PROBLEMS

*Towards a Historical Technometry**

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1. The problem of measuring progress in the "technical history of technology".

At present in the study of the economic importance of technological innovation the progress of technology has normally been measured with the aid of econometric methods which provide the basis for nearly all quantitative history. But although those aspects of change which are most relevant to economic and social history, such as investment in technical apparatus, the volumes, costs and gains of production, increases in technical training, demographic movements and so forth, as well as certain other phenomena, such as industrialization, may be reasonably accurately measured in econometric terms, those features which constitute the internal history of technology, or what E. Olszewski has called the « technical history of technology », are neglected in such an approach.

If the technical history of technology is to be included in quantitative history, or whatever label we are to give it, then we must first establish the means of quantification specifically designed to cover technical phenomena and provide methods which will be capable of illustrating in quantitative terms the peculiarities of technical evolution. Taken together such methods constitute "historical technometry". Although using the same units as the

* This article summarizes a paper given to the *Colloque of ICOHTEC* in Tokyo (Aug. 1974) which will be published with the conference proceedings; certain of the basic concepts were developed in a paper given at the *XIVth International Congress of the History of Science* (ibid.), available in the published proceedings, and have been contributed to the volume in memory of F. Melis.

centimetre-gram-second (cgs) system, technometry must apply these units within a conceptual schema which will allow us to identify certain features that establish the superiority, or greater efficiency or development, of one technical apparatus over another of a similar type, or of one designed to perform similar functions and purposes. Both superiority and progress are strictly related to the phase of the development of civilization, in so far as this can be seen as a process of ever increasing rationality.

Four such phases which are of particular relevance for our argument can be identified immediately. These technical stages can clearly be related to certain cultural and social values, with which they do not always coincide, and indeed from which at time to time they may even seem to diverge. But the growing rationality of a technical apparatus (a machine, a process etc.) can be seen in terms of: greater efficiency in conformity with the scientific knowledge either of the present (a) or of a given period (b); its belonging to a more advanced stage in the development of forecasting (c) or of automation (d) connected with super-organic evolution.

2. The use of the concept of "efficiency" (a) of a technical apparatus or process.

The concept of the "efficiency" of a technical apparatus is a criterion of the economic value of the apparatus itself. This economic value is also however essentially technological or internal to the apparatus, from which the term takes on a specific sense (e.g. as in the terms "thermal efficiency", "mechanical efficiency", "practical" or "aggregate efficiency") which must not be confused with similar terms such as profitability, income, net product etc., as used in economics, for the practical results may well be quite different even though they share certain theoretical assumptions. For example, from a technical point of view an electric motor working at high efficiency (say 0.95) may be more "costly" (and hence less preferable) in a given economic situation, a given place and time, than say a donkey or some other domestic animal (with an ergonometric efficiency of perhaps 0.20) when the cost of hay is only 1/10th the cost of the electrical energy which the motor would need to produce for the same work. The components then of technometric calculations differ from econometric calculations. The obsolescence or life of a technical apparatus, for example, is often omitted from a technometric calculation while various properties which are often considered non-economic (such as air, health, intelligence) are left out of econometric calculations of costs when estimating returns and efficiency.

As it is well known the concept of "efficiency" [*rendimento*] originates in the 18th century, being related to the principle of the *minimum*, and was formulated in precise terms for different fields (in logic "sufficient reason", in optics "minimum distance" in economics "minimum cost", "effort" or "means") from Leibnitz and Maupertuis to the Physiocrats. Certain concepts such as labour and utility were extended from men and animals to machinery and then incorporated into an integrated social and political world-view which proclaimed the maximum "public happiness" (which is of course the same as the minimum public misery). But the analysis of mechanical efficiency in physics and the other "natural sciences" developed differently from that of economic efficiency, and the physicists' concept of efficiency and output was never used by economic historians before the XXth century.

