DE DIVERSIS ARTIBUS

COLLECTION DE TRAVAUX
DE L'ACADÉMIE INTERNATIONALE
D'HISTOIRE DES SCIENCES

COLLECTION OF STUDIES
FROM THE INTERNATIONAL ACADEMY
OF THE HISTORY OF SCIENCE

DIRECTION
EDITORS

EMMANUEL POULLE
ROBERT HALLEUX

TOME 45 (N.S. 8)

BREPOLS

PROCEEDINGS OF THE XX[th] INTERNATIONAL CONGRESS OF HISTORY OF SCIENCE (Liège, 20-26 July 1997)

VOLUME V

THE SPREAD OF THE SCIENTIFIC REVOLUTION IN THE EUROPEAN PERIPHERY, LATIN AMERICA AND EAST ASIA

Edited by
Celina A. LÉRTORA MENDOZA, Efthymios NICOLAÏDIS
and Jan VANDERSMISSEN

BREPOLS

Bottlenecks : 18th Century Science and The Nation State

Arne Hessenbruch

In the 18th century, the town gate was a place where measurement was carried out routinely. Illustration I depicts a queue of carts bringing goods to market. They are lined up in front of a small house : the weighbridge. There is a line of soldiers, representatives of authority, the presence of whom guarantees that no one gets past without paying. The city wall in the background funnels the traffic so that all carts have to get past this or a similar point. The main places where indirect taxes were levied all had this funnelling effect in common : town gates, harbours, shops, mills, and turnpikes. All these places are in effect bottlenecks. Circulation flows through the bottleneck. The traders bring their merchandise to the bottleneck because they have to, for instance in order to get to the city market (thus " bottleneck " is a much more appropriate concept than, say, " junction "). It is not only merchandise which flows through this bottleneck. There are at least three spheres of circulation which meet in the bottleneck : merchandise, measuring instruments, and money. The triad of the three spheres makes it necessary to look at heterogeneous historical sources, not just the publications of the Academies. The requirements of the state, the history of wars, and especially, the history of administration are pertinent. In a sense, the order of the new world of the nation states is crystallised in the bottleneck.

In this paper, I will discuss the importance of these bottlenecks for the fiscal-military nation state and for science with the examples of the two Scandinavian states : Denmark-Norway and Sweden-Finland. The nation states were forced to raise revenue lest they be overrun by their neighbour. Revenue is never easy to come by, as tax payers will not pay unless forced to. The state had limited resources with which to raise taxes, which can be seen from the fact that tax levying was often farmed out. The bottleneck provided an excellent means of coping with limited resources. State officials had merchandise flow through particular bottlenecks, and so the state could deploy its forces just there.

The Scandinavian states are typical. They resemble other Northern European states in that they developed into fiscal-military states with a state administration ticking over even when sovereigns changed. They all established more bottlenecks and expanded the civil service. Southern European states such as Spain and Portugal, or indeed Greece (still a part of the Ottoman Empire) did not, or at least they did so to a much smaller degree. This division between Northern and Southern Europe is also visible in the institutionalisation of science. The bottlenecks are the crucial points for the development of science and a major activity of the national Academies of Science was to find solutions to problems arising at the bottlenecks. The import of the focus on bottlenecks is that the three spheres of circulation mutually impact upon each other and (for the history of science) that the development of science is directly dependent upon the funding by the state and the state's deployment of science in these special locales.

Excise tables of the fees to be paid illustrate the confluence of the three spheres of circulation. The Danish excise regulation for 1779 (Illustration 2 : *Forordning angaaende Consumtionens*...), for instance, lists the fee for barley groats (Byggryn) as 48 shillings per barrel, and for French or Rhinelandish spirits (Brændeviin) as 14 Rixdaler for a hogshead and 4 shillings per " pot " for the domestic variety when sold in Copenhagen (2 in the other towns). Such tables always contain three columns. The first column contains the commodities (grain, spirit, cloth) ; the second column lists the units of measurement (Pund, Lispund, *etc.*) which is different for each commodity, because each commodity is measured with a different instrument ; the third column lists the fee to be paid for one unit of commodity. Taxation tables always present such triads : commodity, unit of measurement, and money.

There is an increase in literature emphasizing the role of quantification and the state. Norton *Wise's The Values of Precision* provides essays giving an insight into many aspects of numbers for the purpose of state administration. Eric Brian's *La Mesure de l'Etat* provides an analysis of the role of numbers in 18th century France. Ted Porter's *Trust in Numbers* discusses the mechanisms of control provided by numbers within administrations, and Rosser Matthews has connected up thumbnail stories about the role of numbers in medicine leading up to the clinical trial. More generally, Bruno Latour's *Science in Action* depicts science generically within terms of circulation of scientists and inscriptions (but not merchandise) and metrology[1]. But noone has yet pointed to the confluence in controlled spaces as the places where almost all

1. M.N. Wise (ed.), *The Values of Precision*, Princeton, Princeton University Press, 1995 ; E. Brian, *La mesure de l'Etat - Administrateurs et géomètres au XVIII^e siècle*, Paris, Albin Michel, 1994 ; T.M. Porter, *Trust in Numbers - The Pursuit of Objectivity in Science and Public Life*, Princeton, Princeton University Press, 1995 ; J. Rosser Matthews, *Quantification and the Quest for Medical Certainty*, Princeton, Princeton University Press, 1995 ; B. Latour, *Science in Action*, Milton Keynes, Open University Press, 1987.

18th century measurement took place. I believe that the concept of bottlenecks could be fruitfully employed in history of science generally.

The paper has three sections : in the first I will describe the context of the military-fiscal state, which will show that the role of indirect taxation (and thus of bottlenecks) increased during the 18th century. It will attempt to put some numbers on the circulation of merchandise. The context of the military-fiscal state will also illustrate the state's motivation to establish such bottlenecks and in particular the deployment of measuring instruments.

The second section deals with these instruments. The main issue is precision, the demand for which increased markedly in the 18th century. This second section will also describe the concomitant development of increasing calibration and the professionalization of measurers (surveyors). Instruments can change with time, they can be fiddled with, or they can simply fail to work properly. Routine calibration enables all parties involved to put more trust in the accuracy of the measurements, as does their use by professional and certified individuals. Two examples of scientific instruments will illustrate the development of precision instruments for the specific problems of measurement at a bottleneck.

