output; this concentration increased to nearly two-thirds by 1930.[67] The large firms were concentrated around the major port areas, which were both a source of raw materials as well as demand, and were characterized by significantly higher throughput rates due to the adoption of roller milling. With the increasing competition, concentration and specialization in the industry, and the marginalization of the small country miller, there was a felt need to help the millers become more professional. At least two institutions spearheaded the attempts to transform milling into a modern industry: industry associations and the press.

After 1870, several industry associations were set up, which at first sought to regulate the conditions for sale of flour, but later became a forum to establish procedures and governance mechanisms, as well as to serve as nodes to disseminate knowledge and information. Regional associations included the Sheffield Association (founded 1873), the London Association (founded 1878), Liverpool and Manchester District Association (active c1878), etc.[68] However, the association that undoubtedly had the greatest impact on the industry was the National Association of British and Irish Millers (NABIM) formed in 1878. Its general aim included

[65] Perren, 'Flour milling': p. 425.

[66] *PP 1886 Vol. XXI, First Report of Royal Commission on Depression of Trade and Industry*, p 93, memo from Liverpool Corn Trade Association.

[67] Perren, 'Flour milling': pp. 432-33; Tann and Jones, 'Technology and transformation': pp. 62-66.

[68] Macrosty, 'Grainmilling': p. 331.

> 'The collection of information bearing upon all departments of the trade, technical, practical, and commercial, with a view to improve the quality of its products and increase the ratio of its profits.'[69]

In terms of NABIM's membership, it received strong support from millers in London, Liverpool, Sheffield, Leeds, the Bristol Channel and South Wales area, Northamptonshire, and other locations where large milling firms were established; in-country and small milling firms failed initially to see the benefit of this association.[70] The association functioned as a 'clearing house' for knowledge and information. For instance, a series of annual conventions were organized by NABIM between 1884 and 1890 on topics such as 'Bookkeeping for millers', 'Gradual reduction milling', 'The Carter and Zimmer sorting system', 'The world's wheat crop and wheat values', etc.[71] It also acted as the 'educator' and a promoter of milling as a 'science' beyond its obvious industrial origins. The association complemented the various efforts that were underway to establish some sort of organizational structure for technical education in general; for the milling industry, NABIM, and the individuals associated with it such as William Voller and William Dunham, provided the general structure and supervision of technical education.[72]

The association also acted as a 'pressure or lobby group' on behalf of its members, and the milling industry more generally. For instance, NABIM wrote to the Board of Trade in 1878 expressing the opinion of the milling trade regarding the metrological units to be used in the sale of wheat and other grain. It had canvassed the regional and local millers associations, corn merchants and agriculturists through a series of more than 20 meetings held across the country throughout 1878. This testifies to the organizational ability and the overall influence that NABIM had within the milling and wheat marketing trades.[73] Apart from these roles, NABIM was also involved in the quality standardization and grading process for wheat. For example, it proposed various amendments to the LCTA standard contract forms in 1896. One particular amendment it suggested regarded the proportion of dirt and foreign matter that should be allowed in the grain imported from India. This suggestion was, however,

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[69] Jones, *The millers*, p. 139.

[70] Ibid. pp. 141-44.

[71] Ibid. p. 148.

[72] Ibid. pp. 150-56; Voller was one of the pioneers of technical education; Dunham was the founder of the trade journal *Miller* (London).

[73] TNA, BT 101/43, letter by William Chatterton, president of NABIM, Nov 7, 1878.

rejected by the LCTA on the basis that the limits suggested by NABIM were 'impracticable'.[74]

Another institution that had a similar impact in the professionalization of the milling industry was the rise of various technical and trade journals that were exclusively devoted to the miller. The journal, *Miller*, was started in 1875 by William Dunham, and G J S Broomhall started the journal *Milling* in 1891.[75] Publications such as these served as forums to exchange information, knowledge, opinions, developments, etc. that directly affected the millers and how they conducted their trade. In it one would find information about new developments in the milling process pioneered by milling engineers such as Herbert Simon, or about the state of the wheat crop in Britain or its foreign sources, letters seeking opinions about the best method of mixing grain to get the ideal flour, news articles on developments affecting the wheat, milling and baking trades, etc. The editorial, technical, commercial and correspondence content was supplemented by the growing amount of advertising. Such journals provided much of the basis of news, ideas and discussion for both formal and informal networks of communication throughout the industry.[76]

Consequent to the radical changes occurring in the milling industry, the quality assessment of wheat, the important raw material for the industry, also experienced some changes. Accordingly, the manner in which grain quality was considered, the quality attributes of grain that were important for making flour of a given quality and the manner in which they were measured were re-examined and refined.

It was generally acknowledged within the trade that corn of higher density had greater bread making qualities. An article in *Miller* in 1879 stated that 'the value to the miller of a certain variety of wheat depends upon the quantity of fine flour it will yield.'[77] Wheat of least specific gravity was known to yield a lower quality of flour and vice versa. The proportion of albuminoids or flesh formers was thought to determine the quality or fineness of flour. It was found to increase as the density of grain increased, and was one of the principal reasons why denser grains were considered to have better bread making ability. 'More flour is produced from corn of

[74] LCTA, Arbitration Sub-committee, entry for 1896.

[75] Jones, *The millers*, pp. 18-21, Broomhall had started another publication covering the corn trade called the *Liverpool Corn Trade News* (1888).

[76] Ibid., pp. 20-21.

[77] *Miller*, May 5, 1879, Technical Issue, p. 193.

higher specific gravity, and more bread from such flour, than from inferior corn or inferior flour', a report from 1834 had claimed.[78] Although lighter, coarser grains could yield a larger proportion of flour, this was achieved by including coarse bran and thereby reducing the quality of flour obtained (table 6.1).[79] Generally, the millers, and bakers, preferred wheat varieties with high natural weights to the 'softer' wheat varieties with lower densities.[80]

But it was not only the density of the grain that was important to the miller: the 'strength' of the grain or flour was crucial to the miller (and the baker) as well. The strength was initially defined as the ability to absorb and retain moisture, which later was modified to indicate the quantity and quality of gluten the grain contained.[81] Stronger flour was preferred because the number of loaves obtained from a given weight of flour were more than those obtained from weaker flour.[82] Hard wheat of the low yielding (and conversely high density variety) were considered to be stronger wheats, whereas softer wheats were considered to be of the weaker kind. British wheats, on the whole, were considered to be of the weaker kind.[83] The miller basically had to balance both the density as well as moisture characteristics of the grain, as those varieties with the highest-bushel weight with low moisture content usually gave the greatest amount of flour.[84]

Table 6.1
Comparison of Wheat Quality over 3 years

Variety: Red Wheat	1st Year	2nd Year	3rd Year
Weight per bushel (*lbs*)	63.3	62.2	59.1
% of albuminoids in the flour	14.2	13.1	12.8
% of coarse bran	2.9	2.3	5.9
% of flour on milling	68.3	71.5	73.3

Source: Miller, *Nov. 3, 1879, p. 682*

78 *PP 1834 Vol. VII.*

79 *Miller*, May 5, 1879, Technical Issue, p. 193; Nov. 3, 1879, p. 682.

80 Walton, 'British cereals': pp. 39-40.

81 Jago and Jago, *Breadmaking*, p. 291.; also, Jones, *The millers*, p. 60.

82 J. Percival, *Wheat in Great Britain* (Reading, 1934), p. 69.

83 Ibid., p. 71.

84 Ibid., p. 72; also, Jago and Jago, *Breadmaking*, p. 369; Jones, *The millers*, pp. 59-60.

Apart from these, other differences were also of importance to the miller. Before the introduction of the rolling mills, when wheat was ground between millstones, the colour of the grain was also important to the miller, as invariably some of the bran or coat of the grain was also ground along with the fleshy part. Flour from red-grained wheats was never as white as that obtained from white-skinned wheats; white flour commanded a higher price in the market. In any case, white wheat was known to yield a slightly higher proportion of flour than red wheats. This difference in the colour of wheat became less important once the roller system of milling was adopted after c1880, as with this new technology very little of the bran was mixed with the rest of the flour and flour from red-grained wheat could be as white as that from white-skinned wheat.[85]

One of the greatest skills that a miller had to possess was to know which varieties of wheats to process and mix together as 'grist'; i.e. flour that the bakers would accept as consistent and which suited their trade. Flour itself could be graded into different types: whites, firsts (or best households), seconds (or second households or standard wheaten), thirds (third households or fine middlings), fourths (or coarse middlings or sharps), and wholemeal.[86] Millers scarcely recognized a consistent system of grading flour, however, each flour grade required a different quality of grain.[87] Mixing of different wheat qualities also allowed the widest possible use of inferior grade of wheats, which by themselves would have been unsuitable for making baking flour, particularly in London and other larger towns. Mixing also eked out the supply of expensive best quality wheat, and enabled the miller to enhance his margin by mixing expensive and inexpensive wheats and still sell the mixed flour at a price higher than that of inferior quality flour.[88]

A typical mixture recommended in the eighteenth-century included one part best quality wheat to one part second-best quality wheat to two parts inferior quality wheat.[89] Such a mixture implied a price ratio of about 100:91:81 for best, second and

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[85] Percival, *Wheat*, p. 72.

[86] Petersen, *Bread and Britain*, pp. 53-54.

[87] J. Kirkland, 'The relative prices of wheat and bread', *The Economic Journal* 6 No. 23 (1896): p. 479.

[88] *PP 1814-15 Vol. V*, p1353, evidence by E G Smith; Petersen, *Bread and Britain*, pp. 158-9.

