Soho Steam Engines
The First Engineering Slide Rule and the Evolution of Excise Rules

Thomas Wyman

The most important business relationship in the history of the development of the steam engine was that of Matthew Boulton (1728-1809) and James Watt (1736-1819). This paper discusses that relationship and explores how the introduction of the first engineering slide rule by James Watt appears to have influenced the design and evolution of slide rules used by English Officers of the Excise. In 1775, as a result of Watt's research on the thermodynamics of the steam engine and after he had conceived his revolutionary idea of the separate steam condenser, Boulton offered the Scottish "engineer" a partnership with the objective of improving the design of the Newcomen steam engines that his firm produced.[1]

Figure 1. View of the Manufactory of Boulton & Fothergill in Birmingham by Francis Eginton, 1773

The significance of this historical relationship was formally recognized on 2 November 2011 when the Bank of England issued a £50 note with the portraits of Messrs Boulton and Watt and a line drawing of the Whitbread steam engine. Watt's statement that reflects his obsession with the design project also appears on the note, "I can think of nothing else but this machine".

Figure 2. The £50 Note

The two were joined by William Murdock (1754-1839), and the three men became the driving force behind improving steam engine design, which was a key element in sparking the Industrial Revolution. Of the three men who were involved in improving the design and operation of the steam engine, James Watt remains the best known today. This is notwithstanding the fact that Boulton was one of the first manufacturers to introduce modern production and marketing methods at his Soho plant in Handsworth. There he produced buckles, buttons, and other inexpensive metal goods as well as high quality sterling silver and copper-based ormolu tableware with a golden hue, which for a time, rivaled that produced by the foremost London and European makers. Boulton also widened the use of steam technology when, in 1788, he established his steam-powered Soho Mint to produce high quality coins and medals. One writer observed:

> There are a number of reasons why Boulton's name is not as familiar with people today. At the heart of it is that he doesn't fit neatly into any one particular box. He was a true polymath. Legends tend to be established early, and unlike Watt's son, James Watt junior, Boulton's own son, Matthew Robinson Boulton, did not commission a hagiographic biography of his father. Similarly, because he was not an engineer per se, he seems to have been accorded a lower status by Victorian writers and historians. And of course he didn't get a unit of energy named after him!

Regional conspiracy theorists might also argue that Boulton has suffered because he came from Birmingham rather than London. During his career he clashed with a variety of institutions in the capital, not the least the Royal Mint and Goldsmiths Hall. Consequently, there might have been some settling of old scores after his death by downplaying his achievements. But perhaps most critical of all, unlike his friend and competitor, Wedgwood, none of the enterprises named after Boulton survive today so that his 'brand' has inevitably faded from view.[2]

As testimony to their broad range of interests, both Boulton and Watt were members of the Lunar Society of Birmingham, a dinner club and informal society of prominent and learned gentlemen, who met regularly for nearly 50 years between 1765 and 1813 in Birmingham, England. At first called the Lunar Circle, "Lunar Society" became the formal name by 1775. The name was chosen because the society would meet during the full moon, as in the absence of street lighting, the extra light made the journey home easier and safer. The members who referred to themselves as lunarticks also included Erasmus Darwin (grandfather of Charles Darwin), Thomas Day, Richard Lovell Edgeworth, Samuel Galton, Jr., James Keir, Joseph Priestley, William Small, Jonathan Stokes, Josiah Wedgwood, John Whitehurst, and William Withering.[3]

Figure 3. 1792 Portrait of Matthew Boulton

James Watt's Engineering Slide Rule

As a young man, Watt had served as an apprentice instrument maker in London. He was an employee first of John Morgan, mathematical instrument maker, and then of John Neale who made globes and mechanical models of the solar system.[4] With this background and after joining Boulton in 1775, Watt quickly saw that a well-designed slide rule could increase the productivity of the firm's technicians. He commissioned the reputable instrument-maker John Jones at 135 Holborn, whose firm dates from 1776[5] to design and produce a few basic slide rules that were more accurately calibrated than those made for Officers of the Excise. The original slide rules were placed in the hands of trusted Soho technicians where they were very likely regarded as proprietary instruments that gave the firm a competitive edge and employees were admonished to treat them as company "secrets".[6] Watt may even have given John Jones an "exclusive" to make such instruments for his firm to discourage him from seeking other markets for the instrument. Two slide rules used by Watt himself up to the time of his death apparently have no maker's name inscribed on them.[7] Jones' firm became W&S Jones at the same address in 1791 when his sons William and Samuel took over.[8] The restraint on promoting the Soho slide rule dissipated over the years to the point that the slide rule eventually appeared in W&S Jones' catalogs. By 1815, the "secret" was out, and the French, beginning with Étienne Lenoir, began producing simple, precisely calibrated slide rules based on the Soho design. Given their genesis and use, initially by a few trusted Soho employees, the John Jones and later the W&S Jones instruments are generally considered the first engineering slide rules.