The third section deals with money. The history of coinage is not usually seen as a part of the history of science. In fact our disciplinary boundaries normally carve it up into economic history, numismatics, and history of technology. This fact makes coinage a very tricky subject to tackle historically. The literature is diverse and largely incompatible. I wish to argue that the history of coinage is central to the history of science in the service of the state. (For instance, that it was only in the 1660s that the issues of coinage was institutionally separated from weights and measures in Sweden). Coins were produced in mints, in which the highest degree of precision measurement was attained. One could argue that the most sophisticated science in 18th century Scandinavia took place in the mints : under the most closely controlled conditions, carefully executed metal work, chemical assaying and high-precision weighing was performed. Also, in the absence of reliable weights, it was common to substitute them with coins. Money thus literally became a part of the apparatus (balance plus weights) used in the bottlenecks.

In all three sections, a rough indication of the historical development throughout the 18th century will be given ; in all cases showing a steady increase in state machinery, control mechanisms, precision measurement, and stability of value.

THE MILITARY-FISCAL STATE

Until at least 1800, both Scandinavian states were aggressive expansionist military states, constantly interlocked in wars. In the 17th century, Sweden had gained the upper hand, by 1660 controlling most of the Baltic coastal areas. In the 1690s, more than a fifth of Sweden's revenue came from the Baltic provinces, such as Ingria which supplied Sweden proper with large quantities of grain, in 1696 (a year of famine) as much as 800.000 tons[2]. Denmark-Norway having lost most of present-day southern Sweden in 1660 sought every opportunity for revenge. In the Great Northern War (1709-1720), Sweden was faced not only with its traditional Scandinavian rival but also the expanding Russia of Peter the Great and with Poland and Prussia. The Swedish empire eventually crumbled in the face of this massed opposition[3].

The cost of the frequent wars put much pressure on taxation. The period after 1720 increased the fiscal pressures, even in Denmark-Norway which essentially entered into no armed conflict until the Napoleonic Wars, because it was almost always on the brink of war and arming heavily. Sweden-Finland was engaged in constant warfare in a futile attempt to contain Russia. Russia's emergence as a Baltic power rendered control of Baltic trade increasingly difficult for the Scandinavian states and their grip on bottlenecks there was broken[4]. Accordingly, both Scandinavian states had to turn their efforts towards increasing revenue and economic strength from within. They became capable of levying ever higher taxes through creation of domestic bottlenecks, refinement of the state machinery, helped also by a buoyant economy. The price of grain rose considerably towards the mid-18th century, and towards the end of the century, modernization of agriculture (enclosure and privatization of land followed by more intensive farming techniques) was beginning to produce higher yields too. This boom led to an emergence of a private sector of more than negligible proportion. The availability of credit increased.

In 1660, the only accumulation of capital had been in the hands of the king, and to a lesser extent in the church coffers. The landed nobility had received dues in kind and not in money. Land was not bought or sold to any significant degree : peasants tilled the land owned by the gentry against an annual manorial due. By the mid-18th century, banks were coming into existence, and exchange involving money was becoming increasingly common. Hitherto common and open land was being parcelled out, enclosed and owned by the farmer tilling it. This momentous development relied very much on the land becoming a commodity for which the evaluation and pricing of land was a pre-

2. D. Kirby, *Northern Europe in the Early Modern Period - The Baltic World 1492-1772*, London, New York, Longman, 1990, 257.

3. H. Becker-Christensen, *Dansk toldhistorie II- Protektionisme og reformer - 1660-1814*, København, Toldhistorisk Selskab, 1988 ; Knud J.V. Jespersen, *Danmarks historie - Bind 3 : Tiden 1648-1730*, Copenhagen, Gyldendal, 1989 ; S.A. Nilsson, *De stora krigens tid - Om Sverige som militärstat och bondesamhälle ; The Era of the Great Wars - Sweden as a Military State and its Agrarian Society*, Uppsala, Almqvist & Wiksell International, 1990.

4. H. Becker-Christensen, *Dansk toldhistorie II* ; Jespersen, *Danmarks historie - Bind 3* ; E.F. Heckscher, *An Economic History of Sweden*, Cambridge, Mass., Harvard University Press, 1954 ; G. Behre, L.-O. Larsson, E. Österberg, *Sveriges historia 1521-1809 - Stormaktsdröm och småstatsrealiteter*, Stockholm, Esselte Studium AB, 1985.

requisite. Both the increasing privatisation of land of the 18th century and the increasing role of indirect taxation required a wider network of state control with surveying and other measurement.

John Brewer has shown how throughout the 18th century, indirect taxation became the main form of taxation in Britain[5]. The excise, in particular, became an organisation of extraordinary efficiency. Essential to the funding of the many wars of the period. He emphasises as a British specialty : the lack of venality but also the particular form of accountancy which developed and which made it possible for the Treasury to see with clarity what the total income and expenditure of the state was. This allows the historian to follow the British case with some ease. While the Scandinavian revenue figures are less informative than the British ones, it can at least be said that the financing of wars was central to the fiscal systems, that the state tentacles reached further and further into the nooks and crannies of society for the purpose of levying indirect taxes, that this provoked protest, and that the state promulgated standards in order to quell protests and have the operation proceed smoothly[6]. For the importance of the indirect tax, the following points can be made. The most serious public sector borrowing requirements fell within the years of the Prussian war[7]. Excluding loans, it amounted to appr. 20% of the state's revenue, and to about 70% of the land tax. Indirect tax constituted a fair slice of the state's revenue (but not nearly as much as in Britain). Also, it proved a more flexible form of income than the land tax. From the peace time of 1722 to the war time of 1758, the land tax rose by 18%, whereas the indirect tax rose by 54%. The same fiscal pressures apply to the Danish-Norwegian state ; its debt forced ever higher by the mere threat of warfare[8] : and indirect taxation provided growing revenue throughout the 18th century, just as was the case in Britain[9], the importance of bottlenecks is borne out by the statistics. Town gates provided much better control than turnpikes which were more easily circumvented. In the early 1670s, characteristically, Danish provincial towns levied appr. 88.000 rigsdaler annually. By comparison, the number for Copenhagen is 69.000, and for the countryside it was only 48.500.

The excise duties of both Scandinavian states reveal the sophistication of the systems of measurement. The Swedish Purchase and Consumption Tax Bill of 1756 distinguished between five different forms of taxation :

5. J. Brewer, *Sinews of Power - War, Money and the English State 1688-1783*, London, Routledge, 1989.

6. K. Åmark, *Sveriges Statsfinanser 1719-1809*, Stockholm, P.A. Norstedt & Söners Förlag, 1961, 400-414.

7. *Ibid.*

8. Figures taken from O. Feldbæk, *Danmarks økonomiske historie 1500-1840*, Herning, Systime, 1993, 152.

9. For Britain, *cf.* Brewer, *Sinews of Power* ; For Denmark-Norway, *cf* : Becker-Christensen, *Dansk toldhistorie II*.