The introduction of the factor of technology in the notion of productivity, which until twenty years ago was still based on the formula $P=f(L^{a}K^{1-a})$ and was limited to the economists' traditional concept of labour (L) and capital (K), was certainly important and made it possible for certain phenomena of growth (and contraction) to be understood through a purely economic and econometric approach. This has related to the consideration of such phenomena as the increase in the division of labour in different economies, economies in mass production, the more efficient allocation of the factors of production, the importance of better training. But while some have given particular attention to the field of "technological innovation", it may still be doubted whether this has served, except in the most general terms (as in the case, for example, of Cipolla's book dealing largely with the pre-statistical era),[1] to clarify the importance of scientific and technological progress and its application in agriculture, the most important of all sectors of the economy until the 18th century. Although the figures for grain yields given by Slicher van Bath, for example, are more precise than Titow's more generic table covering grain, oats, rye and barley, it is still far from clear to what extent these improved yields can be related to manuring, methods of sowing, type of terrain selected, to mention only a few of the factors which result from human choice and practicality, which is hence the same as saying human technology, rather than to the types of seed used (if we leave aside for the moment climatic change and other autonomous material factors). This last factor is of course closely related to genetics and genetic technology, and is almost totally neglected by Slicher van Bath even though it is in fact the only specifically technological attribute of the seed-crop, and as such must be of primary importance in the technometry of seed yields. If in place of plant genetics we consider the importance of the selection of one species or breed rather than another then G. Doria's information about the cattle of Montaldeo becomes equally unhelpful from a technometric point of view. One has only to glance at

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[1] C. M. CIPOLLA, *Storia economica dell'Europa pre-industriale*, Bologna 1974. Some economists include the so-called "third factor" in the formula

$$Q = A(t) \cdot f(KL)$$

where Q is the total volume of production, t the temporal variable and A is a cumulative index of technical progress or efficiency.

modern studies on selective breeding of livestock to appreciate what precise definitions of "utility" are needed in any technometric calculation. For while suitability to desired ends, or in other words utility, is certainly an economically relevant factor, the development and attainment of the specific means and processes most suited to that end is in itself also a technical factor which derives from principles which may well be totally alien to economics. Generally, however, the technical "minimum" is connected with both an economic "minimum" and with other considerations, except where purely technical results are being sought, as in the case of athletic records for example. Leaving such values aside, however, it is possible to establish efficiency and output in purely technical terms, and these may subsequently later have repercussions on economic factors.

In technometric terms maximum efficiency (in theory or "ideal conditions") is measured as 1 (or 100%), but as there is an insuperable barrier arising from certain generally accepted conditions (in a system in which matter or energy are conserved it is impossible for either to increase so allowing values greater than 1) in practice C>P (i.e. the return, or Product, is always less than expenditure or Cost). In certain economic processes, however, P>C occurs, and in fact one might argue that the entire discipline of political economy derives from the need to achieve P>C in economic activity. But this economic result can only be obtained a) in monetary terms, or at least by reckoning current earning b) by deeming certain cost factors to be not economically relevant c) and especially when natural or "non-enthropic" factors are constituent, even if only partially, in the costs. It is for such reasons that econometric analysis appears distorted in technometric terms and can offer technometry little assistance, whereas technometric analysis on the other hand can furnish valuable aid to econometrics. One can even argue that the economic analysis of a productive process ought always be preceded by a technometric analysis, because the latter can always subsequently be translated into econometric terms simply by introducing economic values such as of "energy". Even more often, certain forms of "matter", may well be simply omitted in the econometric calculation either becaues they are deemed to be freely available or because they are undervalued, or simply not valued at all, when determining the price of "labour" for example or when there is an abundance of a certain type of material which consequently is not considered as an economic asset. In agriculture, for example, the availability of rain water, of the naturally dispersed mineral deposits required for cultivation, of heat from the sun, of power from the winds, or shelter from them, or of other "natural factors" is not always included in calculations of the "value" or cost of the land. Similarly in an industrial process, the availability of gratuitous natural resources (such as water supplies) or of intelligence, or cultural and technical training (which relate to the typical "non-enthropy" of behaviour-information-intelligence) or of competence and ability amongst the managerial and executive groups is not always adequately valued in the remuneration (wages and salaries) of labour, or else is measured quite differently from say the price of the calories involved (in the case of mental activity at least this would appear to be minimal) due to the impact of other economic and non-economic forces, for example market forces. And one would point out that the notion of plus-value originates from the formula $P>C$, that an economist might verify this in terms of technometric principles, drawing also on ergometrics and the biological sciences, and that while technometry is not yet in a position to fully evaluate the "information" provided intellectual activity (philosophy, art etc.) econometry can at least consider its market value.

