Metrology and the State: Science, Revenue, and Commerce

William J. Ashworth

"Natural measures of quantity, such as fathoms, cubits, inches, taken from the proportion of the human body, were once in use with every nation," taught Adam Smith in his lecture "Money as the measure of value and medium of exchange," delivered in 1763. "But by a little observation," he continued, "they found that one man's arm was longer or shorter than another's, and that one was not to be compared with the other; and therefore wise men who attended to these things would endeavour to fix upon some more accurate measure, that equal quantities might be of equal values. Their method became absolutely necessary when people came to deal in many commodities, and in great quantities of them (*1*)." Smith's comments and the rationale underpinning them became increasingly urgent toward the end of the eighteenth century.

The actual term "metrology," to describe weights and measures, was coined in the early nineteenth century by the mathematical examiner at Trinity House and the bookkeeping authority and ex–mathematical master at Finsbury Square Mercantile School, Patrick Kelly. The requirements of increased trade and the fiscal demands of the state fuelled the march toward a regular form of metrology. Measures originally gained their meaning (and practice of gauging) from the local understanding of the object being measured. For an emerging integrated national market to properly function, a reduction in the number of different types and versions of weights, measures and containers is required.

A uniform system of taxation meant accounting for foreign and domestic customary variations in weights, measures, and containers. Not surprisingly this could be a tiresome, complicated, and time-consuming process. As a result, the state's revenue activities gradually impinged upon the diversity of British and colonial metrological practices and containers and packaging, because it tried to recast such things to aid its own activities. This was not without immense opposition. Such a preoccupation was also the obsession of other European countries during this period. Measurement as such was not the primary issue; rather, it was the fact of a state-defined version, increasingly alienated from the object being gauged, being implemented over local versions that really rattled dispersed communities. The state, after all, was hardly the most trusted agglomeration of institutions, with the board of excise quite literally the least. Everyday folk may have been suspicious of state approaches to quantification, but they themselves lived by their own version, dominated by a local notion of a "just measure." To have transregional (let alone international) standardized abstract measures requires a legitimating form of knowledge, the agencies to enforce it, and a process of regional education (*2–4*). The interesting issue is not diversity but rather when diversity was seen to be a problem.

School of History, University of Liverpool, Liverpool L69 3BX, UK. E-mail: W.J.Ashworth@liverpool.ac.uk

Diversity of Meaning

Legislating for a system of regularized weights and measures was one thing, but making containers to strict specifications, that is, all the same, was another. The technology, skills, and sheer cost in manufacturing standardized casks (or packaging in general) was simply not feasible. This problem haunted all eighteenth-century attempts of imposing accurate measures like that of the bushel. How could a village Turner or Cooper correctly calculate and build an accurate representative of a bushel? What materials should be used, and what should be the relation between circumference and outer body? How could the vessel be made to avoid tampering, and how should the grain be poured into the vessel?

The heavily taxed item of coal is a case in point. It was generally sold by volume rather than by weight, and this depended upon capacity. The vessels used to measure the coal varied greatly from place to place and over time. For example, the Newcastle chaldron increased by a factor of 3 over the course of 150 years. W. D. Patlenden (*5*) claimed the changes in measures in the coal trade were because of technical developments and tax evasion. By far the largest consumer of coal was London, which received its supply from the northeast and especially Newcastle. Each shipload of coal was levied according to the number of chaldrons or keels it carried. The commissioners examining the public accounts during the 1780s complained that a chaldron was "different at different Places. The chaldron at the Port of Lading, whether Newcastle or Sunderland, is more than the chaldron at the Port of London (which is according to the Winchester Measure) in the proportion nearly of Twenty-one to Eleven (*6*)." The actual gauging was done by men known as "meters" who were appointed by the commissioners of customs. Not only could the size of chaldrons vary, but their value depended on the size of the pieces of coal and their water content. Merchants would buy their coal in lumps as large as possible and sell them in medium sizes known as "round coal." This was abolished in the Weights and Measures Act of 1835, which legislated that from January 1836 all coal was to be sold by weight only. Similar problems plagued the gauging and selling of an array of other items, including grain and salt (*5–7*).