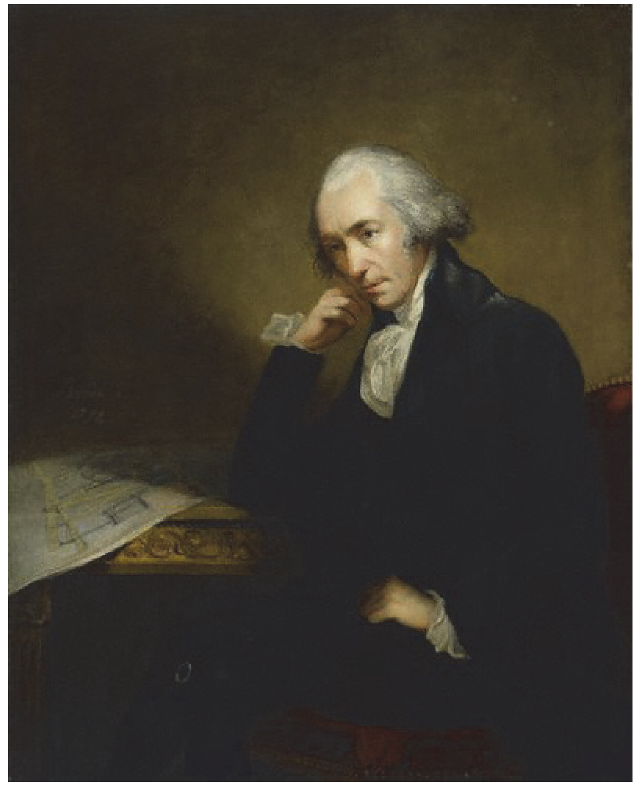


Figure 4. Portrait of James Watt by Carl Fredrik Von Breda

Figure 5. The *Soho House* in Handsworth, Birmingham, a Regular Venue for Meetings of the Lunar Society

We are indebted to John Farey who, in 1827, published *A Treatise on the Steam Engine, Historical, Practical, and Descriptive*, which includes a chapter on the "Application of the sliding rules for calculating the dimensions for the parts of the Steam-Engines". Farey wrote:

> The Soho sliding rules are made of box-wood, 10½ inches long, with one slider and four logarithmic lines on the front face;

and at the back are tables of useful numbers, divisors and factors, for a variety of calculations. Sliding rules of this kind are still called the Soho rules, and they are so correctly divided by some of the best makers of mathematical instruments in London, that they are capable of performing ordinary calculations with sufficient accuracy for practice; and by means of tables at the back of the rule, most questions in mensuration may be very readily solved.

These sliding rules were put into the hands of all the foremen and superior workmen of the Soho manufactory, and through them, the advantage of calculating by means of the sliding rule has become known amongst other engineers, and some do employ it for all computations of ordinary mensuration; but the habit of using it upon all occasions, is almost confined to those who have been educated at Soho.[9]

From Farey's writings, that the slide rule was important in supplementing the design capabilities of Soho technicians and increasing their productivity is evident. The slide rule produced by John Jones was a simple instrument with four scales on its face identified as A, B, C, and D and none on the reverse side. This slide rule has been well described elsewhere.[10]

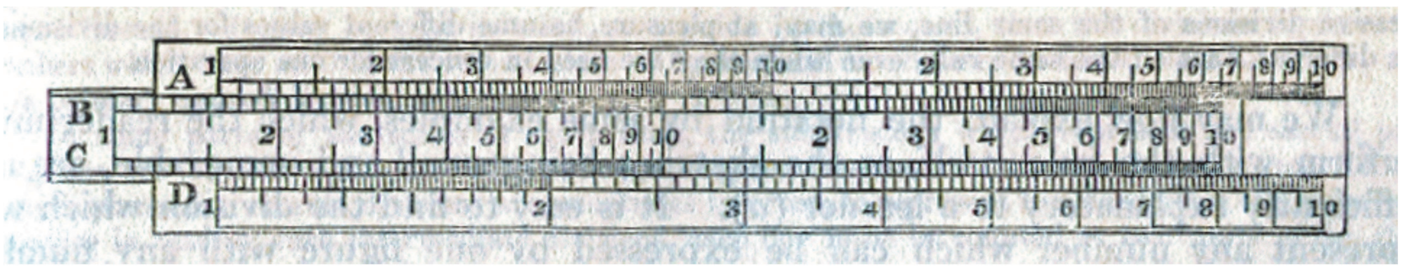


Figure 6. The "SOHO Sliding Rule" as Depicted by John Farey is Described as "10 1/2 inches long, 8/10 (inches) broad, and about 2/10 (inches) thick" [11]

<u>The Evolution of the Excise Rule</u>
<u>Beginning with Type 1</u>

Although conjectural, makers of excise slide rules appear to have been influenced by Watt's initiative and Jones' design when they saw that their traditional right-angled parallelepiped two, three, and four slide excise rules with square or nearly square cross-sections could be substantially improved by converting to a flat design with more precise calibrations.