The notion of output or efficiency is then a measure of convenience or utility obtained by comparing the result with the effort (or cost) expended to obtain it. This is seen clearly in the concept of "yield" used in agriculture, of "gain" used in industry. But economists could use the concept more precisely were they to study more accurately the specific features of thermal, hydraulic, optical, luminous, quantic or propulsive efficiency, or even the use of efficiency in physics. The concept can be adapted to translate physical magnitudes into magnitudes of similar types, in order to define more clearly the notion of "labour" as is done in the engineering formulae which distinguish between "useful work", "motive work" and "passive work", relating all three to the degrees of resistance, or the costs, to be overcome. The same is true of the notion of energy. In the same way that advances in other human sciences rely on the adoption of theories formulated in the natural, physical and mathematical sciences (for example the theory of information used by palaeographers and glotologistes, who employ a concept of "output" when examining signs, or else the calculations of probabilities which are fundamental to "quantitative historians") so we must understand that economics may well benefit from the development of technometry, and not only in terms of commercial programming, and that economic historians can gain from it too.

As a precise technometry has existed in mechanics for some two centuries now, this is the area with which we should start. The origins and development of the economic notions of gross product and return, or of nett product and gain, in terms of the "internal" economy of a machine was similar to that of the notion of efficiency and output. This created a need for the definition of the units of measure for work and power (H.P., calory, watt) together with the elaboration of various general principles and concepts regarding the conservation and transformation of matter, energy etc., and methods for measuring these, of which the "Watt indicator" was of course a major discovery. "Organic — or mechanical — efficiency" was taken to be the relationship (expressable as a percentage) between the work done by a machine, say a steam engine, and exerted on the drive shaft in order to activate another machine, and the work produced by the expansion of the steam on the piston. The efficiency of a heat driven machine (efficiency in converting thermal into mechanical energy) was calculated analogously with water driven machines, and calculated for individual cases with reference to the "ideal machine", once Sadi Carnot had defined « ideal or maximum thermal efficiency », so in turn excluding "mechanical efficiency". The two outputs combined together then give the total output (the practical or useful output), which is derived not only from the differences in temperature between the heat at entry and exit (i.e. in the condensor) and from the inertia and friction of the mechanism (studied as tribology) but also from the size of the machine itself (in marine internal combustion engines output increases in greater proportion than total volume of cylinders) and so in order to assess its suitability for use as fixed or self-transporting machinery it is necessary to consider weights, volumes, etc., as well. Sadi Carnot's scientific definition was for the theoretical maximum output, that is of the optimal thermal requirements of a heat driven engine. The definition was theoretical in that it was established in solely thermal terms, with regard, that is to say, to only one of the factors involved. Nonetheless it provided an essential criterion without which it would not be possible to measure even in average terms the developments in efficiency from the Newcome engine (less than 0.01) or the Chaillot engine (0.005) or the "Wheal Abraham" (0.20 at maximum theoretical power), to the steam turbines of our own century: 0.43 at practical efficiency after the Otto (0.30) or the Diesel (0.35) motors.

So while outputs greater than 1 are common in economic calculations (because as we have seen certain cost factors are not consumed) in technometric calculation (based on the laws of the conservation of energy and matter) the figure 1 is a ceiling which could be surpassed only in some alternative conceptual, but now practically not attainable, physical system.

For "fire" engines or motors, thermal efficiency is calculated according to its various components (boiler area, steam pressure, temperature etc.) while for mechanical efficiency and for operative machines rather less systematic data are available which are however equally important for gauging efficiency and hence also for establishing the developments in terms of output — and hence also of "productivity".