[89] Petersen, *Bread and Britain*, p. 159. Historically, wheat had been divided into 'best', 'second' and 'third' quality categories according to some quality attributes for the purpose of setting the Assize of Bread, 12 Henry VII cited in *PP 1814-15 Vol. V*, p. 1344.

inferior quality wheat respectively.[90] As the availability of foreign wheat increased, best quality imported wheat was mixed with lower quality domestic varieties.[91] This and the eventual abolition of the assize in 1836 greatly increased the choice of wheat available for the miller to mix in various proportions, vastly increasing the complexity of the mealing process. By the latter half of the nineteenth-century, millers required knowledge about the varieties available, its sources, and quality; the millers craft now required a great deal of experimentation and risk. Millers had to consider, for each variety of wheat, whether it would contribute to one or more aspect of flour quality: strength, colour, taste or general appearance. Consequently, wheat buying was governed by experience, general principles and a considerable degree of detailed knowledge, and no two millers agreed on what constituted ideal grist.

Consider for instance this exchange between two millers in 1878. One miller, with 30 years of milling experience, describes an 'ideal milling process [for] making the best and greatest quantity of flour from a given quantity of wheat.' For this he uses an 'ideal' grist composed of 20 *bolls* each of No. 1 American, Canada Club, Saxonska, Californian or Oregon and British wheats (each *boll* being equivalent to *240lbs*). These 100 *bolls*, according to this miller, could yield 60 sacks of fine flour, an additional 5 sacks of 'overheads' (a lower grade of flour), 15 *cwt* of 'feeding' seconds, and about 30 *cwt* of bran. The gross margin in this case would be about £12 and 5s. In response to this, another miller claimed that, using a different configuration of machinery, for the same grist combination, he could obtain 23 sacks of 'new process' flour, 44 sacks of first grade flour, 8 *cwt* of 'thirds' and 32.5 *cwt* of bran at a gross margin of £22 and 18s.[92]

In another instance, one miller invited comment on whether the following mixture 'ought to make a good sack of bakers flour': 3 sacks red winter; 2 sacks Michigan; 2 sacks No. 2 spring and 5 sacks of English white.[93] He received at least five suggestions from other millers, all different. One correspondent suggested that the

[90] Petersen, *Bread and Britain*, table 6.2 on 160. The average prices in the table have been calculated from evidence provided to the Select Committee on Sale of Corn by Richard Page, *PP 1834 Vol. VII*, p356. These are unweighted averages and weighting them with the mix proportion suggests an average price of 88 for the grain mix compared to the relative prices of individual grain qualities.

[91] Petersen, *Bread and Britain*; *PP 1834 Vol. VII*; *PP 1814-15 Vol. V*, various testimonies.

[92] *Miller*, Letters on 'Milling Reform', Apr 1 and May 6, 1878.

[93] *Miller*, Feb 2, 1880, Letter no. 669, p. 922.

proportion of English wheat was too high and instead recommended that 3 sacks of Michigan be used instead of 2, and that English white be limited to 2 sacks. Another correspondent suggested the original mixture would result in 'lack of strength and colour' and suggested eliminating English white altogether and adding an extra sack of No. 2 spring to the mixture: alternatively, the red winter, No. 2 spring and the English white could be mixed in equal proportions. A third correspondent suggested leaving the English white out altogether, grinding the remaining mixture separately, and then letting the meal sit in the sack for a few days before mixing. The fourth correspondent suggested that if this was milled in the country then 6 parts each of No. 1 American spring with 'sound' new English white wheat, mixed well in a bin a week before grinding, could give the desired results. The fifth correspondent recommended one sack each of Dantzic and American spring, three sacks each of American white and American winter and four sacks of English white (part new and part old).[94] Thus, milling was not an exact science; it remained an acquired skill based upon experience and experimentation.

Mixing was important since a direct volumetric relationship existed between grain inputs and flour output. Consider this example from more recent times. The Chicago CBT specified grade number 2 soft red winter wheat (SRW) uses 58 pound per bushel test weight as criteria. A miller usually bases grain price to flour ratios on the assumption of a 73% flour extraction rate, implying that 2.36 bushels would be required to produce 100 pounds of flour. A reduction of test weight from 58 pound to 57 pound per bushel has two implications. First, at the same extraction rate, the miller now needs 2.40 bushels of wheat to produce 100 pounds of flour. Second, a reduction of test weight, and hence quality of the grain, is likely accompanied by a reduction of extraction rate to say 70% which further increases the quantity of grain required, 2.50 bushels, to produce the same quantity of flour. The resulting cost differential of wheat to flour is not always reflected in the price discounts for the different wheat qualities.[95]

Of course, to the British miller in the late nineteenth-century it was not only the price of individual variety of wheat that was of ultimate importance, but the relative costs

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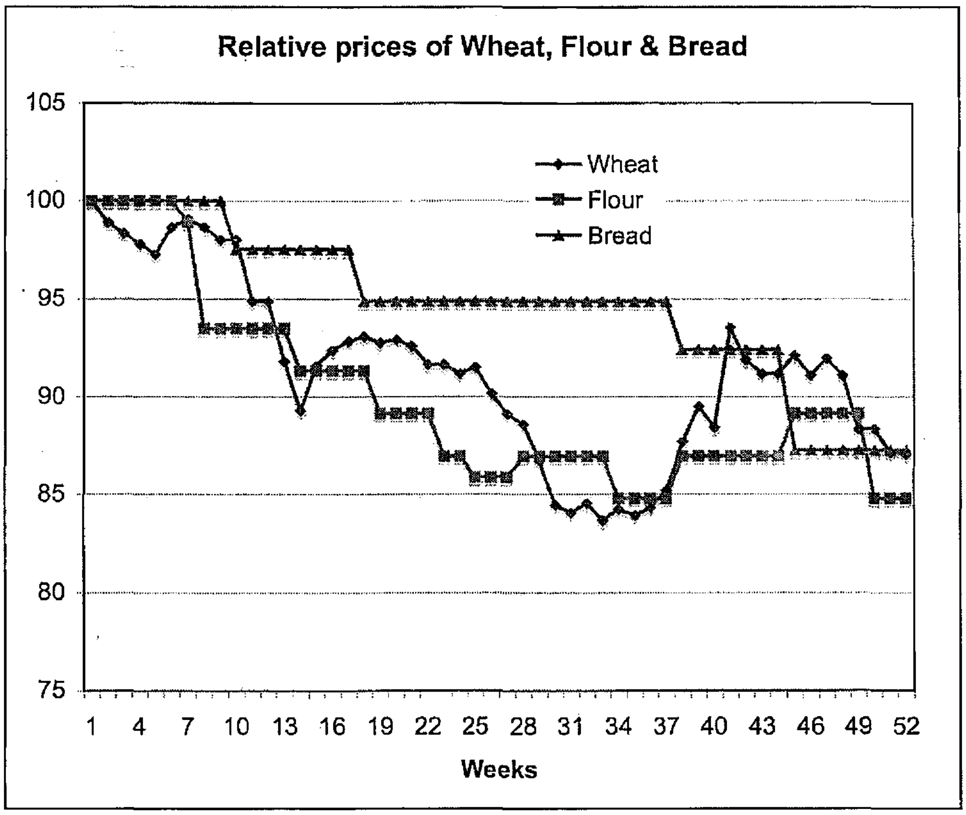
[94] *Miller*, Letters: reply to 669, Mar 1, 1880, p. 45-46; Apr 5, 1880, p. 119; See also Kirkland, 'Bread prices': p. 481, for yet another example of grist mixture.

[95] E. Jones, 'The role of information in US grain and oilseed markets', *Review of Agricultural Economics* 21 No. 1 (1999): pp. 250-51.

Figure 6.7



Source: Based on price data reported for 52 weeks between Mar 1894 and Feb 1895 in Kirkland, "Bread prices," 481-82

differentials between the individual varieties due to the blending of flours. The miller had to balance his margins according to the price of bread and the price of wheat. Comparing the price of flour to the price of bread and wheat over a 52-week period between 1894 and 1895, we see the degree to which the millers had to manage this balancing act. Figure 6.7 compares the price of wheat to flour assuming that the following mixture of grains is used to make the grist: 30% each of No. 1 Spring American and Fine Russian and 20% each of Red Winter and Fine English. Moreover, millers were often forced by competition to sell flour at less than its value as compared to wheat or to the corresponding quality of the flour to make its price remunerative.[96]

The foregoing discussion highlights the significance of assessing wheat quality to the miller. As the milling process became more specialized and sophisticated, the

[96] Kirkland, 'Bread prices': pp. 481-2.

differences in quality between varieties as well as the *consistency* of quality in a given variety became crucially important. Measuring quality was necessary to achieve the desired quality of flour, and to enable the millers to remain profitable. How did the millers measure the quality of grain?

Throughout most of the nineteenth-century millers relied upon the visual inspection of samples to purchase grain, the attributes of relevance being the density, colour, texture, and the extent of cleanliness. When the volume of imported grain increased and the number of varieties available multiplied, the millers, like the merchants, began to rely upon the grades and standards set by the various commodity associations, such as the LCTA or the Liverpool Corn Trade Association. The correspondence between millers presented above regarding the different varieties and grades of wheat is indicative of this shift. We discern a trend of shifting reliance from visual inspection and assessment of quality to a gradual acceptance of the grading and standards developed by the various commodity associations. Millers purchasing domestic grain continued to do so based on older techniques of visual inspection and natural weights, although the importance of domestic wheat had diminished by the twentieth century; only about 19 percent of home grown wheat was used for bread making by 1914, down from 60 percent in c1860.[97]

Notwithstanding this shifting reliance on grades, assessing the quality of grain still depended upon the 'empiricism of the practical miller'.[98] The following extract from *The Miller*, c1875 is illustrative:

> 'In purchasing wheat and choosing the description necessary to secure a uniform brand of flour, millers must often feel the want of a reliable test to guide them. It requires a very long and constant experience to judge the quality of even those wheat appearing daily in our markets; but we are left with the most unpleasant uncertainty when new descriptions are introduced to our notice.'[99]

By the last quarter of the nineteenth-century, techniques for assessing the quality of wheat were still fairly uncertain. One expert wrote in 1890 that 'it will be well for mixing purposes to consider wheat as coming under one of three heads – strong,

[97] Perren, 'Flour milling': p. 425, table 1; Jones, *The millers*, p. 59; Percival, *Wheat*, p. 71.