1) The domestic customs duty was to be levied when agricultural or manufactured goods were brought to town, market or to certain designated administrational areas (including the mining districts). The tariff was paid per barrel :

- wheat flour : 8 öre
- wheat, rye flour, and peas : 5.5 öre
- rye, barley, malt : 4 öre
- oats : 2 öre

2) The port excise duty.

3) Home excise, levied on home brewing and home baking. The fee had to be paid at the local excise office. For brewing it was measured by the quantity of malt bought.

4) A sales excise, to be paid by brewers, bakers, butchers, meat traders, *etc*.

5) Mill duty[10].

The duties were set nationally and it is to be noticed again that specifications were always in terms of the trinity : commodity, a unit of measurement and a price. The tax payer brought the commodity to the bottleneck, a location where state-disseminated weights and measures were found. Here a measurement was performed by a civil servant, to some extent trained and certified by the state ; and the tax was to be paid in coins also disseminated by the state, the value of which was vouchsafed for by the state.

When the state promulgated standard weights and measures, it was explicitly in order to control abuse. The state defined ground rules for the many professions which dealt in day-to-day measurement : measurers, weighers, carriers, port controllers and firewood measurers[11]. It repeatedly decreed that standard metropolitan weights and measures be used exclusively in customs affairs. In 1687 it was decreed that all local weights and measures be destroyed and replaced with standards[12]. The repetition of such legal measures indicate that the position on the ground continued to be under less than full control. Bottlenecks ameliorated this problem.

MEASURING INSTRUMENTS AND THEIR USE

Accounts kept in the Copenhagen Town Hall enable an estimate of the calibrations carried through and secondary standards sold, thus giving an indication of the spread of calibrated measurement in Denmark-Norway of the time. The magistrate's Chamber of Calibration received just over 1.637 rigsdaler in 6 months of 1772 for sold weights and measures and calibration fees. Calculating from the prices and fees given this would correspond to, for example, the sale of 96 fitted salt barrels, 96 tin pots, 96 sets of 10 *lispund* weights, 96 sets of 1 *lispund* weights, plus the calibration of 96 salt barrels, 96 oil barrels, 96 tin pots, 96 tin jugs, 96 iron rods (1 *alen* long), and a 10 *lispund* metal weight. And this activity increased : in 1794, the income for calibration and sale of calibrated weights and measures had increased to just over 2.795 rigsdaler[13]. These numbers give an indication of the numbers for the late 18th century. The Copenhagen Town Hall has no similar records, allowing the historian to compare with earlier times. But it is possible to sketch the historical development by utilizing the rules and regulations related to weights and measures. This section will give an outline of these along with an account of the professionalization of measurers and then turn to two specific instruments as examples of the concerns for precision measurement in the context of taxation.

Danish weights and measures were reformed in 1683, when a regulation was devised in consultation with Ole Rømer[14]. Rømer had intended all weights and measures to be reducible from one standard length. Standard weights, for instance were given by cubic vessels of standard length, containing pure water. But the reality of weights and measures remained a far cry from Rømer's grand plans for order[15]. The 1683 regulation prescribed national standards and was followed up by supporting regulations intended to ease through the introduction of the new standards on a national scale. In order to ensure that weights and measures were indeed standardised, the Copenhagen magistrate was given monopoly of their sale. But craftsmen resisted this monopoly vigorously also after Rømer succeeded in wresting the monopoly from the magistrate in the late 1680s. When it was clear in 1687, that old measures were still being used, their destruction was prescribed but to no avail. Eventually, the king had to interfere in a dispute which dragged on until 1698 between the pewterers, the magistrate and Rømer. A new regulation now gave the Copenhagen magistrate and 4 provincial towns monopoly on sale of standards[16]. The difference between legal prescription and actual practice remained, but it was reduced. From 1698 onwards the Copenhagen magistrate began to take advantage of its monopoly. Accounts reveal that the magistrate made a nice profit over the cost of labour for cooper and smith when selling weights and measures. Citizens could also bring their weights and measures to the Town Hall for calibration against a fee[17].

10. K. Åmark, *Spannmålshandel och spannmålspolitikk i Sverige 1719-1830 - Akademisk avhandling*, Stockholm, Isaac Marcus' Boktryckeri-Aktiebolag, 1915, 81-88.

11. *Cf. Anordning om Maalere, Veyere, Vragere, Haufne-Fogder oc Faufnsettere*, Copenhagen, Bockenhoffer, 1683.

12. H. Becker-Christensen, *Dansk toldhistorie II*, 126.

13. Københavns magistrat, MC600 : 1696-1795 : Justervæsen, Copenhagen Town Hall.

14. " Ole Rømer ", *Dictionary of Scientific Biography*.

15. K. Meyer, " Dansk Maal og Vægt fra Ole Rømers Tid til Meterloven ", in *Beretning fra Meterudvalget om dets Virksomhed i Tiden fra dets Nedsættelse den 9. Juli 1907 indtil den 31. Marts 1914*, Copenhagen, J.H. Schultz, 1915, 57-91, esp. 57-70. *Cf.* also A. Hægstad, *Mål og vægt i Danmark 1283-1983 : den legale metrologi gennem 700 år*, Copenhagen, 1983.

16. *Ibid.*, 70-71.

17. Copenhagen Town Hall, Rådstuearkivet, Justerkamrets dokumenter 1696-1819. Also : K. Meyer, " Dansk Maal og Vægt ", 74-76.

By the 1740s, the task of Swedish calibrators was to some extent coordinated with local prefects. In the 1750s, just in time for the expensive war with Prussia, the enforcement of the laws was aided by the specification of punishments. All instruments (barrels, mugs, rods, balances, *etc*) were to be calibrated and hallmarked. Any trader possessing instruments not yet hallmarked was to have them confiscated and fined. Anyone using the wrong measures was to be put in the stocks for an hour, and to receive ninety beatings. Calibrators faking a hallmark were sentenced to death. Anyone changing a hallmarked instrument was fined and " dishonoured ". In the same period the problem of wear and tear was regulated. Weights in particular were known to change with use, and the customs asked Jacob Faggot, the Head of the Board of Surveyors, for advice. As a result the Board came up with guidelines for corrections to wear and tear. Also, topping up was prohibited and exact recompense was prescribed in some cases. In the instruction of 1783, the right of anyone to become a calibrator provided he (gender used advisedly) passed an exam, came to an end. Now, calibrators had to be appointed by the local administration. In the 1790s, the tasks were routinised. For instance, in Stockholm, every month belonged to the calibration of instruments employed in particular trades. In January all butchers, fish mongers and iron mongers were to have their instruments calibrated. In February it was the turn of brewers, bakers, distillers, and vinegar makers, and so on[18].