It is even possible to talk in terms of efficiency in optics (i.e. luminous efficiency) in relation to photo-electric cells, in aerial propulsion, in apparatus for generating heat (in an electric stove nearly all the energy consumed can be transformed into heat, so the efficiency is close to 1, while in motors and converters only the dynamo reaches high values) and in other technical apparatus in which there is an appreciable in-put and output of energy or work, or in which there is a utility (e.g. illumination) or where a transformation occurs (ranging from spatial transport or transformation to molecular or atomic change: r [*rendimento*] quantic is the number of molecules decomposed for every quantum of energy absorbed) or when a physical or chemical reaction occurs (in nuclear disintegration an efficiency of 0.0000001 can be produced). Processes for extracting minerals or for producing alloys, as well as various forms of human effort such as athletics, can be evaluated in terms of efficiency (r) and measured by the general formula P/C where P is the product (the nett product in terms of the task) and C is the input (cost). The evaluation of efficiency is then calculated differently according to the technical apparatus in question and the methods used. Amongst these Piaskowski's method for measuring the rationality of a productive process is particularly ingenious. Comparison of technical apparatus of the same type (those serving similar purposes although at different historical times) indicates a tendency for the relationship P/C to advance toward unity (1 [1975]), which represents the ideal *optimum* established by modern science.

3. THE MEANS OF RELATING A TECHNICAL APPARATUS OR PROCESS OF A GIVEN PERIOD TO (b) SYNCHRONIC OR (a) MODERN SCIENTIFIC KNOWLEDGE.

The *optimum* is the full attainment of the task in question, the maximum utility which is scientifically indicated as 1, as for example in the formula for the output or efficiency (η) of a machine functioning on a Carnot cycle and measurable as $\eta = 1 - T_2/T_1$ where T_2 is the temperature in the condenser, T_1 that in the entry chamber. In an impulse turbine for example

$$\eta_p = 2 \frac{V/V_e}{1 + (V/V_e)^2} \text{ and in a hydraulic motor as } \frac{W}{W_o} \text{ and } W_o = \frac{\gamma Q H_o}{75}$$

where W_o is the theoretical or nominal power, γ is the specific might of the water, Q is the water flow in mc/s and H_o is the height of useful load. Power is expressed in H.P. and output is usually expressed as ρ. (The details of these formula can be found in the standard text-books concerning the different technical fields).

In the first of these formula, which is based on the scientific discoveries of Sadi Carnot in 1824, the rationality, as seen in terms of the efficiency of a technical apparatus, conforms to modern scientific practice (a) since thermodynamics have not in this field changed significantly since 1824. But before 1824 the formula used and also the results obtained were normally different from (a) as the 2nd law of thermodynamics had not been established, even though scientists were moving close to it through empirical experiments which constituted the successive developments of the study of heat and which we shall indicate as (b). The result of such experiments was to improve efficiency and to bring it into closer conformity with scientific knowledge — of the time that is or in absolute terms if we take comtemporary scientific knowledge as an absolute. Although we are dealing basically with a simple definition (« science is no more than prevalent scientific opinion ») it is useful from a technometric stance to take this as an absolute, because it provides us with a unity toward which the efficiency of technical apparatus develops. The constituents of these unities change of course with the development and progress of science.[2] The formula 1 [1975] then represents an ideal efficiency as conceptualized by modern science, so that statement (a) followed by 1 and a square bracket enclosing a date serves to link the date of accepted scientific opinion with the contemporaneous or synchronic technological fact (b).