[98] Jones, *The millers*, p. 61.

[99] *Miller*, Oct 4 1875, 'The study of a method to meet the requirements of millers in the analysis of wheat and wheaten flour', p 196-7.

colour or neutral (*sic*)'.[100] He further pointed out that wheat buying was governed by experience, general principles and by what varieties of wheat happened to be available in supply. After 1880, changes in milling technology were accompanied by development and improvements in testing and measuring the different quality attributes. The increased understanding of the chemical composition and properties of gluten, the substance in grain that lends strength to the flour, aided these developments. Various testing methods and instruments were made available for assessing the quality of flour: Pekar's method of assessing whiteness of flour, Boland's aleurometer to test the strength of gluten, and Robine's method for estimating quantity and likely bread output are some examples.[101] Even so, each miller had to discover for himself the strength of any given flour, as there was 'no satisfactory method of numerically registering strength except through a baking test'.[102]

To summarize, the milling industry, towards the end of the nineteenth-century required more sophisticated ways of assessing the quality of wheat compared to the relatively crude test of natural weight measurements. The millers sought to capture the grain composition in more explicit terms of gluten and protein content rather than the simplistic notion of density. The millers were beginning to rely upon the grades established by LCTA to assess the condition of grain reaching Britain. This was an iterative process with the grading of quality helping the milling industry to become more professional, which in turn, and in conjunction with other changes in the industry, required further refinement of the quality grades themselves. The industry thus played an important role in the standardization of *ex ante* assessment and guaranteeing of wheat quality based on its composition and condition. Even so, assessment and testing on the basis of performance criteria remained the miller's responsibility. The millers had to rely upon baking tests and other measurements to ascertain quality *ex post*.

6.5 *Natural Weight of Wheat: An example of Quality Measurements*

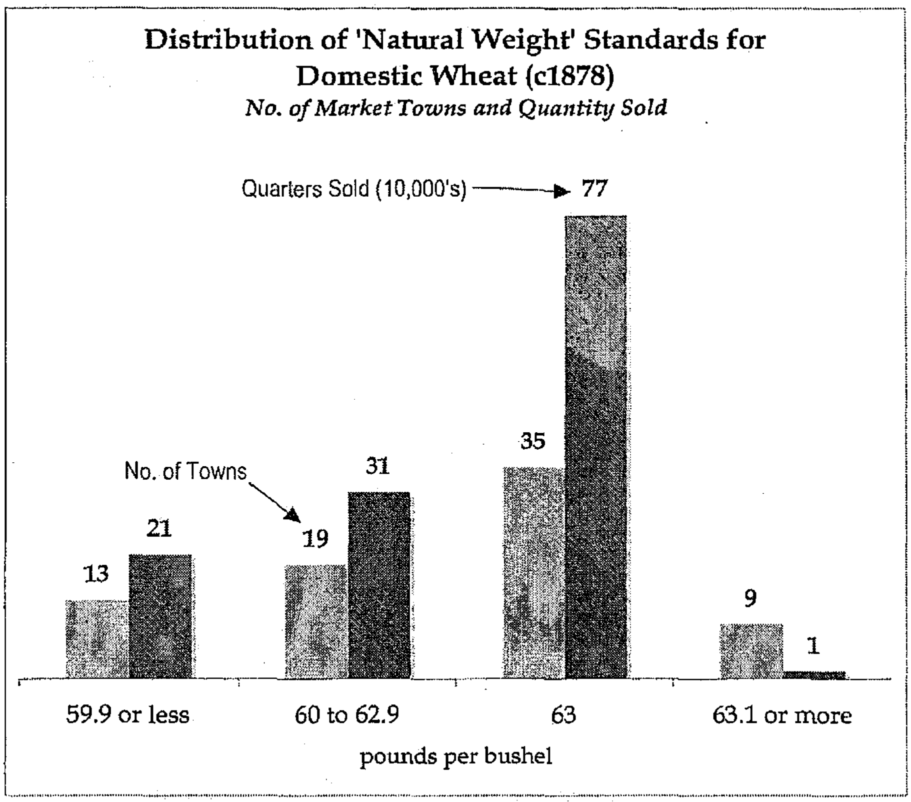
This section uses the example of natural weight measurements to illustrate how one important set of measurements, which were the *de facto* attributes of the composition

[100] W R Voller, *Modern flour milling*, Gloucester, 1889, as cited in Jones, *The millers*, p. 59.

[101] Jones, *The Millers*, pp. 59-61.

[102] Jago and Jago, *Breadmaking*, p. 291; also, Jones, *The millers*, pp. 60-61.

Figure 6.8



Source: PP 1878-79 LXV

of grain, diminished in importance and were used inconsistently across the various trade routes characterizing this trade. It investigates how and why it was difficult to 'fix' or 'standardize quality measurements and how the trade struggled to develop grades on the basis of such fixed measurements. It examines the role of institutions in influencing quality measurements based on a particular attribute, and how they could influence its importance in the overall mensuration activity.

As seen earlier, natural weight measurements were used to approximate the density of wheat and distinguish between different varieties of grain. The differences in the natural weight measurements functioned as numerical grades signifying the relative differences in wheat quality in terms of their flour making ability; the higher the density the better the quality of flour obtained (table 6.1). This was a *de facto* grading system that emerged before commodity exchanges began establishing formal or numerical grades. It was also a practical system that the trade relied upon to make a rapid and straightforward assessment of quality.[103] There was a wide variation in

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[103] *PP 1834 Vol. VII*, p. 87, evidence by Patrick Stead, a corn merchant.

terms of the natural weight of wheat sold in the domestic markets. It ranged from 470 to 512 *lbs* per quarter, that is, 58 to 64 *lbs* per *bushel* (see figure 6.8). In the late 1870s approximately sixty percent of the domestic grain was sold on the basis of 63 *lbs* per *bushel,* about twenty percent was sold according to the *bushel* weighing between 60 and 63 *lbs,* and another fifteen percent was sold according to the bushel weighing less than 60 *lbs.* These estimates were reported on the basis of the weight of the Imperial bushel in pounds by the Corn Inspectors, and assuming that many markets continued to use customary measures, the extent of variation is likely higher than reported here. Foreign wheats showed a similar variation in terms of their natural weight as compared to the domestic varieties grown in England. A comparison of thirty-five distinct varieties of foreign wheats sold in Britain with twenty-five domestic varieties suggests that on an average the natural weight of foreign wheat was somewhat lower than the domestic varieties (see figure 6.9).[104]

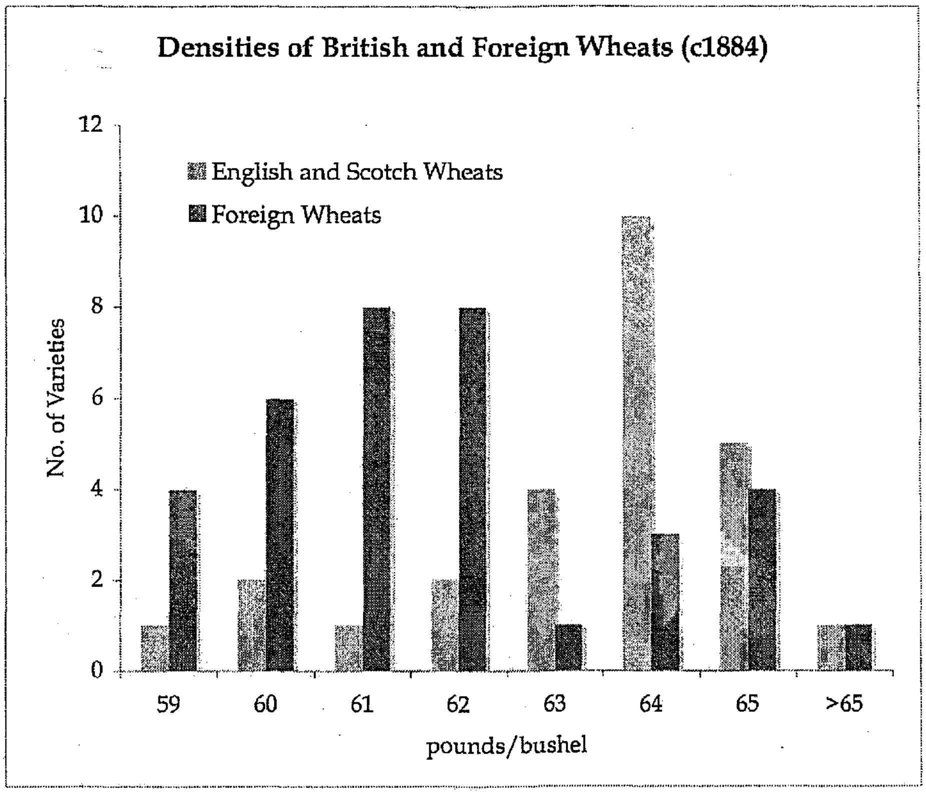
The density of a particular variety of wheat was notoriously difficult to maintain, as it was sensitive to climatic and other conditions.[105] Even under controlled conditions variation in the natural weight of a specific wheat variety on the same plot could vary over time (table 6.1). Thus, variation in natural weight occurred not only across different varieties of wheat, but also across years and different conditions for the same variety. This implies that the degree of control that the farmer had on this particular attribute was limited by a variety of factors, many of which were beyond his control. This was exactly what the system was designed to capture: variations in quality from one season to another for the same variety or between two stocks of the same variety.

However, variation in natural weight estimates could also be a result of the manner in which the volumetric measurements were made. British grains with the highest densities did not always register the highest natural weights. This was due to the shape of the grain itself, which left empty spaces - or large volumes of air in between the grains - when the *bushel* measure was filled. Also, the reliability of this estimator of quality was greater when relatively uniform varieties of wheat were involved, as in the case of American spring and winter wheats. The intrinsically problematic

[104] Jago and Jago, *Breadmaking,* pp. 273-79.

