Volume 36, Issue 9, November 2007 ISSN 0048-7333

ELSEVIER

RESEARCH POLICY

Policy and management studies of science, technology and innovation

CONTENTS

Available online at www.sciencedirect.com
ScienceDirect
Research Policy 36 (2007) 1388–1403
research policy
www.elsevier.com/locate/respol

Science, accounting and statistics: The input–output framework

Benoît Godin

INRS, 385 rue Sherbrooke Est, Montréal, Québec, Canada H2X 2C6

Received 10 October 2005; received in revised form 30 May 2007; accepted 18 June 2007
Available online 6 August 2007

Abstract

Statistics on science are often framed within an input–output framework: inputs are invested into research activities that produce outputs. This framework is a pure accounting framework based on the anticipated economic benefits of science. This paper asks where the framework comes from. It shows that the semantics on input and output in science can be traced back to the economic literature, and its analyses of growth via an econometric equation called the production function. Used extensively by economists in the mid-1950s to study science and its relationship to the economy, the semantics immediately offered official statisticians a conceptual framework for organizing statistics on science. This is due to the fact that the framework was perfectly aligned with policy discussions on the efficiency of the science system.

Keywords: Statistics; Science indicators; Input/output; Accounting; OECD

1. Introduction

With its periodic publication entitled *Report of the World Social Situation*, first published in 1952, UNESCO launched a series of measurements of society based on an accounting framework. The exercise would soon be imitated worldwide, first of all in the United States (US Department of Health, Education, and Welfare, 1970). According to Mancur Olson, contributor to the first such exercise in the United States, while the national income measures the growth or decline in the economy, a social report should measure “social gains and losses” (Olson, 1969, p. 86). The aim of social accounting is to go further than measurements of an economic type: “for all its virtues, the national income statistics don’t tell us what we need to know about the condition of American society. They leave out most of the things that make life worth living (. . .). The most notable limitation of the national income statistics is that they do not properly measure those external costs and benefits that are not fully reflected in market prices” (Olson, 1969, p. 86). For Olson, the national welfare is also concerned, among other things, with learning, culture . . . and science.

Despite these suggestions, the example or model behind a social accounting is that of economic accounting. In fact, “the figures on the national income are probably the most impressive and elaborate type of socioeconomic measure that we have”, admitted Olson (Olson, 1969, p. 86). Therefore, “the structure and parallelism of the chapters of *Towards a Social Report* derives in part from the paradigm of the national income and product accounts” (Olson, 1969, p. 87).

Olson’s proposal for including science in social reports had no impact. Rather, one has to turn to specific publications dedicated to this end. The first such exercise appeared in 1973 and was prepared by the

E-mail address: benoit.godin@ucs.inrs.ca.

0048-7333/$ – see front matter © 2007 Published by Elsevier B.V.
doi:10.1016/j.respol.2007.06.002

National Science Foundation (NSF) in the United States (National Science Board, 1973). Inspired by the work of the OECD in the late 1960s when it collected multiple indicators to document technological gaps between the United States and Europe, the report collected several statistics that measured science according to several dimensions (Godin, 2002). The model used to collect and analyze the newly imagined data on science was framed in terms of input and output. Inputs are investments in the resources necessary to conduct scientific activities, like money and scientific and technical personnel. Outputs are what come out of these activities: knowledge and inventions. A very simple framework defined the relationship between input and output as follows:

Input → Research activities → Output

Since the early 1960s, this framework has guided analysts in organizing statistics into "meaningful" categories, within the academic literature (science and technology studies) as well as official circles like OECD and its member countries. As the OECD stated: "The term R&D [research and development] statistics covers a wide range of possible statistical series measuring the *resources* devoted to R&D stages in the activity of R&D [input] and the *results* of the activity [output]" (OECD, 1981, p. 17). An international community of official statisticians has, over time, developed standards for measuring inputs devoted to R&D activities – known as the OECD Frascati manual – and produced a whole "family" of methodological manuals specifically dedicated to measuring output. Today, both series of statistics are collected and published in documents called compendiums or scoreboards of science and technology statistics.

Where does the input–output framework come from? It is in fact a pure accounting framework based on the anticipated (economic) benefits of science: "in order really to assess research and development efficiency, some measures of output should be found", claimed the first edition of the OECD Frascati manual (OECD, 1962c, p. 11). This framework is not alien to a long tradition of cost-benefit analyses in engineering and its use in policy decisions.[1] It is also not alien to input–output tables, as originally developed by Leontief,[2] and used in the System of National Accounts. In this paper, however, the origin of the framework is traced back to the economic literature and its analyses of economic growth via an econometric equation called the production function. At exactly the same time governments were getting interested in measuring science systematically, such analyses were very popular (and still are today). Several of these works were published under the auspices of the US National Bureau of Economic Research (NBER). These were the first real attempts to integrate science into the economic equation. They immediately offered a semantic and framework to official statisticians for organizing statistics on science.

Some authors have argued that economics has been framed into an accounting "metaphor" for a very long time (Klamer and McCloskey, 1992). A metaphor is a figure of speech used to understand one thing in terms of another. This paper is concerned with how economics and the accounting metaphor got into a specific kind of activity – science and scientific research – an activity long reputed to be not favourable to measurement. The paper is divided into three parts. The first reviews the economists' model for studying science and its impact on the economy: the production function. Framed within an input–output vocabulary, the semantic was perfectly adapted to the official collection and interpretation of statistics. A large part of this section is devoted to the NBER conference organized in 1960 which examined for the first time in history various aspects of the "model". The second part looks at how the semantics of input and output entered into official statistics on science and technology. The work of the OECD and an influential consultant, Chris Freeman, serves here as the vehicle for examining the impact of the input–output framework on official science and technology statistics. The third part looks at what remains of the accounting framework in current official statistics. It argues that the input–output framework is a symbolic representation or metaphor and has little to do with accounting as such.