One problem in trying to establish standards was the fact that official state institutions holding original weights and measures differed from one another. The exchequer's standards stemmed from the reign of Henry VII and was frequently the one named in legislation. A statute passed during his reign legislated that "standard weights and measures be made and sent to the several Cities, Boroughs, and Market Towns therein mentioned." This was subsequently done, but soon "the said standard weight and measures were found defective." Consequently, another statute was passed in which it was specified that "the measures of a Bushel shall contain eight Gallons of wheat, and that every Gallon contain eight Pounds Troy of Wheat, and that every Pound contain 12 ounces Troy weight, and every Ounce contain 20 sterlings, (now 20 Penny-weight,) and every Sterling, or Penny-weight, be of the weight of 32 corns of wheat that grew in the Middle of the Ear of Wheat, and that a Standard of a Bushel and a Gallon after the Assize be made and kept in the King's Treasury for ever." The new measures were thus ordered and distributed while the old ones were returned and destroyed. As a result, the exchequer now contained a standard brass bushel and a standard gallon (*8*).

In February 1696, during the passage of an extremely important bill concerned with establishing an excise duty on malt, an experiment was conducted in the presence of certain members of Parliament and several excise officers—George Tollet, Philip Shales, Thomas Jeff and probably the most authoritative economic technician and gauger of the time, Thomas Everard—to ascertain the content of the standard bushel. It was decided that the said standard should be a cylindrical vessel with a diameter of 18.5 inches, a depth of 8 inches, and contents of 2150.42 solid inches. The dimensions were rounded off to these figures to make them ''convenient… without counting to the hundredth Part of an Inch.'' This new standard for the Winchester bushel was made law in the above malt act. The excise officers also compared the standard troy weights with the standard avoirdupois weights and found that 15 pounds avoirdupois was equal to 18 pounds, 2 ounces, and 15 pennyweight troy. Hence 140 ounces avoirdupois was equal to 218.75 ounces troy. Therefore ''The Bushel, as now settled, contains 2150.42 Solid Inches…and will contain of common spring water 1134.344 Ounces Troy'' (*9*, *10*).

The measure for wine was taken from the gallon sealed at the Guildhall in London. It was officially by this measure that all wines, brandies, spirits, strong waters, mead, perry, cider, vinegar, oil, and honey were to be measured and sold. The Guildhall wine gallon was assumed to contain 231 cubic inches, whereas a hogshead was presumed to hold 63 gallons. However, following a claim made by a certain Dr. Wybard that the standard wine gallon actually only contained 224 to 225 cubic inches at the most, two general excise officers, Richard Walker and Philip Shales, made an experiment to test his claim. They carefully constructed a vessel out of brass in the form of a parallelepipedon with sides 4 inches long and a depth of 14 inches. This gave a volume of 224 cubic inches. They presented the vessel at the Guildhall in London on 25 May 1688 to an audience consisting of the lord mayor; the commissioners of the excise; the astronomer royal, John Flamsteed; the Oxford astronomer Edmund Halley; and several others. The vessel was filled with water and emptied into the old standard wine gallon, which was filled exactly. Nevertheless, ''for several reasons, it was at that time thought convenient to continue the former supposed content of 231 Cubic Inches to be the Wine Gallon, and that all Computations in gauging should be made from thence as above.'' Thus, there was no check on the gauger through a reliable standard vessel (*11*, *12*).