[105] *Miller,* Mar 1 1880, p. 109, 'Chemistry of Breadmaking - Part III: Lectures by Prof. Graham. Refer to table by Lawes & Gilbert showing influence of seasons on the character of wheat crops.

Figure 6.9



Source: Based upon analysis reported in Jago and Jago, 'Breadmaking', 273-79

nature of British wheat meant that high density did not necessarily translate into high natural weights.[106]

This could be overcome by packing the grain in a compact manner into the bushel measure. 'Closely filled' grain would increase the natural weight estimate compared to 'loosely filled' grain in the same volume. The height from which grain is poured into the measure determined whether grain was loosely or closely packed: the greater the height, the closer the grain was packed, and hence greater the weight per volume when measured.[107] In addition, the practice of heaping increased the amount of grain that could be packed into a *bushel* measure, by as much as one-eight to one-

[106] Walton, 'British cereals': p. 51; A. S. Wilson, *A bushel of corn* (David Douglas, Edinburgh, 1883), p. 21.;

[107] Issac Roberts, 'Determination of the Vertical and Lateral Pressures of Granular Substances', *Proceedings of the Royal Society of London*, Vol. 36. (1883 - 1884), pp. 225-240, p. 240; Kula, *Measures and men*, pp. 47-49; A. D. C. Simpson, 'Grain packing in early standard capacity measures: Evidence from the Scottish dry capacity standards', *Annals of Science* 49 No. 4 (1992): pp. 342-44; Also *PP 1834 Vol. VII*, Appendix 12; R. T. Balmer, 'The operation of sand clocks and their medieval development', *Technology and Culture* 19 No. 4 (1978): pp. 615-32.

quarter. The extent of the heap in turn was dependent upon the physical shape of the vessel. The flatter the vessel, the greater the volume of the heap would be and vice versa.[108] Even when the bushel measure was not heaped, the method used for 'striking the grain', that is ensuring that grain was filled only to the brim of the measuring vessel and no more, could make a difference. Experiments conducted around c1830 confirmed that when the same variety of wheat was 'stricken' using a round cylindrical roller as opposed to a flat ruler, the difference in natural weight could be as much as 6 *lbs* per bushel (56 *lbs* instead of 62 *lbs* respectively).[109] As the quantity of grain measured varied due to differences in measurement practices, this affected the natural weight estimates, irrespective of the quality of the grain.

Thus, variation in natural weight estimates was a result of the variation in the density of individual ears of wheat as well as due to variability of measurement practices. In other words,

$$w_n = f(d, m)$$
$$d = f(v_w, E, T, S)$$
$$m = f(p_{(l,c)}, h, s_{(r,f)})$$

where w_n captures the variation in natural weight, d captures the changes in density of grain and m captures changes due to the prevailing method of measurement. The density estimate was dependent upon the particular variety of grain v_w, the environmental conditions E (such as quality of soil, climatic and other geographical conditions, etc.), the method of cultivation or the level of technology T,[110] and other social factors S (e.g. civil disturbances, political instability, etc.).[111] The variation due to method of measurement was dependent upon whether the grain was loosely or closely packed ($p_{(l,c)}$), the extent to which heaped measures were provided (h), and the method of striking grain if the measure was not heaped ($s_{(r,f)}$). Thus, without understanding the measurement practices, or indeed standardizing them, it was difficult to separate the effect of changing quality of wheat on its natural weight measurements. This unpredictability or inconsistency of natural weights was

[108] Connor, *English Measures;* Kula, *Measures and men*, pp. 49-51.

[109] *PP 1834 Vol. VII*, Appendix 12.

[110] Changes to natural weight due to cultivation technology are discussed on page 186.

[111] The basis of this is the report by Prof. Graham appearing in *Miller*, Mar 1 1880, p. 109, 'Chemistry of Breadmaking – Part III.

certainly known by c1880, if not earlier, and trade journals were disseminating such information to millers.[112]

The use of natural weights as a basis for setting contract terms during the nineteenth-century was complicated by the multiplicity of units used to make such measurements. Some markets used load per quarter, or stone per quarter or pounds per quarter, other markets measured in bushels, still other used gallons, coombs, bags, bolls, sacks and centals.[113] Even the configuration of the volumetric units themselves differed across markets. The smaller Winchester bushel, preferred by the state before the nineteenth-century, was not acceptable to the merchants and growers in the southwest where a larger bushel measure was used.[114] In Cumberland, the bushel used was the Carlisle bushel, which was three times the size of the 'ordinary one'.[115] Similarly the definition of stone and load too differed across the markets.

Throughout the nineteenth-century, there were numerous (unsuccessful) attempts made to standardize the sale of wheat, either on the basis of weight-only or volume-only measurements.[116] The question of how much should a *bushel* of wheat weigh continued to dodge the trade throughout the nineteenth-century. The state dealt with the multiplicity of customary measures by requiring the corn returns to be expressed in terms of Imperial *bushels*, even if grain contracts were made using local measures. In fact, early nineteenth-century legislation specified fixed weight equivalents of grain for both the Imperial as well as the Winchester *bushels*, whereas in later legislation the weight equivalents are specified only for the Imperial *bushel*.[117] As far as the corn returns were concerned, in c1820 the natural weight of wheat was assumed to be 59 pounds per bushel, that of barley was 51 pounds, oats 37 and rye 57 pounds per imperial bushel.[118] Throughout most of the nineteenth-century, the state interest in standardizing grain measurements reflected its endeavours to

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112 *Miller*, 1880 (Vol. 6), p. 109.

113 Fay, 'Corn sales'; *PP 1834 Vol. XLIX; PP 1878-79 Vol. LXV, Summary of Returns.*

114 Sheldon et al., 'Customary corn measures'; Fay, 'Corn sales': p. 212.

115 Fay, 'Corn sales': p. 216.

116 *Parl. Deb.*, Apr. 27, 1858; May 18, 1858; July 4, 1859; *PP 1868-69 Vol. II, Bill to Establish Uniform Measurement in the Sale of Corn*, p. 5; *PP 1883 Vol. II, Bill to Ensure Uniformity of Weight in the Sale of Corn*, p. 193; and other such Bills as included in *PP 1890-91 Vol. I*, p. 427; *PP 1898 Vol. I*, p. 381, etc.

117 *PP 1834 Vol. XLIX*; Order in Council under Corn Returns Act, 1882, reproduced in *PP 1888 Vol. X, Report of Select Committee on Corn*, p. 134 ff.

118 *PP 1834 Vol. XLIX.*

accumulate, as consistently as possible, the average price of grain in domestic markets through the corn returns. As long as these returns are seen to be capturing fluctuations in grain prices, the use of local measures as well as measurement practices was left undisturbed. This is confirmed by the following extract from a memorandum from the Comptroller of Corn Returns:

> "The maximum error which may arise through sales being made by weight instead of by measure, or by weight and measure combined, and the improper return of such sales is very inconsiderable, apparently less than one per cent [and] even the existence of so much error is not proved. It is also an error of a kind that would be compensated in good seasons in consequence of the Imperial [bushel] weighing more than the customary [measures] by which sales with weight and measure combined are made."[119]

By requiring that all grain measurements be reported in standard measurement units, the issue of 'how much quantity did a bushel of corn contain' was resolved rhetorically at level of the state, even though at the transactional level the use of multiple measurement units continued as before.

A parliamentary select committee of 1834 had concluded that the standard measure to be used throughout all markets for the sale of grain should be a combination of weight and volume measurements as 'the combination may be used for the purpose of identification [of quality, as well as] employed as the standard of quantity.'[120] Nevertheless, disagreements as to the significance of measuring by natural weight continued within the trade. Some groups claimed that natural weight measurements were actually weight measurements, whereas others countered this by claiming that they were actually volume measures qualified by their weight equivalents.[121] Both volume-only and weight-only measurements for grain each had their strong proponents throughout the nineteenth-century.[122] Merchants from the south preferred the sale of corn by volume-only measurements, whereas merchants in the

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[119] *PP 1878-79 Vol. LXV, Memorandum by comptroller of corn returns*, p. 134, memo to the Board of Trade in 1879.

[120] *PP 1834 Vol. VII*, p. xxvi.

[121] *Parl. Deb.*, Apr. 27, 1858.

[122] *Parl. Deb.*, Apr. 27, 1858; May 18, 1858; July 4, 1859.

north preferred the sale by weight-only measurements, especially in markets such as Liverpool.[123]

By the late 1870s, several merchant groups had come to prefer weight-only measurements. There were some debates within the trade around c1878 as to which metrological unit – the *hundredweight (cwt)* of 112 *lbs* or the *cental* of 100 *lbs* – should be regarded as the standard.[124] The *cental* became popular around Liverpool and was used for a brief period on the US-Liverpool trade routes. However, its use diminished towards the end of the century, and the trade mostly used the Imperial weight units such as the *bushel, pound* and the *cwt* (see chapter 2). In fact, the *bushel* came to be used primarily as a unit of weight and not of capacity in the wheat trade. Sale of grain by the bushel assuming a weight equivalent was thought to be 'nominally by measure of capacity, but in reality by weight'.[125] By c1890, most within the trade had come to prefer the weight-only measurements for the sale of grain in general.[126] The Corn Sales Act of 1921 eventually made it mandatory to sell grain by weight-only measurements. This mirrored the shift in mensuration practices that had already occurred sometime in the late nineteenth-century and the declining importance of the natural weight measurements within the trade in general.