Figure 7. An Early 12-inch Two-Slide Boxwood Excise Rule with a ¾ x ⅝-inch Square Cross-Section and Inscribed "Richard Bull 1693". Note the small, cramped numerical calibrations.

The history of what might be called Type 1 excise slide rule can be traced back to the late 1600s. When they first appeared, they were wooden instruments with square or nearly square cross-sections measuring less than an inch on each side and having two slides. Later models appeared with three and then eventually with four slides, with cross-sections measuring approximately 1.1 x 0.8 inches. Lengths of these boxwood instruments varied from six to twenty-four inches. These Type 1 excise rules continued to be made into the early to mid-1800s reflecting an unwillingness of users to abandon this type.

<u>Type 2 Excise Rule</u>

A flat excise rule design, Type 2, became available in the late 1700s. Evidence for this transition is a flat single-sided excise rule made by Roberts. It is a hefty 24 x 1 3/8 x 9/16-inch boxwood model in this author's collection and is inscribed "Wm Park 1789" thereby providing a clue as to when the transitional one-sided excise rules first appeared. This Type 2 appears to be a transitional link between the excise rules that appeared earlier, with nearly square cross-sections, and the comparatively sophisticated excise rules that became available in the mid-19th century.

An early Type2 excise rule is a 12 x 1½ x ⅜-inch, two slide boxwood excise rule with pre-Imperial markings that was produced by Dring & Fage between 1804 and 1824 while the firm was located at 20 Tooley Street, London Bridge. The scales from top-to-bottom include the traditional two cycle "A" and "B" scales, a "Segt. Standing" scale, a conventional two cycle "N" scale on the second slide, and a "Segt. Lying" scale. There are no scales on the reverse side of the slides or on the back of the rule, although the edges and back are attractively striped. The production of this unusual excise rule was limited to the time needed for makers to develop more sophisticated instrument with scales on the front and back.

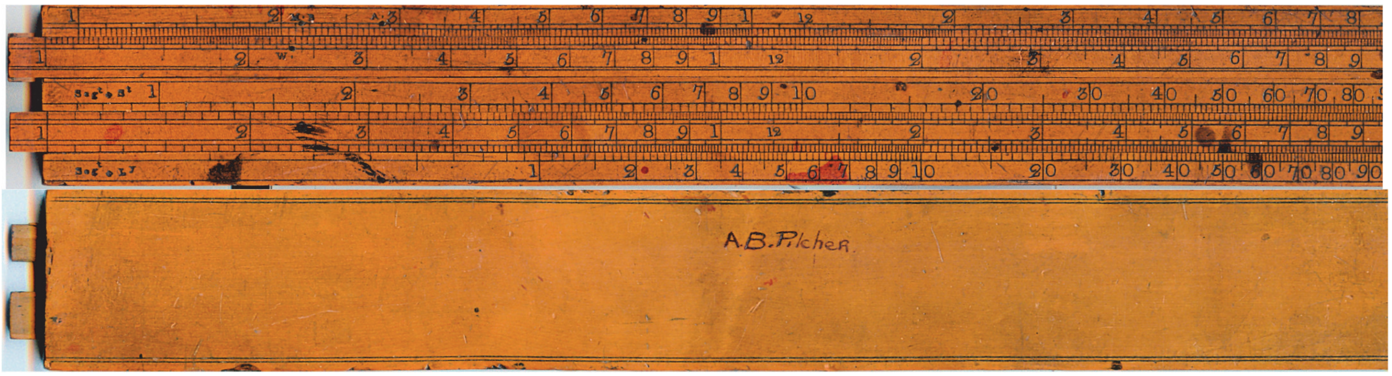


Figure 8. A 12-inch, One-Sided, Dring & Fage, Pre-Imperial Excise Rule with Two Slides Produced Between 1804 and 1824 when the Company was Located at 20 Tooley Street, London

The interesting thing about the excise rule shown in Figure 8 is that the reverse side is without scales and similar in that respect to the Watt-inspired Jones-made slide rules. This excise rule represents a break or a transition design from the earlier excise rules with nearly square cross-sections to the later two-sided, double slide excise rules. This same 12-inch, one-sided slide rule with minor dimensional differences (thinner and slightly wider) was also produced by Dring & Fage after 1824 as evidenced by the Imperial gauge points on a specimen in this author's collection.