The gallon for wine had been defined several centuries earlier, in 1303, as a vessel containing eight tower pounds of wheat. All the subsequent legislation referred to wine gallons, which, without specifying, thus legally stemmed from this definition. The story gets even more confusing. Lord Crayford's later committee on weights and measures (1758) was curious to ascertain why customs and excise gaugers used a wine gallon of 231 cubic inches, which was 51 cubic inches less than the beer and ale gallon of 282 cubic inches. The commissioners of excise told them that they believed the difference stemmed from a memorial dated May 1688 from the commissioners of excise and hearth money to the treasury. It seems that there was some initial confusion after the results confirming the Guildhall experiment, showing the wine gallon to be 224 cubic inches. Originally the excise commissioners recommended the standard to be taken at this revised figure. Merchants soon got wind of the suggested change and enquired whether they could sell at the new standard. However, the powerful attorney general, Sir Thomas Powys, quickly ruled against any alteration because it would adversely affect the revenue (*13*). Precision and accuracy (in the sense of obtaining a constant result) was invariably a factor of legislation, commercial procedures of convention, and, vitally (as revealed here), the crown's purse.

Metrology and the State

Between 1660 and 1714, acts were passed that attempted to define the measures to be used nationwide for ale, beer, coal, corn, herrings, soap, salt, fruit, malt, cider, and perry. These were mainly excised goods clearly demonstrating that revenue concerns were one of the motivating factors. The Winchester bushel was imposed upon the malt trade in a financial act of 1701, accompanied by the claim that ''there is a great variety of Bushels and other Measures of different Contents and Gauges used…for the measuring, buying and selling of all sorts of Graine, Salt and other Commodityes…to the great defrauding and oppressing of the people.'' The same sentiments appear to be behind an act the year before concerning measures for retailing ale and beer (*14*–*17*).

All of this poses a paradox. To appear fair, taxation should be universally applied and governed by a set of standards equitably applied. However, the imposition of such measures required illiberal methods that often rode roughshod through widespread diversity. Within this context, the work of the Polish historian of metrology, Witold Kula (*18*), is particularly useful. Kula has demonstrated that, before the establishment of the metric system on the continent over the course of the nineteenth century, concrete concepts such as the finger, foot, and ell (elbow) were in everyday use. They had no abstract, standardized denomination, and accounting for the weight or measure of a commodity was a qualitative process that varied from region to region (and indeed within regions). It was a process suited to small communities and local markets. Consequently, making measures accountable to a centralized source of social authority was extremely difficult.

Accompanying the growth of the state's power and the expansion of its reach and combined with increased commerce and expanding markets during the second half of the eighteenth century, weights and measures were increasingly made accountable to an abstract standard separated from people's everyday lives and work. This argument is neatly summarized by Theodore Porter: ''Informal measurement was inseparable from the fabric of these relatively autonomous communities. It broke down with the intrusion of more centralised forms of power—both political and economic—with the relatively private domain of communal life (*19*).'' The people that suffered were most frequently those excluded from some form of institutional power. As Peter Linebaugh powerfully showed (*16*) with regard to the Atlantic tobacco trade: ''The class struggle in the oceanic tobacco trade took a metrological form, because the ambiguities of measures benefited the porters, the crews, the slaves, the lightermen and the 'little inconsiderable persons.' Legislation attempted to standardise the hogshead.'' Greater regularization and centralization was accompanied by increased abstraction, the antithesis to localism and diversity. To legitimate this abstraction and make it appear real, an accompanying form of reason that appealed to a notion of objectivity (and equity) was required (*16*, *18*–*20*).

For much of England's history, the standard of length appropriately had its basis in the nation's most important source of food, the barleycorn. It had to be ''taken out of the middle of the ear, and being well dried, three of them in length were to make one inch; and thence the rest.'' Similarly, the standard weight derived from ''a corn of wheat gathered out of the middle of the ear: which being well dried, 32 of them were to make one penny-weight, 20 penny weights one ounce, and 12 ounces one pound troy'' (a total of 7680 grains). In actuality, there were as many as six different pounds. For example, another troy pound was used for gold and silver that weighed 5760 grains; the tower pound that was used to test coins weighed 5400 grains; and a wool pound, at 6992 grains, was used to weigh ordinary goods. Under Elizabeth I, an unsuccessful attempt was made to impose a single troy pound weighing in at 7000 grains for the purpose of gauging all ordinary items, whereas in 1758 Parliament decided to legalize the single troy pound and enforce the avoirdupois pound for weighing heavy goods. For measures of capacity, a unified approach was taken for both dry and liquid goods: ''eight pounds troy weight of wheat, gathered out of the middle of the ear, and well dried, shall make one gallon of wine measure; and that there shall be but one measure for wine, ale, and corn, throughout this realm'' (*10*, *21*, *22*).