As Witold Kula has shown with abundant material from 18th century Poland and France, it is easy to get different results even when measuring with the same instrument. The local diversity in measuring practice which surveyors faced was great[19]. Not only were weights and measures different in different localities, but the practice of topping up after weighing or measuring was also common. The practice of exchange was not just a question of determining the equivalent value of two wares, or that of a ware in money, but an almost ritualised encounter. In Sweden, topping up could sometimes add 20% or more to the measured volume. Kula has shown that within local communities everyone knew the rules of the game, but with increasing circulation of traders and merchandise, the local varieties became increasingly problematic. The state, which was attempting to coordinate the activities across many local communities had an incentive to standardise, but locals resisted the new ways.

The human measurer thus introduced a moment of uncertainty into the aim of stabilizing value. The solution to this problem proffered in the 18th century was similar to the solution for instruments and coins. Education of measurers amounted to the routinization of standard procedures, and professionalization amounted to certification in analogy with the seal of the sovereign.

18. *Svenska Lantmäteriet 1628-1928*, 2 vols, Stockholm, Sälskapet för utgivandet av lantmäteriets historia, 1928, especially the articles by J. Svärdson, H. Juhlin Dannefelt and E. Williams.

19. W. Kula, *Measures and Men*, Princeton, New Jersey, Princeton University Press, 1986.

Looking back from the mid-18th century, Jacob Faggot, the head of the Board of Surveyors, argued that before 1680, surveying had been performed more as a craft than a science, and that it ought to be done by " washed hands ", referring to the class differences in cleanliness, and the division between intellectual and manual labour.

What follows is a description of the *de facto* and *de jure* professionalisation between 1660 and 1800 — in terms of the creation of a monopoly, of training, and control. The historical sources allows this to be illustrated particularly well for Sweden-Finland, which thus takes pride of place. In mid-16th century Sweden, there were no professional surveyors. Bailiffs, the county chief and a committee of local peasants carried out land evaluation. Local men or boys were employed measure with rods. Complaints from peasants about unjust taxation persisted throughout the century. A Board of Surveyors was set up in 1628 specifically in response to the complaints, and with the aim to make taxation more just and thereby facilitating its collection. The new surveying was to be coordinated by the prefects. All measurement protocols were to be submitted to the *kammarkollegium* Area and quality of the soil (measured by yield of number of haystacks) was to be reported along with the owner's name and number of grown-ups living on the land. A land register was to be collated from this. Initially, maps were not drawn. In the last decades of the 17th century, when the *reduktion* (the state confiscation of nobility-owned land and its subsequent parcelling out to soldiers) was at its peak, surveys were carried out all over Sweden. New regulations were introduced : in 1687, the king prescribed that surveyors take an oath as qualification for this kind of work. It was also decreed that houses and properties be searched as part of the evaluation, and that an inventory be established. Surveys, and by extension evaluations, were controversial, so that four additional local civil servants were to participate. A report of measurements, evaluation, and drawings was to be submitted to the *kammerkollegium* for each unit of land surveyed.

We have repeatedly seen that several trustworthy individuals apart from the surveyor had to take part in the measuring process for the result to be trusted. Who measured mattered and the regulations were getting increasingly explicit about whom to involve. In addition, the question of measurement technique also gained in importance. Some of the early instruments were very simple. Mostly, ropes were employed. It is only towards the end of the 17th century, when the *reduktion* was under way, that geometrical instruments were used. Geometrical was the term employed to distinguish the instruments measuring angles from rods and chains measuring lenghts. These instruments involved more complicated geometrical calculations.

In the 1660s, weights were for the first time separated from the issue of coinage. An inspector was appointed by the *kammarkollegium* to oversee all large balances and weights of the realm, except for the small ones intended for gold and silver which continued to be under the auspices of the minting examiner (*riks-guardien*). In 1665, a declaration was posted that only certain balances and weights were to be employed, but no additional hands were employed to test existing instruments. Calibration was to be the responsibility of the general administration, which was naturally busy with other matters.

Around 1700 a number of initiatives were taken. Surveyors were to be examined and licensed. All rods, chains, and ropes were to be calibrated against the Stockholm unit of length. Also, the intellectually more demanding instruments to be employed by " washed hands " such as astrolabes, quadrants, compasses, spirit levels, proportional circles (invented by Galileo), rulers and similar instrument were to be introduced.

In the early part of the 18th century peasant grievances about the abuse of weights and measures increased. In response, the parliament debated the pros and cons of a corps of well-qualified calibrators (*justerare*) spread out over the entire realm. In 1735 the government decided to add weights and measures to the responsibilities of the Board of Surveyors. Market towns were to have a calibrator taken under oath, who also had to pass an exam at the Board of Surveyors. Calibrators were to be remunerated through fees, and it was to become compulsory for traders to have their instruments calibrated. As a result of Scanian peasant resistance in the 1750s and 1760s, a new instruction for surveyors was introduced in 1766. It prescribed in much greater detail just what was to be measured and reported back to the central administration. In addition, the peasants involved had the right to appoint independent " reliable " (what this implies is not specified) observers when the quality of the soil was to be evaluated, except when the evaluation was simultaneously done for the purposes of determining the tax level. These independent observers were to try to mediate and resolve any dispute, before the case was referred to local courts. Because of these practical organisational problems, the instruction of 1766 reiterated the need for the introduction of calibrated instruments. Now, the practice of surveying was prescribed in even greater detail. There were rules for the setting up of corner stones, and rules for dealing with the topography of the land. Reconnoitering in advance of the actual measurements was emphasised. And there were further rules for the way in which maps were to be drawn and information to be recorded. In the winter and in all hours of leisure, the surveyor was to make fair copies of all his drafts. The kind of paper, pen and colour to be employed was prescribed too. By 1783, a new surveyors' instruction specified further the process of evaluation of land quality. Fields, meadows, newly cultivated land, forest etc. were now to be evaluated separately. Within each kind there were several gradations for the possible value. At the same time the ways in which compensation for exchange of superior against inferior land could be paid (manure, labour, or money) was determined.

In the rest of this section, I will examine two sample instruments which both illustrate the concerns of precision measurement within a network for the purposes of taxation. The first, described in a publication in the *Transactions of*

the Copenhagen Academy illustrates the production of a metropolitan standard aiming to improve the levying of an alcohol excise[20]. It addresses the problems of precision and reliability and calibration in the metropolitan setting in order that the instrument be used elsewhere. It was entitled " On the means of examining, testing and evaluating all spirits traded, both in terms of their measure and their quality, *etc* "[21]. The author, Franz Heinrich Müller, stated that the Customs Office had set him the task of making an instrument for the purpose of assessing alcohol content, in order to " measure their value in money ", while also emphasising that every trader can use it, since he must know the value of merchandise to avoid harming either himself or his customer and retaining the faith of the public. As we shall see, the parallel with the second instrument examined below, Ekström's grain tester, is extensive : precision measurement employed for the purpose of evaluation ; the making of a standard instrument initiated and paid for by the state but intended also for the market.