Jane and Mark Rees commented as follows on this flat form of the gauging slide rule with particular reference to one produced by Edward Roberts and dated 1795:

> Before the end of the 18^{th} century some makers, including Edward Roberts (London, 1749-1795), were making rules with only two slides inset into the face of a solid but flat stock. These rules are invariably longer (18 to 24 in.) than the normal 12 in. length of gauging rules. [Not so, as evidenced above.] Having only two slides the lines are fewer – two lines of logs (double) and the two segment lines, indicating that the use was for cask gauging. The absence of any variety lines suggests the rules were intended for use only on British standard spheroid casks. This may have indicated that this type of rule was used more for domestic situations, such as the inspection of breweries, rather than full gauging at ports where foreign casks of variable varieties were arriving.[12]

Still another example of a flat single side excise rule is one measuring 18¼ x 1¾ x ⅜-inches and marked "Joseph Stutchbury, Dove Court, Old Jewry, London" where he worked from 1797 to 1800. This time span of only three years aids in narrowing the time when these rules were produced. The instrument is also inscribed "G. W. Cartwright" who was probably the owner of the instrument. A 15⅜-inch version of this rule is described in the *Catalogue of the Collections in the Science Museum*.[13]

Adoption of the Imperial measurement system in 1824 effectively rendered existing excise rules obsolete. This change-over to the Imperial system created a lucrative broadly-based replacement market for rule makers as well as an incentive to modify their traditional excise rule designs by adopting the flat model. At the same time, some years were needed for the rule-making technology to advance to the point where scales on the front and back of a flat instrument could be produced that accurately aligned and retained calculating integrity. Makers continued to produce flat, one-sided rules with two slides after 1824 as evidenced by a boxwood rule with Imperial markings measuring 18 x 1 3/4 x 3/8- inches and inscribed "J. Long, Maker 20 Little Tower Street, London" who was at this address from 1821 to 1884. The slides are 1/8-inch thick and are prone to break as evidenced by a neatly repaired break in one slide of this specimen.

The foregoing paragraphs record seven similar flat, one-sided excise rules produced by four different makers during the late 1700s and early 1800s. Thus, the first flat excise rules appeared in the last quarter of the 18^{th} century after James Watt joined Boulton in 1775 and commissioned John Jones to produce slide rules for the firm's technicians. Evidently, makers of excise rules became aware of this development and saw advantages in the flat design. After introduction in the late 1700s, this flat single-sided Type 2 design prevailed until replaced by more sophisticated two-sided, multi-scale excise rules in the early to mid-1800s.

Figure 9. The Reverse Side of a Flat One-Sided Excise Rule Produced by Joseph Stutchbury

Figure 10. An 18-inch Post-1824 Excise Rule by J. Long with Two Slides and No Scales on the Reverse Side

Type 3 Excise Rule

The third stage or Type 3 in the evolution of excise rule design is represented by a 9 x 2-inch boxwood slide rule with Imperial markings produced by Cock of London. This rule is constructed with four thin slides (1/16-inch), two on the front and two on the reverse side, slotted into a 1/2–inch thick wooden body.

This design reflects the adherence of rule makers to the earlier all-wood flat excise rule designs but incorporates the concept of scales on both sides of the instrument. Scales on both sides allowed rule-makers to increase the number of scales they offered. Production with four wooden slides that dovetailed into a wooden body obviated the need for metal end plates that appeared later. However, the frail slides must have broken frequently, and this design prevailed for only a few years before rule makers began to produce sturdy two-sided excise rules with end plates.

Rod Lovett's collection of slide rules displayed on his website includes a "third stage" or Type 3, four slide excise rule without end plates produced by Dring & Fage, 19-20 Tooley Street, London, circa 1850. Since these excise rules are comparatively scarce, dating the period over which they were produced with precision is difficult, but apparently did not exceed 25 to 30 years, possibly from 1830 to 1860.

Type 4 Excise Rule

The Type 4 excise rule was a sophisticated two slide, double-sided boxwood rule with brass end pieces or plates that became standard in the mid 1800s. These excise rules were well constructed, accurately calibrated, and were a significant improvement over the right-angled parallelepiped rules that were available to officers for the first 150 years. Makers often produced gauging rods to accompany their excise rules and sold them as a set in handsome fitted leather cases.

The preferred material for making an excise rule was boxwood. Excise rules made of ivory were comparatively rare. However, from time to time, an excise officer would appear who was both able and willing to pay more than the cost of an ordinary boxwood excise rule with brass end plates. Perhaps he wanted to show that "he had made it" or simply wanted to distinguish himself from fellow officers with boxwood rules. For these relatively rare customers, rule makers produced elegant instruments in ivory with end plates of German silver. Based on a comparative analysis of prices for folding boxwood rules and similar ivory measuring rules of the period, the price of an ivory excise rule must have been approximately 6 to 8 times the price of a similar boxwood rule. The proud owners of such fine excise rules must have appreciated the fact that they possessed the culmination of some two centuries of excise rule development.