As can be seen, 1 [1975] and 1 [1824] may both be identical when both occur in a period during which that particular technical field has not advanced greatly. The degrees of efficiency and the percentage outputs in (a) and (b) when compared provide what might be termed an « approximation of the truth » (the term being related respectively either to the historical or to the present technical apparatus) for in this case no attempt is made to measure the economic value of the apparatus but rather its technical actuality in historical or absolute (i.e. in relation to the present) terms. Since the percentage values related at different periods to 1 are not the same, the percentages describing the actual efficiency of the apparatus will change from (b) to (a). An apparatus which 200 years ago was considered good (i.e. which was then close to 1 [1777]) will today seem an outdated device, as in the case of the Newcomen engine whose efficiency will be far short of 1 [1975] with an output of less than 0.01. The technological "truth" then changes over time according to the ways in which the explanations of the phenomena of which it is seen to be a function change, and according to the developments which stem from these explanations. The "ideal machine" represented by 1 can in fact change, as can all the so-called "constants". In a past conception of physics when the speed of light was not held to be the fastest, or at a time when it was common to speak of the augmentation of matter and energy rather than of the conservation of matter and energy, we

[2] Our suggestion are related to the methods proposed by G. Toraldo (« The Concept of Progress in Physics » a paper delivered to the *Convegno di Chiavari* in September 1974 on the theme « The Concept of Progress in Science ») but originate from a pragmatic perspective which is to some extent external to science.

will find that 1 carries a very different significance from 1 [1975]. By using simple proportions then it is possible to discover the rate of proximity between 1 [say 1824] and 1 [1975]. Throughout technology these gradually evolved optimal descriptions and formulae allow us to assess the progress that is made. It is possible, for example, to compare the application of designs for ship-building in the 16th century with those of the 20th century based on modern hydrodynamics. The results of the formulae which were gradually evolved in the 18th century for dyeing black or for bleaching, or the methods used for "enriching" metals, or for mining, can equally be compared with those of the 20th century. Until now, however, economic historians have largely limited themselves to studying « yield rates for crop-seeds » and, as we have pointed out, continue to rely on econometric methods.

Even in agriculture, however, climatic changes and other natural occurrences or factors, in addition to the effects of other technological developments, tend to upset the attempts to assess purely technical advances (such as manuring, irrigation, genetics etc.) by calculating productivity only in terms of yields and conditional economic factors such as investment. Calculations of this type are to be found in the work of F. Mauro,[3] in the work by Slicher van Bath to which we have already referred, and in the studies by E. Le Roy Ladurie[4] and W. Beveridge on climatic change. Using the typical criteria of the economic historian, F. Mauro for example has tackled the problem of "agricultural productivity" following the models of Jean Jacquard and Jean Fourastié, and distinguishes between the overall productivity of the factors of production and the increase in production for an equal or even smaller labour input. But in fact if we are to analyse satisfactorily either position (a) or (b) described previously, it is essential to define at the outset as specifically as possible and to isolate each productive factor in terms of the appropriate technical terminology (i.e. of mechanics, optics, electrics etc.). We must also use the appropriate units of measurement, rather than economic terminology or classifications, despite the alluring analogies which these may provide (e.g. in Mauro do we not find that productivity is « a quotient of the total product which results from the number of products which are necessary to obtain that production »?) and the greater abundance of sources which contain econometric data. It is precisely this failure to isolate technological efficiency from other measures of efficiency which tends to upset the analysis of complex historical phenomena.

So far historians have succeeded in distinguishing between those technical factors which are the work of man and those such as climate change which

[3] F. Mauro, *L'Europa del XVI secolo*, (ital. trad.) ed. Mursia 1974, esp. pp. 225-8.

[4] In « Zeitschrift für Agrargeschichte und Agrarsoziologie » 1960.

are largely independent.[5] But even in the case of seed yields it is essential, as we have already seen, to distinguish clearly between the factor of genetic improvement, which pertains specifically to the seed itself, and other factors such as the nature of the soil on which the seed is grown which is itself subject to improvement for climatic, thermal or irrigational reasons and also from the development of knowledge about the function of the soil, the development of vegetal biology and other branches of science and technology. In technology then, whether it be historical or not, the first task must be to break efficiency down into its individual components.

4. THE MEANS OF PLACING TECHNICAL APPARATUS BY DEGREES OF PREVISION (c) OR OF AUTOMATION (d) WITH REFERENCE TO SUPER-ORGANIC EVOLUTION.