Müller refers to the measuring rods of standard size usually employed to measure the content of barrel by holding them diagonally within the barrel. The much more taxing problem was the alcohol content. His solution was a silver rod which was to be dipped into the liquid in question (see illustration 3 : Scala for en Brændevins Pröver). The portion submerged indicated the alcohol content, and the silver rod was to be given markings denoting this alcohol content. These markings were applied in a metropolitan laboratory where the purest water and alcohol available were mixed in varying proportions and the dip of the silver rod tested. The rod is depicted on the left of the illustration and the columns on the right refer to I : the total quantity of liquid ; II : the mix of water and spirit. The original calibration of the rod was performed at 0 degrees Reaumur (already fairly advanced, requiring control of temperature and a thermometer calibrated on the Reaumur scale). The calibrations on the rod with the numbers in column III, referring to the quotient of water and alcohol. However, this quotient was different for moderate and hot weather (given in columns IV and V, respectively). These quotients were also tested at the time of the original calibration.

Müller emphasised that other methods of alcohol content were less useful : distillation was too expensive ; burning required absence of wind ; a hydrostatic balance was fragile, slow and required to be used indoors ; judging by

20. The alcohol excise was introduced in 1688, *cf.* H. Becker-Christensen, *Dansk toldhistorie II*, 256 and it became increasingly important for the state coffers throughout the 18th century.

21. F.H. Müller, " Om Maaden og Midlerne at undersøge, prøve og vurdere alle i Handelen forekommende Brændevine, i Hensigt til deres Beskaffenhed, som Maal, med videre ", *Skrifter som udi det Kiøbenhavnske Selskab af Lærdoms og Videnskabers Elskere ere fremlagte og oplæste*, New Series, 3 (1788), 202-219 ; he completely changed the design later : " Nøiere Oplysning og Forbedring vedkommende Brændeviinsprøveren og sammes Anvendelse ", *Skrifter som udi det Kiøbenhavnske Selskab af Lærdoms og Videnskabers Elskere ere fremlagte og oplæste*, New Series, 5 (1799), 71-81.

the bubbles created by shaking was unreliable. His rod thus " travelled " better than any of the rival candidates. Still, he did emphasise that the rod was subtle and must be protected from knocks and falls with a padded container. The rod could be used to detect fraud almost instantly. But not all fraudulent techniques were detected by it. One such technique was to heat the liquid just before the measurement was to take place, and thus temperature must be carefully checked. The trust inspired in the value of the merchandise by the spirit tester was to provide savings in transport, insurance and other costs.

This silver rod spirit tester thus illustrates very clearly the issue of calibrating an instrument which can be used with ease out in the field where measurement and evaluation takes place. It also shows the problems of control, authority and fraud.

Towards the end of the 18th century, many such instruments were in demand. The demand for a local precision instrument maker thus became acute. The surveys required good sextants, mural quadrants, geographical circles, levelling instruments, compasses, chains of measurement, good quality paper, *etc*[22]. Customs and excise required a variety of instruments such as Müller's silver rod. But no instrument maker capable of producing the kind of quality which was the norm in European centres lived in Copenhagen, nor were the requisite skills to be found with the already present crafts. It required that someone gathered the experience abroad and returned to set up shop in Copenhagen[23].

The second instrument, a grain tester devised by Daniel Ekström, is equally informative about approaches to measurement (illustration 4 : " Tab VI "). Its purpose was to regularize the measurement of the quality of grain seed by comparing its weight and volume. It was not just designed for official use ; Ekström emphasizes that any tinsmith could make it, and he recommended its widespread adoption. It would improve accuracy of testing even when reproduced with only moderate tolerances, because it required no close measurement of volume ; in conjunction with an accurate balance and weight, it allowed reliable comparisons between grain samples.

The way in which the grain is poured is critical since it affects packing ; in mill practice it was considered cheating to pour grain into a barrel from higher than the hip. Similarly, when testing samples of grain, seed would be dropped carefully into the container from cupped hands as shown. Again, the way of pouring the seed could be employed to pack the seed differently. Ekström's instrument is intended to eliminate the uncertainty of the use of hands in the normal measuring process (fig. 1 on the left hand side of the illustration is

22. K. Nielsen, *Hvordan Danmarkskortet kom til at ligne Danmark - Videnskabernes Selskabs opmåling 1762-1820*, Århus, 1982, 12.

23. D.Ch. Christensen, " Spying on Scientific Instruments - the Career of Jesper Bidstrup ", *Annals of Science*, **52** (1994).

Ekström's instrument, the hands on the right simply indicate the usual procedure which he aims to eliminate). The container *ab* has an adjustable floor *c*. The container *ab* is now put underneath another container *ghik*, which has a hopper at the bottom that can be opened and closed. With the hole closed, the seed is poured into *ghik*. The rod *lm* determines the height between *ghik* and *ab* and can be set to a standard distance. Thus, to whatever capacity the container is set, the distance between hopper and floor remains the same. By opening the hopper, the seed then falls into *ab* in a standard way unlike the pouring from cupped hands.

In preparation for the measurement, the seed was to be dried to prevent the water content from influencing the measurement. Ekström suggests standard ways and lengths of time for the drying process. Once the grain samples to be compared are equally dry, a known weight of the first grain type is poured into the container until the grain fills the container to overflowing, and the surplus is levelled off, flush with the rim, using a specially constructed tool which Ekström describes in some detail. The container is then emptied, without changing its capacity ; grain of the second type is then also poured in, until it also fills the container exactly to the rim. It is interesting that Ekström is not satisfied to use a container of fixed capacity. Probably, this is so that the container can be adjusted to the standard weights for each kind of grain.

With many grain testers of this kind, the quality of seed could be ascertained everywhere. Ekström referred to the need for distributing grain testers by mentioning the most recent Royal decree on barrel measures. The state actively supported this kind of work ; in fact Ekström performed the experiments on the order of the *kammarkollegium* at the royal grain depot. Ekström also claimed that the instrument would help to mediate in international grain trade, referring to Dutch standards and the requirements of the Dutch market[24].