The foregoing discussion highlights several important issues for consideration. Before the advent of commodity grading, natural weight measurements were crude, practical, and relatively straightforward indicators of grain quality. They were both numerical and quantitative and served as *de facto* grading attributes. They were used in conjunction with inspection of several other attributes that revealed the condition of grain: natural weight measurements captured only the composition aspect. Such measurements were inherently unreliable primarily because the variation in natural weight could be the result of factors influencing the measurement methods. Such effects were difficult to isolate without knowing the manner in which measurements were made in a specific context. Even where measurement techniques could be standardized (pouring grain into the measuring vessel from a standard height, or

[123] *Parl. Deb.*, May 18, 1858; July 4, 1859.

[124] TNA, BT 101/43, extract from J E Beerbohm's *Evening Corn Trade List*, dated Nov 5, 1878 p. 7; BT 101/49; BT 101/127.

[125] *PP 1893-94 Vol. XI, Report of select committee on corn sales*, p. vii & xiii.

[126] Ibid.

using a uniform striking method, etc.) the multiplicity of measurement units in use could result in the observed differences in natural weight.

The use of natural weights as a basis of contract terms continued in domestic markets for sale of domestic wheat, as no grades were developed for such sales. With expansion of the import trade, and the demand for more sophisticated quality assessment methods, the use of natural weights in quality testing diminished by the end of the nineteenth-century. Both LCTA and CBT used several other criteria apart from natural weights to ascertain the composition as well as the condition of the grains. When the USDA was able to establish numerical grades in the early twentieth century, it did so without reference to natural weights. Natural weights declined in use as an *ex ante* quality assessment criteria, although they continued to remain an important test factor *ex post*.[127]

The issue is why did this shift occur? Why did the reliance on natural weights, a crude but largely effective indicator of quality, diminish at the same time that commodity exchanges began grading wheat? The following section analyses this issue and through it examines how changes in the trade structure - a function of organizational, technological and economic factors - affected the mensuration activity within the trade.

6.6 *Mensuration, Standards and Institutions*

This section examines the overall role of institutions in the management of quality within the wheat trade. It illustrates how institutions were important in selecting which attributes were measured to determine quality and examines the reasons underlying their selection. The section explores the role of institutions and third-party organizations in guaranteeing quality based on numerous quality measurements and standards. It further demonstrates how institutions were important in managing the mensuration activity in the absence of universal standards.

[127] For example, standard contracts developed for use in the late twentieth century by FOSFA International (Federation Of Oils, Seeds and Fats Associations Limited) or GAFTA (Grain and Feed Trade Association) include 'test weight' (or grain density) as one of the specifications in international grain contracts along with several other attributes such as protein content, moisture, oil content (for oilseeds such as soyabeans), presence of foreign material and damage to kernels.

There were two important trends in the mensuration practices within the whea trade, as far as measurement of quality was concerned. First, there were importan changes in who assessed quality and who guaranteed it. Second, there were important changes in how quality was assessed in terms of the attributes o: 'summary criteria' used to measure quality. Both the *who-measures* and *how-measured* aspects shaped the standards and measurements in the grain trade.

We have seen how the British farmers and millers favoured different quality attributes of the wheat grain. To the farmers, the composition of the grain was important in terms of its density; the lower the density of the individual grain, the higher the quantum of the yield obtained by the farmers. The composition of the grain was also important to the millers. However, they preferred the density of the grain to be higher, as it increased its bread-making ability. In addition, the millers were also concerned about other compositional attributes, such as colour, shape, and texture, as well as the condition of the grain. Practically, grain with certain 'undesirable' attributes, e.g. high moisture content, high impurities, etc., could be corrected and re-sorted into higher grades. But, grain with undesirable compositional attributes could not be corrected for. In such a scenario the buyer (e.g. millers) would be the one to measure for quality.[128] The primary logic here is that there was little incentive for the seller (e.g. farmers, traders) to sort the commodity, as the quantity - not quality - of the grain was of importance to the seller. If required, the seller would prefer to sort using as few attributes as possible. The buyer, on the other hand, preferred to sort it as finely as possible, on more attributes or at least different from those chosen by the seller. These considerations shaped the contract terms, buying practices, and quality assessment in domestic wheat markets (figure 6.3).

With the increase in import of foreign wheat this situation altered dramatically. The LCTA enabled the standardization of both product grades and contracts terms. The question is why did it begin to develop such standards? At least four arguments can be identified in the literature on commodity exchanges and quality standards. First there is the reduction in the measurement cost argument. This view suggests that because primary commodities are essentially heterogeneous, absence of product standards or quality grades would have resulted in costly, repeated and duplicative

[128] Barzel, 'Measurement cost': pp. 29-32.

examination by buyers and sellers.[129] Another view is the transaction cost argument, which suggests that standardized contract terms (that included terms regarding product quality) helped to institutionalize arbitration mechanisms and helped the 'clearing house system' within commodity exchanges.[130] The third view is the internationalization of farms argument, which suggests that commodity exchanges were instrumental in developing quality grades on the basis of which futures trading could develop. The significance of this is that a futures market could transfer the price risk to a specialized group of speculators (the broker-merchants). This helped to link local farms to the international markets.[131] Finally, there is the creation of trust argument, which supports the view that third party or 'official' grades are better able to guarantee quality than individual inspection or certification.[132] It is unclear which of these arguments could provide a satisfactory explanation for why LCTA began to develop wheat grades and standardized terms. It is likely that a combination of factors influenced the emergence of standards.

The LCTA wheat grades were based on several attributes, including natural weight, moisture content, cleanliness, and other descriptors (such as long or round berried for New Zealand corn). Other corn associations, such as the Liverpool Corn Trade Association (LvCTA) also developed such grading methods.[133] The LvCTA began establishing 'contract grades' of wheat after c1855, which differed somewhat from the LCTA. However, by the end of the nineteenth-century, Liverpool merchants were content to use the grades established by the LCTA.[134] The grades so developed were primarily for wheat imports from East Europe, Australia, South America or India. Imports from the US, with the exception of California, were graded at source and were accompanied by certificates of quality by institutions such as the CBT. But why was US wheat graded at source, while wheat from other sources was graded in the UK?

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[129] Pirrong, 'Commodity Exchanges': pp. 232-33.

[130] Ferguson, 'Commercial disputes system': pp. 144-45; Chattaway, 'Arbitration': p. 428; Forrester, 'Commodity Exchanges': pp. 201-03, the 'clearing house system' that Forrester describes refers to the activities of passing shipping and other commercial documents between traders, settlement of contracts, clearing of differences, etc. all in relation to 'string transactions', p. 203.

[131] Daviron, 'Standardization of tropical products': p. 163.

[132] Merrill, 'Grain grades': p. 61.

[133] Forrester, 'Commodity Exchanges': p. 203.

[134] Minute books of the LCTA, Guildhall Library.

The elevator-based storage system that developed in America in the latter half of the nineteenth-century enabled formal grading, and in fact required it. The grain (wheat) was graded at the point when the farmer brought it for storage at the shipping point. The elevator agent upon examining the quality of the grain settled with the farmer both the grade of the grain and its value. This grain was stored in the elevator along with grain of similar quality, thus segregating the identity of the grain parcels from that of the individual sellers. The seller (farmer) received value according to the lowest quality that the grain could be graded into. This strengthened the incentives of those shipping the grain to elevators to maintain quality before storage.[135] Once the graded grain was loaded onto ships or railway cars for transport it was nearly impossible to mix grain of varying qualities. Such opportunism problems and malpractices were possible prior to storage. The only dissipation of quality could occur due to damage caused by moisture and poor storage conditions. The incentives to maintain quality prior to shipment was high, but not during the transportation of the already graded grain. This problem was alleviated somewhat when the US government begun supplying moisture content certificates, which could then be used to compare with the actual condition of the grain when it arrived at its destination.[136]

In contrast, handling facilities for grain imported from other countries such as Argentina and Australia were extremely crude. Crude handling methods exposed the grain to varying weather and insect condition and the absence of elevators meant that it was most efficient to ship grain in bags. This made it virtually impossible to create parcels of grain of standardized grades by combining grain from individual growers prior to shipment, as was possible in the elevator based storages of North America. Further, with individual shipments retaining their identity, inspecting quality at the importing country economized on the number of measurements necessary along such a trade route. There were few incentives to prevent dissipation of quality prior to bagging and storage. But all things being equal, this system would have given the shipper an incentive to take care of the cargo at sea.[137] In such practices quality could not be guaranteed prior to shipment. The FAQ system, an *ex-*

[135] Pirrong, 'Commodity Exchanges': p. 237; J. Stewart, 'Marketing wheat', *Annals of the American Academy of Political and Social Science* 107 (1923): pp. 187-88.

[136] Pirrong, 'Commodity Exchanges': p. 237; Merrill, 'Grain grades': p. 66.

[137] This would also have depended upon the contract and shipping terms, i.e. who had the residual property rights on the cargo and who paid for insurance, freight, etc.

post method of grading, was particularly suited in these instances. It adjusted standards to reflect systematic factors affecting the quality of grain from a particular location (level of quality due to grain composition as well as condition due to storage, transport, handling, etc.), and made fewer quality distinctions between different shipments. The method minimized the number of potential disputes regarding product quality.[138] Thus, we notice that the market developed different mensuration protocols for different trade routes.

Why did the British buyer trust the LCTA (or CBT) grades? The grades developed by the commodity associations took into account the composition as well as the condition of the wheat grains, in contrast to the domestic *de facto* grading system of natural weights, which captured the compositional quality of the grain but not its condition. Earlier, buyers had had to rely upon visual inspection of samples to ascertain condition, potentially leading to disputes if the delivered stock did not conform to sample. Additionally, the associations that developed these grades functioned as quality assurance and dispute resolution centres, apart from aiding in the assessment and measurement of quality. Dispute resolution by arbitration became widespread in the latter half of the nineteenth-century as the corn trade associations set up transparent resolution mechanisms. Mostly, disputes regarding the quality and condition of grain 'occupied the time of arbitrators.'[139] Also, British associations helped to address quality problems concerning US graded grain by raising these issues directly with CBT or other exchanges.