The feature (c) of the rationality of a given technical apparatus and its higher or lower placement on the hierarchy of super-organic evolution requires some explanation and definition. Super-organic evolution (the term originates from Spencer and serves to specify social evolution) is for our purposes the increase in the capacity of human beings to create power for themselves through methods and devices formed from independent matter and energy. One example of this is to be found in writing, a means of strengthening memory and communication which was the result of lengthy experiments ranging from the ideograph to the modern alphabet, from elementary grammar and syntax to Aristotelian logic, and from primitive system of enumeration to modern methods of computation. The same process is evident in the simple and then compound machines used to mechanize manufacture when extra-organic power, or motors, was adopted in place of muscle power, or equally in the use of artificial teguments (from clothing to building) which served among other things to increase the natural body system of heat regulation, or in the division of labour (serving to increased individual physical and mental attributes) and in the domestication of animals or the construction of machine-tools (used for making other machines or tools). All these are examples of super-organic evolution, and among them we can distinguish certain phases or degrees. Man's super-organic evolution might be termed hyper-organic in order to distinguish it from the levels reached by other animate beings, because it is marked by mental characteristics which are considerably more complex and also by extra-organic constructions

[5] P. CHAUNU, *Conjoncture, structures, systèmes de civilisation*, in *Conjoncture economique, structures sociales*, Hommage a Ernest Labrousse, ed. Mouton 1974, esp. p. 41.

which are increasingly divorced from, independent of, and even autonomous of man himself who created them, or else which allow for increasing degrees of prevision.

From this two ways of describing the degrees of super-organic evolution emerge. 1) The first stresses the degree of prevision (which corresponds roughly with the stages in the development of the capacity for abstract and conceptual knowledge, an evolution which can be traced from the Socratic "concept" to Hegelian "historical reason", or through the simple and then compound forms of machinery of varying degrees of automation, and auto-reproductive capacity etc.). 2) The second indicates the degree of automation, and stresses non-organic factors.

The second approach arises from the fact that within a single artificial system (i.e. the technical apparatus) or agent, information, executive provision (in general human will) and finally force are all brought together, as has been described by De Latil whose suggestions we by and large accept. The intensity with which these three elements coexist and their independence of human assistance can then be measured in degrees as follows: 1° The agent (or machine) *performs* a simple action and reacts only to a given stimulus (e.g. a mill-wheel); 2° the agent reacts *only* in certain conditions or else reacts to one or more stimuli optionally pre-selected and programmed (e.g. a safety valve); 4° the agent *stabilizes* or regulates its own action the effects of which are modified by selected stimuli but not the programme itself (e.g. a Watt regulator); 5° the agent itself seeks to establish its own *programme* to effect its task and the stimuli can modify both the effects of its action and also its programme (e.g. a rheostat); 6° the agent seeks its own *task* and the stimuli which may modify the effects of its action may also modify both its programme and the nature of its task (e.g. a computer).

The degree then to which the majority of the technical apparatus of a certain period belong represents the level of hyper-organic evolution of that age. The Watt regulator, for example, represents the 18th century industrial revolution (4°), while a guided missile navigating on automatic astronomical bearing represents our own (6° - second half of the 20th century). Fractions of degrees can also be used.

5. THE CONNECTIONS BETWEEN ECONOMICS, SCIENCE AND ETHICS.

Both the actual and the economic aspects of hyper-organicity, by which the aspects of rationality (itself a historical development which advances with historical evolution) present in a technical apparatus are implied can then be measured numerically which allows us to establish their evolutionary, and hence historical, position. Using statement (a) their relationship with the broader economic system can be established, although in this context numerical values may well be inverted as would occur if one moves from an economic system which is limited in time and space (i.e. a system of individuals or groups) to one which is of general utility (in both time and space) which is then both a moral and an ethical system. Using statement (b) scientific knowledge is related to the contemporaneous technical apparatus, while the latter's validity is measured by reference to (a). Statements (d) and (c), finally, provide the connection with the whole, with the entire complex range of evolution in all its principal intellectual and physical aspects and in which all the previous phases are cumulatively contained, so that examples of 6° are to be found side by side with those of 1° either in a single society or else across the societies of man's world.