MONEY

Coinage was always crucial to the collection of taxes, as far back as Roman times[25]. The value of coins was forever in dispute, and there were repeated attempts to standardise them. Furthermore, the precision of the value of coins continued to be an issue and the state mostly took great pains to keep coins as uniform and standardised as possible. The process of minting was highly specialised, involving both precision weighing, chemical expertise, and extreme control. The value of the coin produced under these circumstances was vouchsafed for by the image of the sovereign on the coins themselves, very much

24. D. Ekström, " Beskrifning På en Spanmåls-profvare, inrättad efter Svänskt Mål och Vigt. ", *Kongl. Svenska VetenskapsAcademiens Handlingar för Månaderna Julius, Augustus, September, År 1753*, 224-241.

25. J. Porteous, *Coins in history - A survey of coinage from the Reform of Diocletian to the Latin Monetary Union*, London, Weidenfeld and Nicolson, 1969, 15.

like the standard weights, measures and rods. There was also a geography of measurement with a hierarchy of precision, the highest precision achieved at the mints, the lowest in a provincial marketplace. Measurement and evaluation is thus intimately involved in coinage and many of the problems are the same as in weights and measures. Bottlenecks were also special points where counterfeit coins could be detected.

The main techniques for testing gold and silver content in coins were widely disseminated all over Europe even in the Middle Ages[26]. Weighing was one way of assessing a coin's value, but sub-standard coins could be rendered heavy by an admixture of lead. A more sophisticated measure consisted of the hydrostatic weighing, that is weighing consecutively in air and water which, as we would now say, detects lead by determining the specific weight of the amalgam[27]. The sophisticated test which was known to goldsmiths all over Europe in the Middle Ages and remained an integral part of minting practice throughout the period concerned here was a full-blown chemical analysis. Towards the end of the 18th century, the trade secrets of coin assaying were published in book form[28]. The sample was placed in a small container made of clay. Aqua regia was added and the container was heated to a high temperature in an oven. The impurities were absorbed into the walls of the container leaving the noble metals to be weighed.

These analytical and measuring practices spread throughout society wherever money changed hands. Simple, cheap balances were more widely employed, and many traders would employ hydrostatic balances (especially towards the end of the 18th century), whereas the costly and time consuming full-blown chemical analysis was restricted to only a few places, such as mints. The state attempted to counter coin clipping and the filing off of metal dust with harsh punishments but also by setting limits for the acceptability of coins. They were to possess weights within particular limits. If found too light, they could not be accepted as tax payment. Similarly, the content of precious metal in the coins had to be within certain limits. This was called the *remedium*[29].

26. Sir J. Craig, *The Mint - A History of the London Mint from A.D. 287 to 1948*, Cambridge, Cambridge University Press, 1953. For the so-called trial of the pyx, see esp. 394-397.

27. Ekström also had such instruments in his repertoir ; *cf.* A memorial by J. Faggot to the Swedish estates : " 6.2 Memorial til Riksens Ständers manufactur och Handels deput. ang. mathematiska Instrumentmakeriet, 29 martii 1739 ", Lantmäteristyrelsens expeditionsböcker B1 :14 1731-1740, Lantmäteriverkets arkiv, Gävle ; *cf.* also M.A. Crawforth, *Weighing coins - English folding balances of the 18th and 19th centuries*, London, Cape Horn Trading Coy., 1979, who gives a good impression of the increasing distribution of precision balances towards the end of the 18th century. M. Daumas also covers precision balances on pp. 221-227 of his *Scientific Instruments of the Seventeenth and Eighteenth Centuries and Their Makers*, London, Batsford, 1972.

28. S. Haase, *Eröffnetes Geheimnus der praktischen Münzwissenschaft*, 1762 ; S. Haase, *Vollständiger Münzmeister und Münzwardein*, 1765 ; J.O. Ruperti, *Das Probiren, in so weit diese Wissenschaft zu dem Münzwesen nothwendig gehöret*, Braunschweig, 1765. Note that Ruperti's title refers to assaying as a science.

29. e.g. *ibid.*, 179.

The precision with which the mint produced coins within the limits was extremely important. If the content of precious metal was too high, the coins would disappear from circulation and be melted down ; if it was too low, it would not inspire trust (especially as the state itself might not accept it is tax payment) and it would fall below its stipulated value causing inflation. If coins were produced with too large a spread in the precious metal content, the more valuable ones would disappear. This was called " seigern " in German and the process was denoted " Gresham's law " in English[30]. The Crown thus had a great interest in the production of coinage with very precise contents and weights and in preventing tampering with coins, both for the purposes of having money with which tax could be paid, and for the purposes of enabling trade and avoiding inflation[31].

The value of coins was vouchsafed for by the organisation of the mint in a similar fashion to the organisation of a laboratory : restriction of access, use of sophisticated scientific instruments and accounting practices, enabling the sovereign to keep some degree of control over work in the mints without actually having to be present at the time of minting. Indeed, the mint is also a bottleneck. Furthermore, the work of the Master of the Mint was surveyed by a Guardian, employed for that purpose. The regulations and control techniques at the Mint got ever more sophisticated in the 17th and 18th centuries. At the Royal Danish Kongsberg Mint, the instructions for the Master of the Mint and the Guardian in 1628 and 1629 were very brief by the standards of a century later (the text is roughly a fourth in length). The Guardian of 1629 had mainly to be observant and diligently assay the amalgam before it is struck[32]. By contrast, the instructions for the Guardian in 1730 consisted of 14 paragraphs. He was now obliged to take samples several times during the minting process and it was prescribed who was to be present. He was then to analyse the metal contents in his own laboratory. The locking up and sealing of samples, the accountancy and report required were much more detailed than a century earlier. He was now also allowed to calibrate samples brought to him against a fee, while remaining under his oath of fidelity to the king, thus very much resembling the role of the Stockholm and Copenhagen magistrates[33]. Again, trust, authority, and detailed regulation combine to vouchsafe for a stable value.

The organisation of the Swedish Mint was similar. A manuscript which has been dated to 1720, refers to the practice of minting, the control functions of

30. A. Luschin von Ebengreuth, *Allgemeine Münzkunde und Geldgeschichte des Mittelalters und der neueren Zeit*, 2. ed., München & Berlin, R. Oldenbourg, 1926 ; Craig (note 27).

31. This did not prevent sovereigns from attempting to make a profit from coinage, by issueing substandard coins, but state and trade always paid for this through the obstacles put in the way of smooth collection of tax and exchange of merchandise. *Cf.* Craig, *The Mint*, *passim*.

32. B.R. Rønning, *Den Kongelige Mynt 1628-1686-1806*, Norges Bank/J.W. Cappelens Forlag a.s., no place, 1986, 298-299.

33. *Ibid.*, 310-314.

the Guardian, and the bookkeeping procedures in virtually the same terms as the Danish one of 1730[34]. In it, the authority of the sovereign is addressed : " Those who counterfeit should receive harsh punishment, not just for reaping a large profit but especially for profaning so shamefully the royal prerogative... Noone should disrespect the royal mint ; rather one ought to respect the country's honour and the royal prerogative, not tread it under foot. The ancient Romans considered throwing a coin with the sovereign's image into the latrine a *crimen læsæ Majestatis* "[35].