Table 1. Seven One-Sided Type 2 Excise Rules Produced by Four Different Makers and Described in This Paper

MAKER	DIMENSIONS	DATE	COMMENTS
Edward Roberts London	24 x 1 ⅜ x 9/16-inches	Inscribed Wm. Park 1789	A rare dated rule and thicker than most
Dring & Fage 20 Tooley Street London	12 x 1 ½ x ⅜-inches	1804 - 1824	Winchester markings Maker at 20 Tooley 1804-1882. See Figure 8
Edward Roberts London	18 or 24-inches	Dated 1795	Described by Rees
Joseph Stutchbury Dove Court Old Jewry, London	18¼ x 1¾ x ⅜-inches	Worked 1797-1800	See Figure 9
Joseph Stutchbury Dove Court Old Jewry, London	15⅜ x 1¾ x ⅜-inches	Worked 1797-1800	In London's Science Museum Catalogue
J Long 20 Little Tower St. London	18 x 1¾ x ⅜-inches	Post-1824	Imperial markings. Maker at 20 Little Tower 1821-1884. See Figure 10
Dring & Fage 20 Tooley Street London	12 x 1⅝ x ¼-inches	Post-1824	Imperial markings. Maker at 20 Tooley 1804-1882

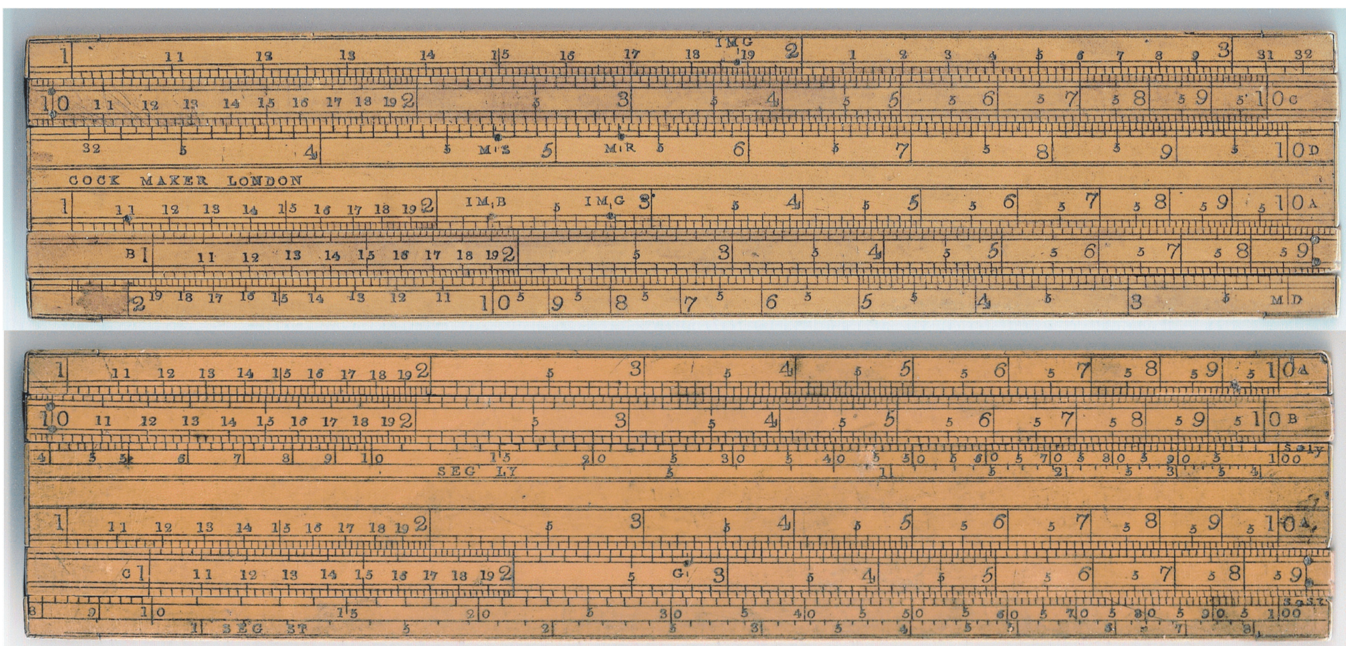


Figure 11. Alcohol Slide Rule by Cock, London with Two Slides on Each Side. From Kemp Town Brewery, Brighton when the brewery closed after a take-over by Charringtons.
(Courtesy D. M. Riches)

After analyzing available evidence, there appears to have been a four-stage, two-century evolution of the excise rule from the earliest models to the sophisticated excise rules that appeared in the latter half of the 19^{th} century. Instrument makers gradually modified their designs and excise officers adapted accordingly. That so much time was required to arrive at the ultimate design reflects a conservatism and reluctance of those involved to abandon proven designs.

Excise rules of other designs appeared and disappeared over the years. For example, there was Brannan's Rule, an interesting adaptation of the conventional excise rule that could be used as a gauging rod and then disjointed for use as a slide rule. These dual-purpose excise rules, the bottom half of which was frequently lost in the gauging process, were produced both before and after the Imperial gallon was adopted in 1824.[14]

Figure 12. A Sturdy, Well-Calibrated 9½-inch Boxwood and Brass Excise Rule with a 5-foot, 6-Piece Dipping Rod and Leather Case Was Produced by Cock of London, circa 1845