In addition to the ability to resolve disputes over quality, the membership policies of some of these associations also gave credence to the grades. For instance, the arbitrators appointed by the LCTA in case of disputes would include millers in addition to merchants and corn factors, ensuring that buyers as well as sellers were represented in the process. At times, NABIM was also involved in the process for setting grades and often made suggestions to LCTA on quality standards.[140] Notwithstanding this, there is no denying the fact that grain traders realized the significance of wheat grades and their role in developing fungible tradable instruments. Even though, the initial reasons for developing formal grades may have been to 'economize on measurement costs in cash transactions in the physical

138 Pirrong, 'Commodity Exchanges': pp. 238-39.

139 Ferguson, 'Commercial disputes system': p. 145; Chattaway, 'Arbitration'.

140 LCTA, Arbitration Sub-committee, entry for 1896.

commodity', the development of a futures market for grain is likely to have had an influence on the nature of grades and the attributes selected to define these grades.[141] Changing mensuration practices involved a greater role for third party organizations in terms of monitoring and managing the mensuration activity. On the basis of the evidence presented here, it appears that this role was focussed more on the imported grains trade than on the domestic trade.

Coinciding with the increased role of third party organizations, there were technological changes that made it possible to de-link the delivery and unloading processes (at the ports) from the quality testing process. The changes primarily revolved around improvements in methods of discharging cargo at ports, changes in milling techniques, introduction of newer testing methods for wheat quality, etc.

Consider the method of measuring the natural weight of wheat to ascertain grain quality. Determining the natural weight required measuring the same stock of grain twice, once in terms of volumetric units and again in terms of its weight. For a bulky commodity like wheat this implied a considerable increase of effort and time at the importing ports where grain from coastwise routes as well as foreign grain was unloaded. Towards the beginning of the nineteenth-century, grain transported on ships would usually be put into sacks in order to ease its removal from the ship's hold, and also during delivery on the wharves. This process involved using the bushel (or some other volumetric) measure, as each sack was expected to hold a specific capacity; for example, the sacks in Liverpool would usually contain four *bushels* each.[142] If grain had to be weighed, it was done once it was sacked and hoisted on to the deck. Each sack, or a sample of sacks, would then be weighed using scales to arrive at natural weight measurements.[143]

Changes in the transport and discharging technology in the latter half of the nineteenth-century altered this unloading process. The sacking process in UK ports could partly be eliminated when foreign grain began arriving in sacks. Grain from India and Australia would be packed in twill bags and could support repeated

[141] Pirrong, 'Commodity Exchanges': pp. 233-34; this inquiry is tangential to the study here is therefore beyond the scope of this research.

[142] Once Liverpool switched to weight-only measurements c1860, sacks would normally be the equivalent of 280*lbs* each, a unit preferred by the baking trade; Dumbell, 'Corn sales': p. 142; Broomhall and Hubback, *Corn trade memories: recent and remote*, p. 24.

[143] *PP 1834 Vol. VII*, pp. xix-xx.

handling and did not require re-bagging at British ports. But, grain arriving from Argentina and the Pacific coast of North America often had to be re-bagged.[144] The introduction of pneumatic elevators in the 1890s further made the sacking process redundant. Grain could be vacuumed from the ship's hold and poured onto scales for weighing, from where it would eventually be discharged out of the ship.[145] At the end of the nineteenth-century, foreign grain was mostly sold using weight-only measurements.[146]

Another important technical development that helped to separate the delivery/unloading and quality testing process was the introduction of instruments that could measure the density of grain directly, such as the chondrometer or grain-tester. This portable mechanical device helped to reduce measurement costs by directly measuring the specific gravity of grain using a steelyard of unequal arms and a copper or brass container of known density.[147] The appeal of such an instrument was that the density of grain could be estimated without measuring grain twice - at first its volume and then its weight. The major drawback of such an instrument was that it could only determine the specific gravity of small samples of 'not more than half a pint.' However, when these instruments were used in conjunction with grain hoppers, this drawback of testing small quantities could be overcome.[148] In this manner, in the latter half of the nineteenth-century, it became possible to separate the process of grain delivery/unloading from the process of quality assessment.

The significance of this is that measurements of the wheat's compositional quality, i.e. its density, were no longer technically interrelated with measurements of quantity i.e. amount of grain exchanged. Quality measurements used in the grades did not have to be physically made during the time of delivery and unloading. This made the FAQ system of grading practically feasible, and may have resulted in less

[144] B. Cunningham, *Cargo handling at ports: A survey of the various systems in vogue, with a consideration of their respective merits* (Chapman & Hall, London, 1923), pp. 4-5.

[145] H. V. Driel and J. Schot, 'Radical innovation as a multilevel process: Introducing floating grain elevators in the Port of Rotterdam', *Technology and Culture* 46 (2005): p. 63. Prior to the use of such pneumatic elevators, bucket elevators were used in places such as Glasgow, Cunningham, *Cargo handling; PP 1834 Vol. VII,* p. xx. However, only once the pneumatic elevators became widespread could large volumes of grain be discharged effectively in much less time.

[146] *PP 1893-94 Vol. XI, Report of Select Committee on Corn Sales,* p. iii.

[147] *PP 1890-91 Vol. XII, Report of Select Committee on Corn Sales,* p. 53-54.

[148] *PP 1890-91 Vol. XII,* p. 54-56.

overall costs of measurement and unloading. Diminution of the interrelatedness thus influenced significant changes in the mensuration activity: it changed the protocols in terms of who measured what, and at and what stage of the commercial process.

The professionalization of the milling industry, reviewed earlier, also influenced the mensuration activity to a great extent. Changes in milling technology, science (primarily in chemistry) and education also influenced quality measurement practices. Scientific study of the wheat grain and the nutritive value of its different parts focused on understanding the chemical and physical properties of its proteins, especially gluten.[149] An increased understanding of the chemistry of wheat and advances in testing increased the sophistication of quality assessment techniques in comparison with the relatively crude and unreliable estimation of quality using natural weight measurements. This was accompanied by an increased effort to educate millers in the 'science of milling'. The NAIBM organized meetings, presentations, symposia, technical classes, etc. to increase the awareness of these methods and further the practical requirements of retraining mill staff.[150] The millers had begun to use the terminology of the grades. Nevertheless, they continued to test the grade quality independently, governed by experience as well as new science of milling and bread making.

What was the significance of the three trends - the development of third party grades, separation of quantity and quality grades, and the sophistication of quality testing by buyers such as millers? The complexities involved in the quality assessment and control were managed through the involvement of third party organizations by the end of the nineteenth-century. This was a form of coordination that the market adopted to make the monitoring and guaranteeing of quality more manageable and effective. Third party coordination of measurements of multiple product attributes involved changes to many different aspects of the mensuration activity: instruments, standards, protocols, etc. Also, different groups developed methods to capture different aspects of the product's quality, be it compositional, conditional or functional aspects. There was no one way of capturing information about the products quality and this was reflected in the different mensuration practices by the millers (buyers) and the trade (sellers). There were differences in

[149] H. Chick, 'Wheat and bread: A historical introduction', *Proceedings of the Nutrition Society* (1957): p. 3; Jago and Jago, *Breadmaking*, pp. 272-73 & 369-70.

[150] Jones, *The millers*, pp. 150-56; Tann and Jones, 'Technology and transformation': p. 68.

mensuration between different groups of traders: US sellers versus rest of the exporting countries, domestic versus importing merchants, etc. Finally, this meant that the trade did not use standardized mensuration practices as far as quality measurements were concerned. The attributes measured, the standards used, the measuring instruments and the measurement protocols all seemed to vary. This is not to imply that few standards existed – on the contrary, we detect an increase in the use of many different kinds of standards (product grades, instruments, metrological units, etc.). Coordination between these various practices was often achieved through market institutions and third party organizations.

6.7 *Conclusions*

This case study highlights three important aspects of standardizing measurements in a historical context: the complexity involved in the mensuration activity, the multiplicity of standards within the mensuration activity, and the role of market institutions in the mensuration process.

As this chapter had shown, the question that the wheat trade faced was which set of product attributes captured *ex-ante* the important aspects of wheat quality? Addressing this involved making a choice of attributes to be measured: abstracting from a menu of possible measurements a finite set or basket of attributes to convey information about the commodity. The selection of attributes depended upon the institutional context, i.e. who measured and what aspect of quality (compositional, conditional or functional) was important to different groups within the trade. Thus, not only was there no single product attribute that could be measured for quality, but different groups considered different sets of attributes important to capture the information that was relevant to them. This fact implies that within the wheat trade, for the purposes of measuring quality, there were different mensuration practices that different groups would depend upon.

Managing quality in such a context meant ensuring that 'facts' about quality circulated within the trade, irrespective of which mensuration practice was used. Conventional view would lead us to expect a high degree of standardization to ensure this. However, this chapter has shown that although the use of standards increased, there was a lesser degree of standardization in the sense of *uniformity* of artefacts and practices. Instead of rationalization from many to few standards, we notice the introduction of several new and specialized standards. A highly complex commodity trade developed a highly complex system of quality measurements managed through a highly complex set of mensuration practices.

The use of many standards and different mensuration practices implied a greater degree of coordination between 'people and things'. The role of institutions was very important in this aspect. Markets developed solutions to several prickly coordination issues. From a historical perspective, this should not be a surprising result; institutions emerge to guide and coordinate activity, and to reduce transaction problems. In the context of the wheat trade, the solutions took different forms: third party monitoring of certain mensuration practices, setting of product standards and grades, developing governance mechanisms (arbitration and dispute resolution), offering guarantees, etc. Institutions helped to develop specific protocols for particular situations and helped to select the basket of attributes to be measured.

Finally, the interesting aspect of this case study is the relative absence of the state in directing the changes to the mensuration activity: relative because the state's influence was not completely absent. Several groups within the state attempted to influence or regulate the metrological units used by the trade; parliament, state departments (agriculture, treasury, etc.), Board of Trade, etc. had all variously tried to standardize metrological units used by the trade. However, as far as the mensuration activities surrounding quality were concerned, there is no evidence of direct state participation similar to that described in chapters 4 and 5. Measurements of quality were mostly managed by markets and market institutions.