The social organisation of the mints and their use of scientific instrumentation was a result of this concern of the state. To glimpse the kind of precision work performed in a mint, we can inspect an 1806 inventory of the Kongsberg mint. From it we can see that precision measurement took place here, along with chemical analyses of various kinds. One room was called " laboratorium ", where a *Probeer-Vægt* (assaying balance) and two *Proberovne* (chemical ovens) were found. Next door was an iron balance with copper bowls and weights of various sizes. In another building was a room with two rough, five precision, and two very high precision balances. Many rooms contained ovens and various kinds of tools for handling materials in the ovens. There was also a *Kontoir* (comptoir or office) where containers with locks were kept. Many doors had locks bearing witness that this was a place with highly restricted access just like modern laboratories[36].

The publications of the Academies also dealt with precision work in minting, as mentioned above. For example, Müller (the same person who devised a spirit testing instrument) depicted many tricks of the trade, analysing various aspects of minting, such as the dimensions of the oven, the best means of producing vials and containers, the impact of various ways of stacking the coal[37]. The analysis was explicitly intended to improve precision.

Conclusion

This account shows that the routine measurement in 18th century Scandinavia took place at bottlenecks provided by the state for fiscal purposes. The bottleneck provides the focus in which the three spheres of circulation (merchandise, measuring instruments, and money) are concatenated. The bottleneck is thus the prime place where the practice of measurement is most commonly found in the 18th century. In Southern Europe, taxes continued to be levied primarily on land, and the nation states did not develop administrations and civil services with the same speed. There was no development of Excises with their routine evaluation of merchandise, and the Academies of Science (Greece did not have one) also languished by comparison.

18th century (and maybe also later) history of science should be seen in the context of the state. The state was involved in most of what has been discussed here. The personal links are explicit. For example, Jacob Faggot, the main force behind enclosure in Sweden, was simultaneously Head of the Board of Surveyors (a part of *kammarkollegiet*, the fiscal department of the government), promoter of the instrument maker, Daniel Ekström, and Member of the Academy of Science. The state was involved in the building of town walls, town gates and other bottlenecks. The state had soldiers posted in such places. The state set up calibration networks and had a hand in the professionalisation of surveyors. Calibration was accompanied by certification : the stamp of authority (of the sovereign of the state) was embossed on coins and instruments. The state employed instrument makers (Ekström was purveyor to the Board of Surveyors) and paid for their education. The state paid the Academy to provide solutions to problems arising at the bottlenecks (in the case of Sweden, the state guaranteed that the Stockholm Academy had a monopoly on almanacs within the reign, which turned out to be quite a money-spinner).

The concatenation of the three spheres of circulation redefines all three. In order for smoothness of operation to take place in the bottlenecks, value must not be an issue leading to conflict. Calibration stabilizes value. The procedure at mints stabilizes value. The stamps of authority stablize value. The more people trust the instruments, the coins, the categories of merchandise, the more stable evaluation in the bottlenecks will be. That coins and instruments are shaped by the threefold concatenation should be obvious. The reconfiguration of the merchandise is akin to the process of commodification described by Marx and splendidly illustrated by Schivelbusch[38]. Marx defines the commodity as the uprooted piece of merchandise which is devoid of any social meaning except as something to be exchanged. As we have seen, the measurement in the bottlenecks provides a stable evaluation of merchandise and configures it

34. The manuscript is entitled : " Humble report on the Mint " (Underdån ödmiuk Relation om Myntet), and is reprinted in K.-A. Wallroth, " Sveriges Mynt 1449-1917, bidrag till en svensk mynthistoria meddelade i myntdirektörens underdåniga ämbetsberättelser ", *Numismatiska meddelanden utgivna av svenska numismatiska föreningen*, 12 (1918), 177-201.

35. *Ibid.*, 178.

36. *Inventarium til den kongelige Mynt paa Kongsberg*, dated 11. januar 1806, Rigsarkivet (State archives), Copenhagen, Finanskollegiet, journalsager, jnr. 503, 1806 ; also printed in Rønning, *Den Kongelige Mynt*, 323-329.

37. F.H. Müller, " Sølvets Prøvelse til Nytte for Mynte-Væsenet og Sølv-Handelen ", *Skrifter som udi det Kiøbenhavnske Selskab af Lærdoms og Videnskabers Elskere ere fremlagte og oplæste*, New Series, 2 (1783), 153-173 ; and " Om Guldprøvens nøiagtigste Omgangsmaade til Nytte for Myntvæsenet og Guldhandelen ", *Skrifter som udi det Kiøbenhavnske Selskab af Lærdoms og Videnskabers Elskere ere fremlagte og oplæste*, New Series, 4 (1793), 1-28.

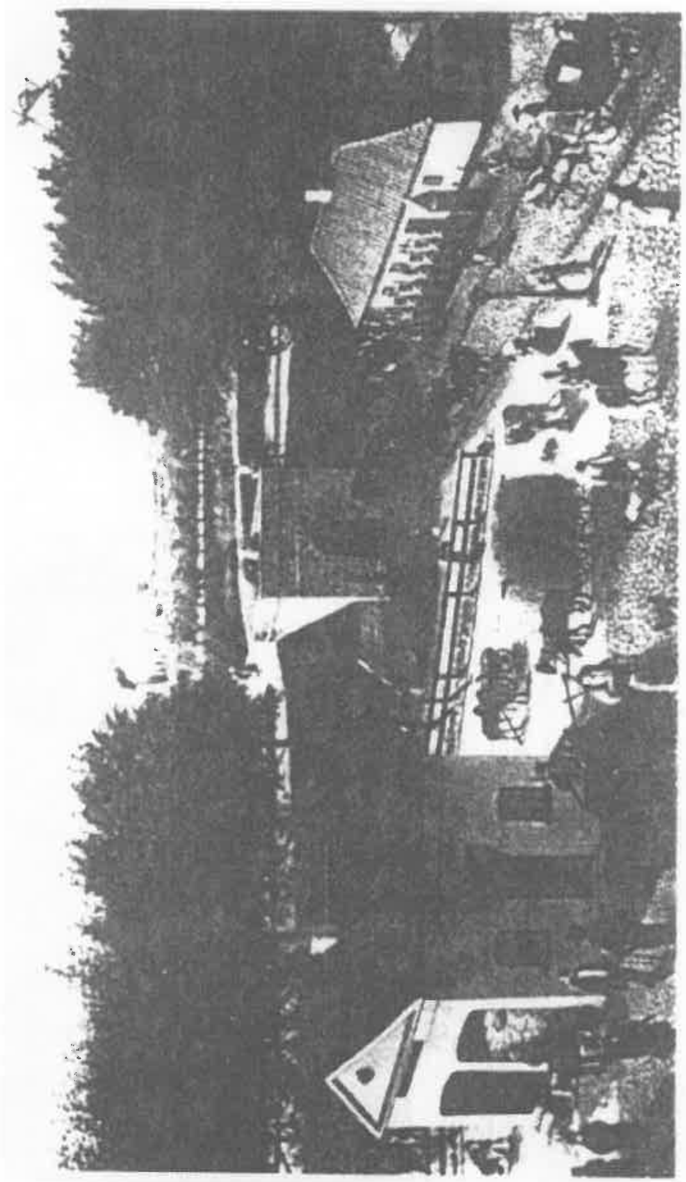
38. " This locational movement — the bringing of the product to the market, which is a necessary condition of its circulation... could more precisely be regarded as the transformation of the product *into a commodity* " (K. Marx, *Grundrisse, Foundations of the Critique of Political Economy* (London, 1973), 534, italics in the original). Quoted in W. Schivelbusch, *The Railway Journey - The Industrialization of Time and Space in the 19th century*, Berg, Hamburg, New York, Leamington Spa, 1977, 1986, 40. Schivelbusch brilliantly unearths the diverse cultural impact of increased circulation as a result of the railways.