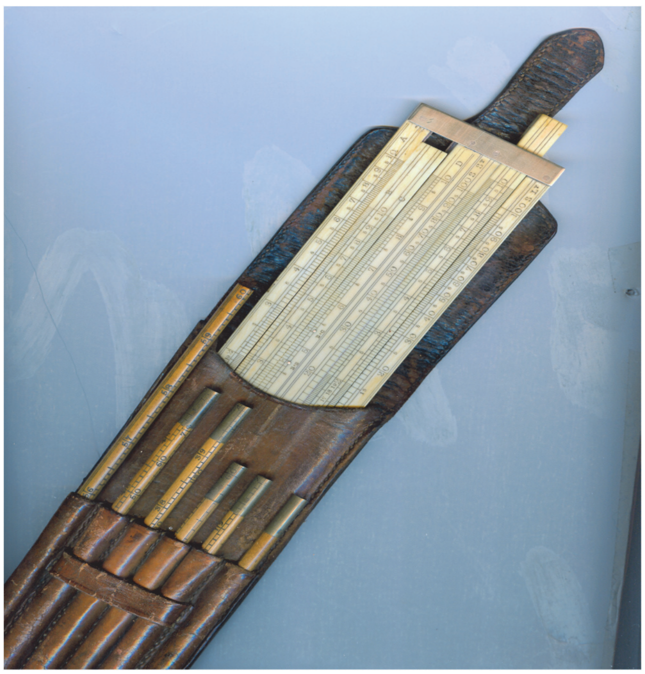
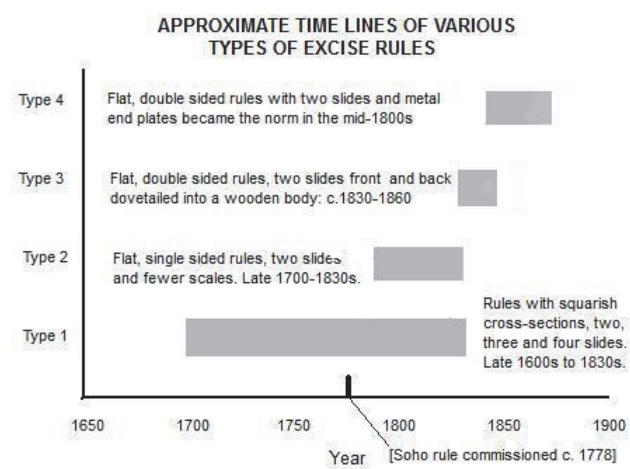


Figure 13. An Elegant 12½-inch Ivory Excise Rule Made by Loftus, 146 Oxford Street, London, c. 1875, in a Fitted Leather Case with a 6-Section, 60-inch Boxwood Dipping Rod

However, setting aside such special adaptations, evidence suggests that there were four basic stages in the evolution of excise rules. The dates shown here are not firmly established. They overlapped, and additional research should help refine these time estimates. Knowing more precisely the periods over which each of the two, three, and four slide instruments were produced would be of interest. More study should also result in elaborating (or perhaps discrediting) the evolutionary sequence offered here. In spite of what remains unknown, the development of excise rules as outlined here appears consistent with available information.

Table 2.
A Depiction of the Evolutionary Sequence of Types 1 to 4 Excise Rules



Because of this research, we can now better understand how the excise rule evolved from a relatively primitive "calculating stick" to a handsome two-sided boxwood instrument with brass end plates. Tracing this evolution, involved searching out centuries-old excise rule designs and developing a rationale to explain the differences that appeared over time. When the available evidence was sifted and assembled, a coherent explanation for the evolution of those designs is suggested.

The Last of the Excise Rules

Excise duties on various products were first imposed in 1643 to provide money for Cromwell's Parliamentary Army and then continued by King Charles II for "royal purposes". Excise Officers were first commissioned by the English government to collect taxes at points of importation and from local producers including innkeepers and pub owners in 1694. For some 180 years from 1694 to1874, this cadre of officers served the Government. However, by the late 1800s, alcoholic beverage production and distribution had become increasingly centralized and warehouses were established where imported goods could be deposited duty free until removed on payment of the duty. This reduced the incentive for local entrepreneurs to produce their own beer, wine, and spirits. Buying from wholesalers was easier and less costly for pub owners, innkeepers, and other retailers than continuing to make "batch lots" on their own premises. Thus, Excise Officers were no longer required to make rounds and collect taxes from individual producers in each community, and most officers were released. Therefore, the Type 4 double-sided excise rules with two slides that were used by Officers of the Excise as they made their rounds and calculated taxes became obsolete.