The historian Julian Hoppitt made the case (*14*) that much of the legislation passed under the later Stuarts concerning weights and measures could be interpreted as an attempt to bring geographically remote areas into line with the more economically active regions of the south and east. Certainly under the Act of Union with Scotland in 1707 an unsuccessful attempt was made to bring areas together through metrology. One of the articles of the act stipulated that Scotland had to adopt the legal weights and measures of England. The earl of Godolphin complained to the Scottish commissioners of excise that the English gallon in the exchequer was some 10 cubic inches less than the Scottish equivalent. In July 1707, the Scottish commissioners of customs in Scotland were quick to highlight the need for uniform weights and measures between the two newly unified nations: ''By reading the 17th Article of the Union, it occurs to us that we ought to have weights and measures of England sent here forthwith, at least patterns, to the end, every port and place be furnished; for we conceive that without these calculations cannot be made, and it is a great trouble to us that early care was not taken thereof.'' Abolishing the Scottish system of weights and measures simply meant Scotland used two systems. The Scottish courts defended the continued use of local measures for internal trade, whereas London directed customs and excise to collect duties with use of English measures. Trying to make a coherent and therefore predictable tax policy under these conditions was immensely difficult (*23–25*).

Attempts to enforce the Winchester bushel returned in 1732 under the auspices of Robert Walpole's administration; again the project failed. In 1742 an anonymous gentleman of the Royal Society was struck by the diversity of supposed standard weights and measures kept in the various London locations, which, as we have seen already, were meant to hold the original authoritive ones. A few years later Crayford's select committee report on weights and measures was published, followed by a second report the following year. Its contents centered upon the inadequacy of current legislation and the weak process of enforcement. Although attempts were made to act on the committee's resolutions, the bills that were subsequently introduced were so late in the session they failed (*8*, *26*).

Crayford's committee examined all the standards kept in the government's exchequer depositories at the Guildhall, Founders Hall, the Watchmakers Company, and the Tower of London. Among the members of the committee were the president of the Royal Society, Lord Macclesfield, and several prominent mathematicians and astronomers. They universally condemned the various official liquid gallon measures and advocated that the wine gallon kept at the exchequer, and not the one housed in the Guildhall, be adopted (*27*). The choice was guided by the quest to centralize all the measures and the fact that it was the most commonly used. Despite the committee's failure to pass any legislation, it did instigate new standards for the troy pound and yard, which were constructed in 1758 and 1760 by the mathematical instrument maker John Bird. These were subsequently made the primary references for the imperial system established in 1824. One problem mitigating the standardization and enforcement of weights and measures was the vast array of legislation that allowed exemptions. For instance ''one Act permitted Oats, Malt, and Meal, to be sold differently from other Corn; that was repealed after 20 Years Practice had habituated the People to that way of selling: Another Act excepted, the county of Lancaster, because in the county a larger measure was in use than the Law allowed; and many other instances of the like kind might be shewn (*28*).'' The locally informed and therefore haphazard nature of legislation until this point was thwarting what the Crayford committee termed ''the Principles of Uniformity.'' The committee concluded that ''in order effectually to ascertain and enforce uniform and certain Standards of Weight and Measures to be used for the future, that all the Statutes relating thereto should be reduced into one Act of Parliament; and all the said Statutes now in being, subsequent to the Great Charter, repealed.'' But it was precisely because communities were so devoted to local measures that members of Parliament couldn't agree on authorizing a system that overturned such a highly charged context. As late as 1817, it was estimated by the agriculturist expert on the distillation of spirits and minister of Keith Hall and Kinkell, George Keith, that throughout provincial England there were ''about two hundred and thirty'' different weights and measures and a further 70 in Scotland. He also added that it was extremely frequent to find several different weights and measures in the same county (*28*, *29*).