Chapter 7

Measurements and Transactions: Some Conclusions

This study fills an important historiographical gap in our understanding of how markets managed measurements in transactions. It differs from existing historical accounts by studying the different ways in which markets sought to make measurements reliable in particular contexts, rather than tracing the changes in the metrological standards they used. The existing view in the historiography of markets, transactions and measurements is that the standardization of weights and measures made measurements reliable, simplified economic transactions and reduced transaction costs, as I show in chapter 1. In this thesis, I propose an alternative historical view by making a distinction between mensuration (the practice of measurement) and metrology (the system of weights and measures). This distinction allows me to show how markets linked macro-level metrological standards to micro-level measurement issues through mensuration practices. It was these practices that determined whether measurements were reliable or not. Understanding mensuration practices is therefore the key to understanding how markets managed the measurement issues.

This thesis also makes an important contribution to the historiography on markets, transactions and standards. Thematically, the study explores the extent to which standards made measurements reliable, whereas conceptually it helps to distinguish between two types of standardization processes. One type of standardization, that the existing literature has dealt with extensively, concerns the development of a 'standard' – metrological, product, technical, etc. This study also deals with a different type of standardization, that of developing 'standardized practices'. The important distinction between the two types is that while 'standards' value inflexibility and rationalization (the number of 'values' or 'states' they can exist in), standardized practices incorporate a number of such 'standards' and a degree of flexibility as to which 'standard' to use in a given context. This distinction becomes evident if the metrological standards discussed in chapter 2 are set against the mensuration practices discussed in chapters 4 through 6. In my view, this distinction should have an implication on how the standardization process is dealt with analytically. Real markets do not use particular standards in isolation, but in conjunction with other standards, instruments, tools, etc. Understanding standardized practices in important in unravelling how markets use standards to manage transactions.

Apart from these broad contributions, more specific conclusions can also be drawn from this study. In terms of understanding mensuration practices, this study suggests that there were multiple ways of managing transactional issues stemming from measurement problems. Apart from standardized metrology, markets adopted a variety of strategies that involved improved governance of transactions through regulation, standardized contract terms, third party monitoring of measurements, quality grading and product guarantees, etc. In all the three case studies, markets sought to develop mensuration practices that formalized protocols regarding the selection of product attributes to be measured, the appropriate measurement methods, metrological standards and measurement instruments, and the manner in which observations were to be contextualized.

For example in the case of the London coal trade (chapter 4), the market groups debated whether quantity measurements should involve the estimation of the commodity's weight or its volume and whether the measurements should be done by third party 'monitors' that were publicly appointed by the City of London or not. In the case of grain quality (chapter 6), different groups preferred different product attributes to be measured to assess quality, and the measurement function was 'outsourced' to third party organizations, which coordinated between the various different mensuration practices. Even so, grain buyers and merchants developed different mensuration practices to measure wheat quality, such as product grades and new instruments to measure hitherto un-measurable attributes. The debates regarding standard wire sizes (chapter 5) revolved around the use of appropriate – to each group – measurement instruments and methods, even though there was consensus on the metrological standards that were used. Measurement reliability could be ensured if the product was relatively standardized on the basis of a uniform system of sizes to be measured in a particular way by all groups within the industry.

Such examples from the case studies highlight the importance of understanding the various different strategies that were adopted in markets to manage product measurements. The management methods and mensuration practices were shaped by the decisions that different groups - buyers, producers, merchants, the state, etc. - sought to make, the incentives facing them and their relative bargaining power; in short, they were shaped by conflict and the manner in which that conflict was resolved.

The study has provided some interesting insights into the dynamics that tie together markets, transactions and measurements. For instance, mensuration practices can be understood as 'institutional packages' that were comprised of standardized processes, instruments, standards of comparison, and rules, regulations and protocols that governed the mensuration activity as a whole in specific situations. This view of an institutional package is somewhat different from the one proposed by Sheilagh Ogilvie, to whom an institution is a package of both efficient and inefficient activities.[1] I characterize the package in terms of its form, rather than its function - but I do acknowledge that mensuration practices could do both efficient and inefficient things. Moreover, Ogilvie's institutional packages also account for an interlinked institutional system, rather than individual institutions. Such a system also considers the interplay between inward beliefs and institutional rules, an issue that was discussed in chapter 3 with regard to contextualization. My concept of an institutional package - in the context of mensuration practices - is narrower and more micro in contrast, stressing the interconnections between rules, artefacts and people.

If my view of institutional packages reflects historical mensuration practices, then the following inferences can be made on the basis of the evidence from the case studies. When mensuration practices were altered, it involved making changes to many of the components of the institutional package. In the case of the London coal trade, for instance, changing existing mensuration practices involved making changes to the manner in which coal quantities were measured; from recording its volume to estimating its weight, from public metering to self-monitoring of quantities, discontinuing the use of heaped measures, etc. It also involved making changes to the metrological standards in use; change in measurement units from volume to weight, discontinuing the use of local units, etc. Such changes required the development of new technology to weigh coal on the colliers before unloading. Thus, changes in mensuration practices involved changes in protocols, standards, measurement instruments, etc.

[1] Ogilvie, Economic institutions, p. 668.

Similarly, mensuration practices in the wire trade required a fundamental change in the manner in which sizes of metal wire were used. From the practice of using distinct gauges (as a system rather than as an instrument) for wires made of different metals, or by different producers, or in different locations, the change involved using a single gauge for all metals and all British producers. It also involved developing a fixed series of wire sizes that were expressed as linear measurements using decimal sub-divisions of the inch; a standard that was a departure from older industry standards. Mensuration practices became regulated (change of protocols) even as the wire gauge became a legal standard and hence enforceable through legislation.

In the case of the grain trade, protocols required that different attributes were to be measured by different groups or on different trade routes, and third party guaranteeing of quality measurements became an industry norm. Simultaneously, product quality grades and standards were developed along with standardized contract terms regarding quality measurements, and newer measuring instruments were developed to measure the various different quality attributes that could not be measured previously.

The study also shows that changing the 'package' was an endogenous micro-level process of institutional change. The mensuration changes in the coal trade were not motivated by any technical necessity or technological developments occurring at that time in metrology. They were largely endogenous to the industry to solve micro-level transactional issues. The manner in which it was done involved institutional processes that presented different incentives to the groups that were involved. The case of the wire gauge and the changes occurring in that industry is comparable. Transactional issues within the wire industry, not the metrological debates about the use of decimal measurement units, were the reasons underlying the changes in the mensuration practices. The standards adopted were heavily influenced by institutional factors as opposed to some abstract technical or scientific principles.

We have also seen how this 'package' could be quite resilient to change, and that changes to it could be path dependent. Mensuration practices in the coal trade remained unchanged for centuries. Even when change was first sought around c1800, it took nearly three decades to alter them. The case of the wire industry was similar. From the time that the first proposals to standardize the measurement of wire sizes to the emergence of the British standard wire sizes took about thirty years.

In this case, the changes made to the existing practices were heavily path dependent with the new sizes close to the existing one manufactured by most large producers. Changes to mensuration practices in the grain trade too spanned several decades, and the changes to them were slow and incremental. Nevertheless, in all three cases, substantial changes can be seen to mensuration activity, and the new practices seem to be quite different from those in the early years of the nineteenth-century.

If we think of the process of standardization of mensuration practices as one of creating institutional packages, then it assumes a very much broader significance than is currently found in the literature on the standardization of weights and measures. In this perspective, the historical process of standardization was not restricted to the rationalization or harmonization of the standards used in a given activity. It involved the creation of a package that managed a complex interplay between different groups, components, rules, conventions, standards, instruments, etc.

This is especially evident in the case of the measurements in the grain trade. Instead of rationalization from many to a few standards, we noticed the introduction of several new and specialized standards. The complexity of the trade required the development of a complex set of mensuration practices using several standards. Even in the seemingly obvious case of the uniform wire gauge, the non-obligatory legal wire gauge actually accommodated the existence of specialized *non-standard* wire sizes that the trade could use for special orders. In the case of the coal trade, the changes in the metrological standards did not result in the rationalization of the measurement units in use, *within the trade.* It did, however, involve harmonizing the metrology used within the trade with the new Imperial system. Nevertheless, this was never the immediate objective of either the state or the market. The changes in the practices were intended to solve current transactional issues by making measurements of coal quantities more reliable. Thus, altering or standardizing the package assisted markets to smoothen complex transactional issues.

This particular point becomes significant if we think of the historical and conceptual issues set out at the beginning of this chapter. This thesis draws a historical distinction between metrology and mensuration as well as a conceptual difference between metrological *standards* and mensuration *practices*. There is no claim here that metrology and mensuration are independent and that historically the standardization processes involving them were separate and unrelated. However, it is important to study them in an uncorrelated manner as both historically and conceptually they capture rather different phenomena. Metrological standards helped to make measurements less variable. However, mensuration practices were necessary to make them *reliable.* As we have seen in chapter 3, these two do not mean the same thing. Both these aspects are important while considering transactional barriers and market integration. In this perspective, I differ from Kula and other historians who focus on historical *metrology* to understand measurement issues in historical markets.

There is another important analytical point that this distinction between metrological standards and mensuration practices highlights. As reviewed in chapter 3, literature on the economics of standards sometimes considers standards to be tradable economic goods and analyses them accordingly. Some scholars such as Kindelberger have treated standards as public goods, whereas Romer argues that standards are non-pure private goods. The major distinction between the two is whether standards can be made 'excludable', even though they may be 'non-rivalrous'. Standards, such as metrological units, are available for use by all and their use by any one individual does not reduce the amount available to others. In this sense they are 'non-rivalrous.' On the other hand, measurements used in product or design standards, or other technical specifications could be made limited access only. They have the property of being 'non-rivalrous yet excludable.' Rivalry is a technological attribute, whereas excludability is considered a function of both the technology and institutions.[2] In this analytical framework, metrological standards may be considered as economic goods, but it is difficult to consider standardized mensuration practices as goods: they are clearly institutions. At a broader level, this implies that while considering standardization, it is imperative to be clear whether the process being analyzed pertains to 'standards' as economic goods or 'standardized practices' as institutions.