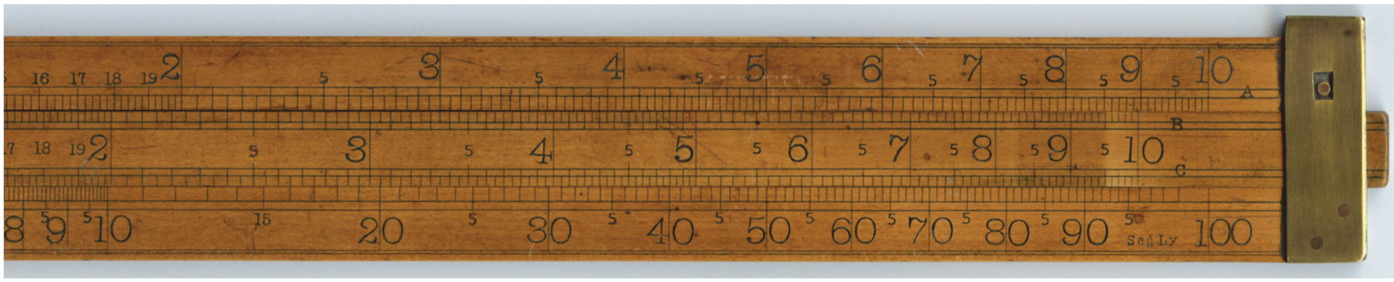


Figure 14. A Simple 24-inch One-Sided Excise Rule by Dring & Fage at 56 Stamford Street, London

However, the demise of the excise slide rule did not actually occur until some years later. Early in the 20th-century Dring & Fage with the address of 56 Stamford Street, London where the firm was located from 1903 to 1946 was still producing excise slide rules for the British government after 1900 as evidenced by a 24-inch one-sided rule with a single slide as evidenced by a rule marked "Customs and Excise 17". The upper scale and the slide scale of this sturdy 5/16-inch thick boxwood rule with brass end strips are two two-cycle log scales, while the lower scale on the body of the rule is marked "Seg Ly" for use in making gauging calculations where casks lay horizontally. Given the length and number of scales, the instrument was clearly designed for use at an entry port or at a major production facility of alcoholic products where excise calculations were made on standardized containers. The Dring & Fage slide rule described here was a holdover from earlier times and is a simplified special purpose design. As such, the final stage in the evolution of the excise rule that spanned over two centuries is represented.

Interestingly, even early in the 20th century the traditional materials of boxwood and brass were still being used in the production of excise rules. The only significant improvement in this particular single-sided boxwood slide rule over earlier models is the spring-loaded tension device in the brass end plates. Other models of this same vintage were not spring-loaded. That such primitive single sided slide rules were still being produced in the 20th century is noteworthy.

<u>Conclusion</u>

While the timing may be seen as a coincidence, the commissioning of the design and the production of the engineering slide rule about 1778 by Watt appears to have unintentionally triggered fundamental design changes in the special-purpose slide rules used by Officers of the Excise. Makers and then users of excise rules were quick to see the inherent advantages of the flat rule with the easier-to-read and more accurate scales and began to adapt accordingly.

Watt may have been unaware that in recognizing the value of a well calibrated slide rule, commissioning its production, and placing it in the hands of his technicians proved to be important steps in the development of the slide rule, steps that greatly expanded its utility. Thus, we can say that James Watt was the father of the engineering slide rule, and while perhaps not a cornerstone of the Industrial Age like the steam engine, the engineering slide rule contributed to engineering excellence over a longer time span than that over which steam prevailed as a primary source of power for reciprocating steam engines.

The era of the reciprocating steam engine eventually ended, and relics that survived have become museum pieces. For example, a Boulton and Watt engine built in 1820 at the Soho foundry in Birmingham a year after James Watt died was moved to Kew Bridge from the Grand Junction Waterworks Company's Chelsea works in 1840. In 1848, this engine was converted to work on the Cornish cycle, using higher pressure steam.

Today, the Boulton and Watt engine is the oldest engine in the Kew Bridge Museum as well as the oldest known waterworks beam engine in the world. The engine stopped working in 1944 and was restored to working order in 1975. Looking today, one is immediately struck by the immensity and service record of this well-engineered two-story high steam engine built by master craftsmen nearly two centuries ago that served London for over a century!

A contemporary of James Watt, Sir Humphrey Davy (1778-1829), British chemist and inventor of the Davy safety lamp for use by coal miners, captured the significance of Watt's contributions to society in the following words:

> Look round the metropolis; our towns, -- even our villages, -- our dock-yards, and

> manufactories; examine the subterraneous cavities below the surface, and works above; contemplate our rivers and canals, and the seas which surround our shores, and everywhere will be found record of the eternal benefits conferred on us by this great man. Our mines are drained, their products collected, the materials for our bridges raised, the piles for their foundations sunk, by the same power; machinery of every kind, which formerly required an immensity of human labour, is now easily moved by steam; and a force equal to that of five hundred men is commanded by an infant, whose single hand governs the grandest operations. The most laborious works, such as the sawing of stones and wood, and raising of water, are effected by the same means which produce the most minute ornamental, and elegant forms. The anchor is forged, and the die is struck, the metal polished, the toy modelled, by this stupendous and universally applicable power; and the same giant arms twist the cable-rope, the protector of the largest ship of the line, and spin the gossamer-like threads which are to ornament female beauty. Not only have new arts and new resources been provided for civilized man by these grand results, but even the elements have to a certain extent been subdued, and made subservient to his uses; and by a kind of philosophical magic, the ship moves rapidly on the calm ocean, makes way against the most powerful streams, and secures her course, and reaches her destination, even though opposed by tide and storm.[15]

This is a fitting tribute to the genius and perseverance of James Watt. That he is featured on England's £50 banknote is of little wonder!