In 1814 a commons select committee reported that ''the great causes of the inaccuracies which have prevailed, are the want of a fixed standard in nature, with which the standards of measures 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 also the want of proper Tables of Equalisation, by means of which the old measures might have been made to establish a mode of connecting the Measures of capacity with weight.'' Nature had by now become the state's legitimating authority to crush localism. However, the problem was twofold: First, there was no physical standard with which to police deviation, and secondly, as previously seen, there was confusion generated by the proliferation of statutes concerned with variations in weights and measures. The 1814 committee was composed of 23 members, all now reliant upon scientific information supplied by two of Britain's leading men of science, the experimental natural philosopher and physician, William Hyde Wollaston, and the professor of natural philosophy at Edinburgh University, John Playfair, both of whom had worked extensively on pendulum vibrating seconds in the latitude of London. A bill was put forward in 1815 ''for establishing and preserving an uniformity of weights and measures'' but failed after its second reading. A new committee was subsequently formed in 1816 to further investigate pendulum-vibrating seconds as a source for grounding metrological standards, this time led by the member of Parliament for Bodmin and future president of the Royal Society of London, Davies Gilbert (*14*, *30*).

The new committee again contained the elite of British men of science, many of whom were, or went on, to be employed in major state institutions. The members consisted of the commissioner of the board of longitude (from 1818), Wollaston; the secretary of the board of longitude (from 1818), Thomas Young; the leading precision instrument maker and fellow of the Royal Society, Edward Troughton; the natural historian and president of the Royal Society, Joseph Banks; the secretary of the Royal Society and until 1814 a medical officer in the army, Charles Blagden; the army surveyor and fellow of the Royal Society, Henry Kater; the secretary of the Admiralty and one-time topographer of South Africa, John Barrow; and lastly, the lieutenant governor of Woolwich Military Academy, one-time director of the Ordinance Survey, and fellow of the Royal Society, William Mudge. Their results were brought out in 1818, but again their findings ultimately failed to come up with a solution. Yet another committee was subsequently formed on how best to define the standards and implement them into legislation. This time it was led by the former members of the above committee along with the addition of the minister of Parliament and, from 1819, lord of the Admiralty, George Clerk (*31*).

The work of these and additional committees finally culminated in the imperial system of weights and measures in 1824. The new metrology was aimed at reaching a balance between scientific objectives, practical requirements, and commercial reception. The implementation of abstraction to overcome localism and diversity was considered too dangerous to be made the evangelical basis of a new metrology. It had to be consistent, recognizable, and simple in the sense of being easily understood and enforceable. Exactness was a negotiation of all these boundaries. Unlike the French metric system, which was perceived in Britain as having been an expensive failure and commercial disaster, the 1824 solution was a pragmatic compromise. The customary practices and use of old measures were far too deeply ingrained to be simply replaced at a stroke, as had been demonstrated in France. As the precision instrument maker Jessie Ramsden had observed in 1792 while investigating the standard for proof spirit (*32*), "To retain the present value of Proof, will, no doubt, have many advantages: it will prevent that confusion which always happens in commerce, when any change of value, or denomination, of merchandise takes place." The new imperial weights and measures took the most widespread and everyday consistent standards in use and simplified them into a coherent system. The key imperative of the act was to ensure as little disruption as possible to the commercial environment (*14*, *32*, *33*).

Lineal standards were now regularized and derived from the imperial standard yard, which was based on a pendulum vibrating seconds in London at the proportion of 36 to 39.1393. The standard for all measures of capacity derived from the imperial standard gallon, which contained 10 pounds weight avoirdupois of distilled water weighed in air at a temperature of 62° Fahrenheit and a barometer reading at 30 inches. All duties, allowances, drawbacks, payments, and accounts under any law of excise were to be made to these standards. This, of course, meant that all prior existing statutes related to this issue were repealed. For example, the wine gallon of 231 cubic inches was replaced by the imperial gallon, defined as 277.274 cubic inches and being the space taken up by water poured into a 10-pound avoirdupois weight at the legally defined temperature and pressure. The imperial standards established three weights and measures from which all other metrological standards derived. They were the yard, the troy pound, and the gallon. All measures of length were now to stem in parts or multiples of the yard, as constructed earlier by John Bird at the request of the Crayford committee in 1760. Similarly, all weights were now derived from the troy pound as originally constructed, once again, by Bird in 1758 (*34*, *35*).