The thesis and the case studies allow us to draw other inferences too. We have seen how market institutions continued to play an important rôle in managing measurement issues in the nineteenth-century, as they had historically done in the

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[2] Kindelberger, 'Standards': p. 377 and 389 ff. He is influenced by Samuelson's characteristics of public goods, and he extends this reasoning about the non-rival nature of public goods to standards, see P. A. Samuelson, 'The pure theory of public expenditure', *The Review of Economics and Statistics* 36 (1954). Also, P. M. Romer, 'Endogenous technological change', *The Journal of Political Economy* 98 No. 5-Part 2 (1990): pp. 73-74.

period before metrological standardization. The evidence in this study shows that institutions influenced the choice of product attributes to be measured, the measurement tools and protocols to be used, and the incentives regarding why measurements were required and by whom. Such decisions were not based purely on technical or technological principles. Often, scientific rationality had to contend with economic rationality - the case of wire sizes is a good example of this.

The importance of the market institutions is underscored by the realization that there was seldom one way of measuring something; there were no 'true' measurements towards which markets had to converge to. If measurements are the contextualization of the observations made through the process of mensuration, then they depended not only upon the cognitive ability but also upon the rules of the society within which they were contextualized and the institutional framework within which they are set. There is no reason to assume that measurements became less variable and more reliable because the metrology was standardized in the nineteenth-century with the introduction of the Metric and Imperial measurement units. In fact, it was really the management of mensuration practices that enabled measurements to become complex and sophisticated, reflecting the need - due to the rapid economic growth and other changes occurring at the time - to ensure greater consistency, conformity and uniformity i.e. to ensure *reliability*. A standardized metrological system did not eliminate the need to have functioning market institutions that managed this aspect of market transactions.

There is evidence suggesting that newer institutions emerged to assist markets in managing measurement issues. For instance, commodity exchanges and trade associations developed detailed mechanisms to standardize measurements of quality or to arbitrate disputes arising from disagreements about quality measurements. The grading of commodities by third party organizations, such as the London Corn Trade Association, Liverpool Cotton Exchange, or the Chicago Board of Trade, is an example of institutional mechanisms that emerged in the nineteenth-century to manage increasingly complex measurements. The relatively crude way of grading wheat quality according to its density, gave way to more sophisticated methods that took into account several different ways of measuring quality. Similarly, the Standards Department within the Board of Trade (BoT) was not only the custodian of the Imperial measures, but also became involved in monitoring, setting and enforcing specific standards to address particular measurement issues. For instance, the BoT monitored the extent to which mechanical engineering industries used standardized screw-thread measurements developed by Whitworth. The BoT also helped to standardize specific measurement instruments such as engineering gauges and the chrondrometer – an instrument to measure the density of grain. In other cases, markets altered and adapted existing institutions. Public meters in the coal trade were replaced by private meters, continuing the institution of third party monitoring of measurements, but with considerably different rules. Commodity exchanges shifted the 'nodes' of measurement away from the physical market and acted as third party guarantors. Such institutional changes reflected changes occurring in mensuration practices, and in turn helped also helped to shape them.

We have also gained some important insights into how different groups influenced different aspects of the mensuration practices. In all three cases, we notice how different groups of producers, merchants, and buyers sought to gain control or influence different aspects of the mensuration activity, be it the protocols surrounding the attributes to be measured, the standards used for comparison, strategies for monitoring the measurements, etc. Such efforts exhibit the dynamic forces that shaped how markets managed mensuration practices throughout the period that is studied here. No one group clearly dominated the activity in any of the three cases studied. Their preferences and ability to control different aspects of mensuration were largely institutionally determined.

The study also raises important issues regarding the depth of the state's involvement in removing transactional barriers, particularly those related to measurements. The most common historical view - that metrological standardization *by the state* helped to reduce transactional barriers and integrate markets - is an awkward and clumsy generalization. The case material from the three industrial sectors presented here suggests that at times the state attempted far more than metrological standardization by getting involved in standardizing mensuration practices, whereas at other times it solved metrological issues rhetorically *for its own purposes* and left the micro-level management of mensuration to the market. This is most evident in the case of the wheat trade, where the state declared a fixed density of grains to be used in the corn returns, irrespective of mensuration practices prevalent within both local and international grain markets.

The ability of the market to seek government involvement is also evident in the case studies, supporting the view in the literature that historical markets were not abstractions of neo-classical markets (chapters 1 and 2). Rather, market groups could, and did, appeal for state involvement in order to strengthen their respective positions in the market and the state could, and did, chose to get involved or retreat from market regulation. Coal merchants lobbied the state and secured its intervention when substantial changes to mensuration practices seemed inevitable. On the one hand, the state acted to solve coordination failures by introducing regulation to alter existing mensuration practices by compelling London merchants to measure coal quantities by weight rather than volume. On the other hand, it withdrew from the daily monitoring of measurements by abolishing the public metage system. Similarly, producers and buyers of wire products appealed to the state when their negotiations regarding a uniform wire gauge reached a stalemate. The state became involved as an arbitrator to break the deadlock between the dominant market groups and secure a consensus for a uniform legal gauge. The boundary between the market and the state thus appears porous and heavily contoured (i.e. not smooth) in this context.

To end, the following extract from a parliamentary report in 1819 captures the essence of how things had changed and yet remained the same during the nineteenth-century:

> 'The standards of weights and measures being once determined, they are still liable to considerable modifications, according to the manner in which they are employed, and the state of the substances concerned; so that various directions for weighing and for measuring have been given.'[3]

This extract was meant at that time to illustrate how the state (or various monarchs) had attempted to regulate mensuration practices in the market before the nineteenth-century. It is telling that this thesis has shown how relevant this statement could be even at the end of the nineteenth-century as much as it was at the beginning of that period. Mensuration practices continued to remain important in determining how markets managed measurements.

[3] *PP Vol. XI 1819*; Appendix B, section 3: Manner of Using Weights and Measures.

Glossary of Select Terms

Conformity — This term refers to one of the ways of achieving 'sameness' in measurements and relates to how closely repeated measurements conform to a *pre-agreed value*. This assumes that groups have chosen a particular value for the measurement to assume, from a possible set of several, equally likely or 'correct', values. See ***reliability, variability, uniformity, consistency, precision.***

Consistency — This term refers to one of the ways of achieving 'sameness' in measurements and relates to how consistent measurements were *over time*. Were measurements made in a given instance consistent with measurements in previous instances? See ***conformity, reliability, variability, uniformity.***

Objectivity — This term is used in the manner that Ted Porter (1994) described it. Objectivity in science is taken to be synonymous with realism i.e. correspondence between knowledge and the world. When contrasted with subjectivity, the term means impersonality, unambiguity and an absence of arbitrariness from the standpoint of an outsider. See ***quantification.***

Precision — This is a term used in measurement science to refer to those measurements which, when quantitatively measured, cluster around a given value with little deviation or no deviation. When this tight clustering corresponds to the 'true' value of the measurement, they are considered to be both *precise* and *accurate* (see sec. 3.2.2 of main text). Measurement *error* is normally concerned with the issue of how tightly (or not) measurements cluster around a given or 'true' value. Compare ***variability, reliability.***

Quantification — This term is considered in the manner captured by the phrase *l'esprit géometrique* or the quantifying spirit. It refers to the passion or desire to measure, calculate or quantify. Although quantification involves the application of mathematical techniques, it is different from the need to express objects purely in terms of numbers. Quantification involves seeing quantities within objects, as opposed to qualities, thereby increasing precision and achieving objectivity. See ***precision, objectivity***.

Rationalization This term means reduction in a systematic manner, and when considered in the context of standards, it refers to the systematic reduction in the number of standards. This process may or may not lead to a decrease in variability among standards, or in the different variety of standards used. Similarly, rationalization is not the same as achieving reliability. See ***variability, precision, reliability***.

Reliability This term refers to the property of measurements to have a clear meaning in any given context i.e. the property of 'sameness'. This may or may not involve making measurements less variable or invariable (see ***variability***). Reliability could be achieved through a combination of factors or in a variety of ways (see ***uniformity, consistency, conformity***). It is possible for the same measurements to have different meanings (values, 'states', etc.) in different contexts. The measurement in both contexts could be reliable provided that the meaning in each context is clear. See also ***precision***.

Traceability This is a term used in metrology to refer to the property of measurement units whereby, through a chain of references established between different units, any given unit can be traced back to a primary unit defined by the metrological system; e.g. the *metre* in the metric system, or the *inch* in the imperial system. The National Institute of Science and Technology (NIST), defines traceability as the "property of [measurement] or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties" (see section 2.4.2)

Variability This term refers to the property of standards, measurement units, or any measurement estimate, etc. to assume a range of values, or to exist in a number of 'states', or to have different meanings, depending upon the context. Thus, if a *bushel* is equivalent to either 80 or 90 *lbs*, depending upon the context, the *bushel* may be considered to be a variable standard or measurement unit (figure 2.1). In this case, variability is distinct from deviation, which denotes incorrectness or error as when the standard, etc. does not correspond to a given value or state or meaning. Compare with ***uniformity, consistency, conformity.***

Uniformity This terms refers to one of the ways of achieving 'sameness' in measurements and considers if *different groups* used uniform, i.e. similar, set of practices to make measurements. Did different groups in different locations measure the same attributes, use the same tools, had similar set of rules to contextualize measurements, etc.? Compare ***consistency, conformity, variability, reliability.***

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