in particular categories. Marx thought of the commodity as defined by exchange in the market. This paper suggests that one could think of the commodity as defined by the state.

In all cases of evaluation, there were different levels of exactitude. Precision was geographically differentiated. In the case of coins there was weighing, hydrostatic weighing, and chemical analysis. In the case of surveying, there were rods or chains, geometrical analysis on the basis of simple determinations of angle, and high precision surveying instruments. In the case of merchandise, there were simple rods or balances used with coins, there were copies of copies of standard weights and measures, there were standards kept in the capital and finally there were high precision scientific instruments. The level of exactitude was related to the locale. After all, high precision was not always required. It was expensive, demanded great care and controlled surroundings. Low precision was cheap, quick and possible almost everywhere. The highest precision was to be found in the capital where standards were generated under great control. Copies of the standards were promulgated and used in the provinces under diminished control. The bottleneck provides the means for approximating the conditions to those achieved at a standards setting location in the metropolitan centre.

The bottleneck could be seen as a pre-history of the laboratory in that they are places where control of the environment enables precision measurement. Labs are now more specialised and they do not always evaluate commodities. That is one more reason that their economic role is not always very explicit. But it would be possible to examine the economic role of a great many modern laboratories in which evaluation is performed as a part of state regulation. In these cases, the economic role is similar to that of the 18th century. And standards (such as weights and measures) certainly continue to be of great importance in the modern economy.

ILLUSTRATION 1



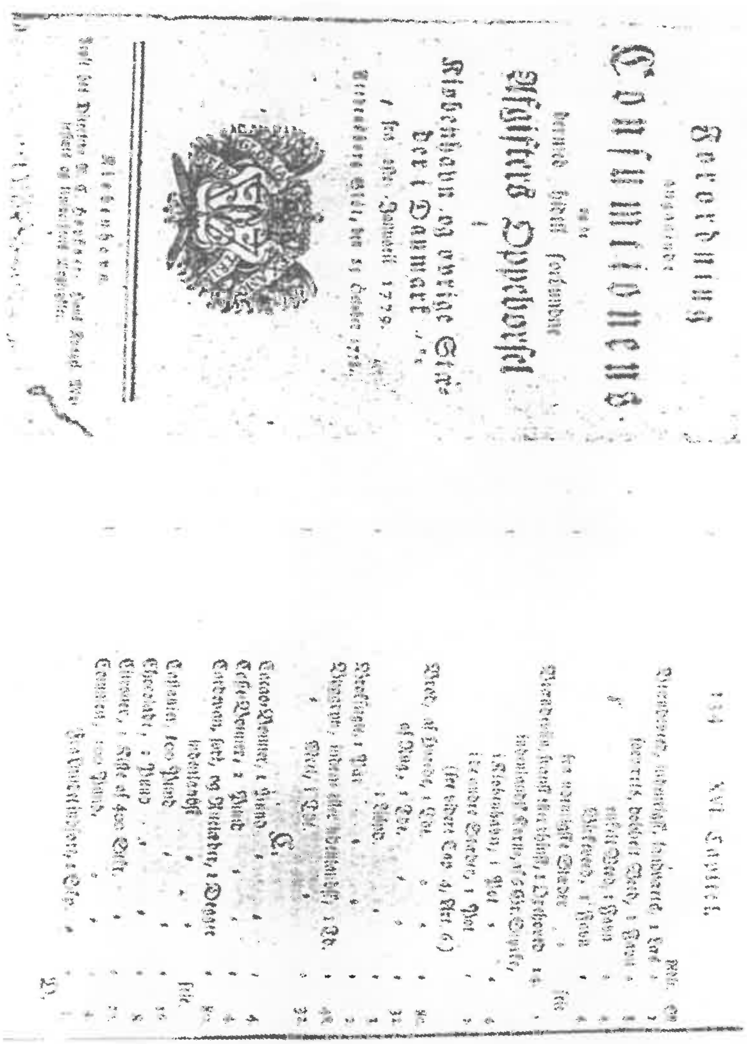


ILLUSTRATION 2

ILLUSTRATION 3

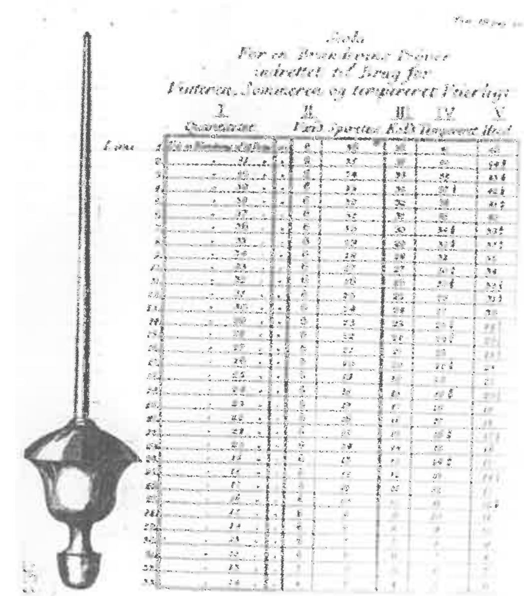


ILLUSTRATION 4