The next really significant legislation came with the Weights and Measures Act of 1835, which legally abolished the Westminster bushel and all local and customary measures in the marketplace, along with practices such as striking the commodity. Everything now had to be sold by the imperial bushel. The combination of this and the earlier 1824 act inspired Joshua Bateman, the author of a very popular nineteenth-century excise manual (*36*), to gleefully declare "The Winchester bushel, and all local or customary measures are abolished. Heaped measures are also abolished." To ensure that time was saved and mental labor was mechanical, all calculations were "reduced to tables." In addition, inspectors were authorized to check all weights and measures in their own areas. "Great Britain," declared a recent historian of metrology, "was on the verge of creating one of the most efficient metrological officer corps in European history" (*34*).

References and Notes

1. A. Smith, in *Lectures on Justice, Police, Revenue and Arms; Delivered in the University of Glasgow and Reported by a Student in 1763*, E. Cannan, Ed. (Oxford Univ. Press, Oxford, 1896), pp. 183.
2. W. J. Ashworth, *Customs and Excise: Trade, Production and Consumption in England 1640–1845* (Oxford Univ. Press, Oxford, 2003), chap. 15.
3. S. Schaffer, in *Rethinking Social History: English Society 1570–1920 and its Integration*, A. Wilson, Ed. (Manchester Univ. Press, Manchester, 1993), pp. 128–157.
4. For plebian suspicions of state quantification, see R. Sheldon, A. Randall, A. Charlesworth, D. Walsh, in *Markets, Market Culture and Popular Protest in Eighteenth-Century Britain and Ireland*, A. Randall, A. Charlesworth, Eds. (Univ. of Liverpool Press, Liverpool, UK, 1996), pp. 25–45.
5. W. D. Patlenden, in vol. 20 of *Bulletin of the Cleveland and Teesside Local History Society* (Society of Middlesbrough, 1973), pp. 12–14.
6. For the commissioners, see U.K. House of Commons, "Thirteenth report of the committee appointed to examine the public accounts," *Sessional Papers*, 1785, vol. 44, p. 18.
7. See also the Public Record Office, Customs 41/1, 14 July 1713 (Kew, UK, 1713).
8. C. Leadbetter, *The Royal Gauger; Or, Gauging made Easy, As it is actually practised by the Officers of His Majesty's Revenue of Excise* (E. Wicksteed, London, ed. 2, 1743), p. 119.
9. C. Leadbetter, *The Royal Gauger; Or, Gauging made Easy, As it is actually practised by the Officers of His Majesty's Revenue of Excise* (E. Wicksteed, London, ed. 2, 1743), p. 120.
10. One pound troy was in proportion to the cubic inches contained in a wine gallon, whereas 1 pound avoirdupois was "very near" the cubic inches contained in an ale gallon.
11. "Proposals for altering the gauge of wines and brandies," [Cholmondley Houghton Papers, Cambridge Univ. Library, manuscript no. 44/93, n.d. (probably early 1730s)].
12. C. Leadbetter, *The Royal Gauger; Or, Gauging made Easy, As it is actually practised by the Officers of His Majesty's Revenue of Excise* (E. Wicksteed, London, ed. 2, 1743), p. 117.
13. U.K. House of Commons, "Report from the committee appointed to enquire into the original standards of weights and measures in this kingdom," *Sessional Papers*, 1758, vol. 19, p. 376.
14. J. Hoppitt, *Eng. Hist. Rev.* **108**, 82 (1993).
15. R. E. Zupko, *Revolution in Measurement: Western European Weights and Measures Since the Age of Science* (Memoirs of the American Philosophical Society, Philadelphia, 1990), p. 26.
16. P. Linebaugh, *The London Hanged: Crime and Civil Society in the Eighteenth Century* (Penguin, London, 1991), pp. 162–163.