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This paper was originally presented at IM 2012 and has been edited and expanded for publication in the *Journal of the Oughtred Society.*

ENDNOTES

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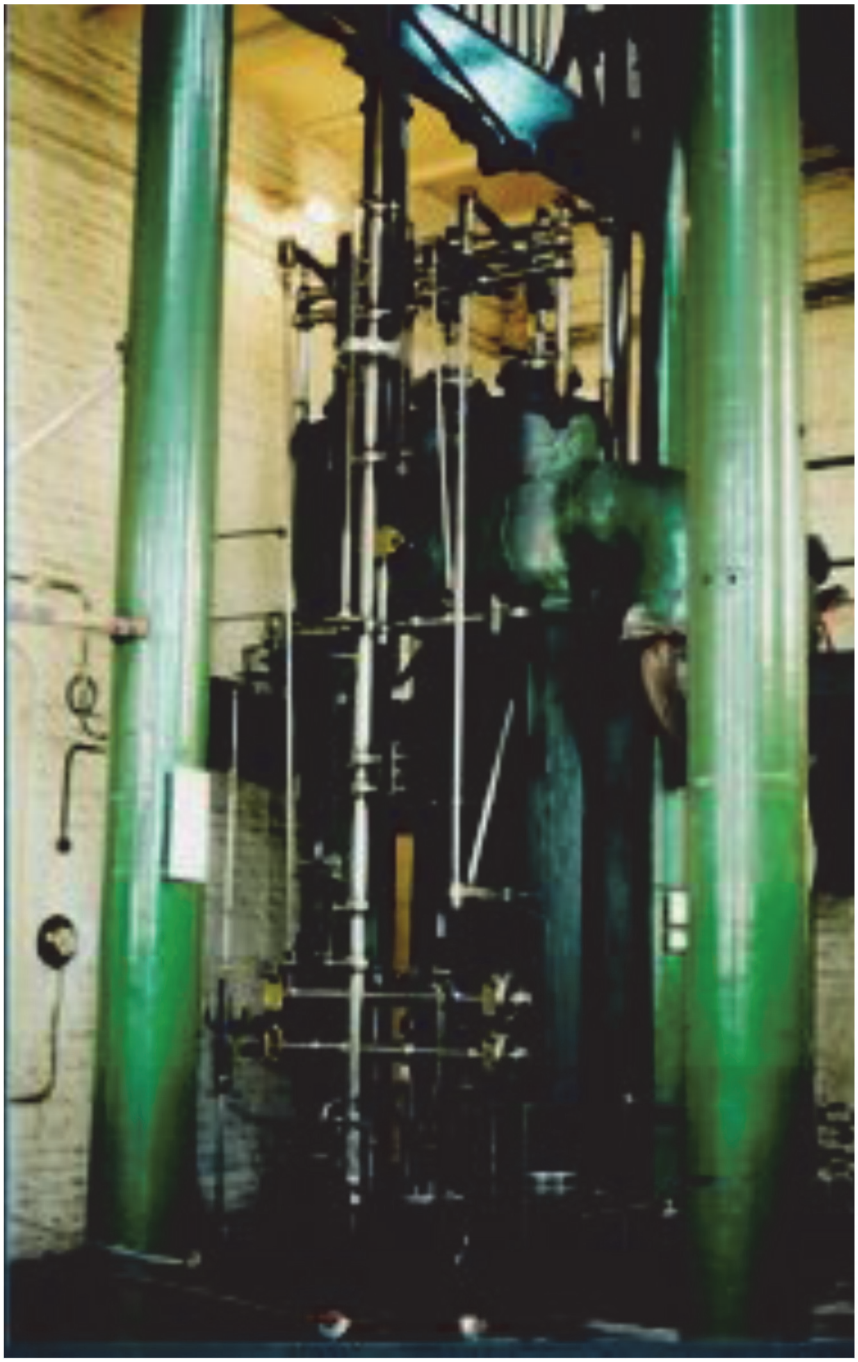
15. Hills, Rev. Dr. Richard, James Watt, Volume 3, Triumph through adversity, 1785 - 1819, Landmark Collectors Library, 2006. pp 253-254. Sir Humphrey Davy, as a leading chemist of his day, is best remembered for his discoveries of sodium and potassium as well as for his contributions to the discoveries of chlorine and iodine. He also discovered magnesium, boron, and barium.



Date of manufacture	1820
Cylinder Diameter	64 inches (1.62 metres)
Stroke	96 inches (2.4 metres)
Weight of Beam	15 tons (15.1 tonnes)
Water output per stroke	130 Gallons (590 litres)
Water output per 24 hours	2.5 M Gallons (8 M litres)
Strokes per minute	6 - 6 1/2
Last worked	1944
Returned to steam	1975

Figure 15. Details of the Boulton and Watt engine at Kew Bridge, London