17. For the seventeenth-century commentator, see *A Sure Guide for His Majesties Justices of Peace* (Penguin, Harmondsworth, 1663), p. 441.
18. W. Kula, *Measures and Men*, R. Szreter, Trans. (Princeton Univ. Press, Princeton, NJ, 1986), p. 70.
19. T. Porter, *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life* (Princeton Univ. Press, Princeton, NJ, 1995), p. 223.
20. Colonies usually, but not always, adopted the measures of the occupying country (*24*).
21. *Brit. Rev. London Crit. Rev.* **IX**, 159 (1817).
22. J. T. Graham, M. Stevenson, *Weights and Measures and Their Marks: A Guide to Collecting* (Shire Publications, Haverford-West, ed. 3, 1993), pp. 3–4.
23. G. S. Keith, *Different Methods of Establishing an Uniformity of Weights and Measures Stated and Compared* (J. Johnson & Co., London, 1817), p. 1.
24. J. J. McCusker, *William Mary Q.* **30**, 599 (1973).
25. For numerous other Scottish-English legal variations in metrology, see R. E. Zupko, *Revolution in Measurement: Western European Weights and Measures Since the Age of Science* (Memoirs of the American Philosophical Society, Philadelphia, 1990), pp. 5–7.
26. "An account of a comparison lately made by some gentlemen of the Royal Society of the standard of a yard, and the several weights lately made for their use," *Philos. Trans. R. Soc.* **42**, 541 (1742).
27. During the Middle Ages, City of London officials were in charge of stamping and testing bronze and brass weights at the Guildhall jointly with the Worshipful Company of Founders until 1579 (*37*).
28. U.K. House of Commons, "Report from the committee appointed to enquire into the original standards of weights and measures in this kingdom," *Sessional Papers*, 1758, vol. 19, p. 352.
29. G. S. Keith, *Different Methods of Establishing an Uniformity of Weights and Measures Stated and Compared* (J. Johnson & Co., London, 1817), p. 2.
30. R. E. Zupko, *Revolution in Measurement: Western European Weights and Measures Since the Age of Science* (Memoirs of the American Philosophical Society, Philadelphia, 1990), pp. 105–107.
31. R. E. Zupko, *Revolution in Measurement: Western European Weights and Measures Since the Age of Science* (Memoirs of the American Philosophical Society, Philadelphia, 1990), pp. 107–108.
32. W. J. Ashworth, *Technol. Culture* **42**, 27 (2001).
33. For an account of the implementation and reception to the French metric system, see K. Alder, in *Values of Precision*, M. Norton Wise, Ed. (Princeton Univ. Press, Princeton, NJ, 1997), pp. 39–71.
34. R. E. Zupko, *Revolution in Measurement: Western European Weights and Measures Since the Age of Science* (Memoirs of the American Philosophical Society, Philadelphia, 1990), pp. 178–179.
35. B. R. Leftwich, *Customs: The Story of a Great Department* (Customs and Excise Museum, Liverpool Galleries and Museums, n.d.), p. 207. John Bird gained immense prestige during the eighteenth century for the precision instruments he made for the astronomer royal, James Bradley.
36. J. Bateman, *The Excise Officer's Manual, and Improved Practical Gauger; Being a Compendious Introduction to the Business of Charging and Collecting the Duties of Excise* (A. Maxwell, London, 1840), pp. 28–29.
37. J. T. Graham, M. Stevenson, *Weights and Measures and Their Marks: A Guide to Collecting* (Shire Publications, Haverford-West, ed. 3, 1993), p. 1.

Metrology and the State: Science, Revenue, and Commerce
William J. Ashworth (November 18, 2004)
Science **306** (5700), 1314-1317. [doi: 10.1126/science.1102551]

Editor's Summary