From the start, a distinction and a clarification must be made. The input–output framework should not be confused with another framework, called the linear model of innovation (Godin, 2007). The former is an accounting framework for science activities, and is concerned with measuring upstream and downstream quantities and establishing empirical relationships between the two. The linear model of innovation is devoted rather to explaining research activities themselves. It takes the following form:

Basic research → Applied research → Development
→ (Production and) Diffusion

---

[1] For the introduction of accounting in "science policy" (or public decisions and programs involving scientific and technological activities), see Porter's discussion of the role of engineers in cost-benefit analyses (Porter, 1995). On accounting and science generally, see Power (1994).

[2] Leontief founded input/output accounts, and developed his first I–O tables in the 1930s for studying the effects of technological change on the American economy. See Leontief (1936, 1953a,b).

Certainly, the activities or steps identified by the linear model are usually measured using inputs and outputs. But the linear model is an analytical one – that owes a large debt to statistics, certainly – while the input–output framework is an accounting framework that leaves research activities themselves as a "black box".

2. The production function

We often read in the literature that Solow was the first author to quantify, although imperfectly, the impact of science on the economy. This is probably because his article is part of the very formalized tradition of econometrics (Solow, 1957). Yet other authors preceded him by several years, as Abramovitz recalled (Abramovitz, 1989, p. 71), and used the same kind of model: the production function.

The production function is an equation, or econometric "model", that links the quantity produced of a good (output) to quantities of input. There are, at any given time, or so argue economists, inputs (labour, capital, technology) available to the firm, and a large variety of techniques by which these inputs can be combined to yield the desired (maximum) output. As Mansfield explained: "The production function shows, for a given level of technology, the maximum output rate which can be obtained from a given amount of inputs" (Mansfield, 1968, p. 13). Other economists shared his description: "Basically, technological progress consists of any change (. . .) of the production function that either permits the same level of output to be produced with less inputs or enables the former levels of input to produce a greater output" (Ferguson, 1969, p. 386).

The production function was the first "model" used to integrate science into economic analyses. It had several variants: some simply interpreted movements in the production function, or curve, as technological change (the substitution of capital for labour) (Schumpeter, 1939; Valavanis-Vail, 1955), while others equated labour productivity with science (technological change is likely to result, all other things being equal, in labour productivity, and still others correlated R&D with multifactor productivity).

The production function is an old "model". It is directly inspired by classical economics and the maximization axiom, or rationality as efficiency (means-ends): maximizing output for a given input, or minimizing input for a given output. Cobb and Douglas were the first to formalize the idea of the production function in the late 1920s (Cobb and Douglas, 1928; Douglas, 1948). With regard to science, we find its first use in Schumpeter's works – a fact often forgotten today. In *Business Cycles*, Schumpeter defined innovation by means of the production function: "This function describes the way in which quantity of product varies if quantities of factors vary. If, instead of quantities of factors, we vary the form of the function, we have an innovation" (Schumpeter, 1939, p. 87). "Whenever at any time a given quantity of output costs less to produce than the same or a smaller quantity did cost or would have cost before, we may be sure, if prices of factors have not fallen, that there has been innovation somewhere" (Schumpeter, 1939, p. 89). Innovation, then, is "the combination of factors in a new way", "the setting up of a new production function": a new commodity, a new form of organization, or opening up of new markets.

Table 1
NBER early studies on productivity, science and technology

D. Weintraub (1932), The Displacement of Workers Through Increases in Efficiency and their Absorption by Industry
F.C. Mills (1932), Economic Tendencies in the United States
H. Jerome (1934), Mechanization in Industry
F.C. Mills (1936), Prices in Recession and Recovery
F.C. Mills (1938), Employment Opportunities in Manufacturing Industries of the United States
G.S. Stigler (1947), Trends in Output and Employment
S. Fabricant (1954), Economic Progress and Economic Change
J.W. Kendrick (1961), Productivity Trends in the United States
NBER (1962), The Rate and Direction of Inventive Activity

We had to wait the patronage of the NBER to see the development of a systematic and continued interest in science and the production function, a development of which Solow was part (Table 1).[3] The 1930s, and the following decades, can in fact be described as the beginning of a long series of studies on productivity and the role of science in explaining growth rates (Godin, 2004a).

In 1960, in collaboration with the US Social Science Research Council (SSRC), NBER organized an important conference on the economics of science. The conference was probably the first time the production function was extensively discussed for studying science. In fact, most of the papers were concerned with an input–output framework. As Griliches reported, the conference's focus was "on the knowledge producing industry, its output, the resources available to it, and the efficiency with which they are being used" (Griliches, 1962, p. 347). Equally, to Machlup, "the analysis of the

---

[3] Precursors to the production function were studies of the 1930s on measuring labour productivity as a proxy for technological change. See Godin (2006).

supply of inventions divides itself logically into three sections": input, input–output relationship (the transformation of inventive labour into useful inventions), output (Machlup, 1962b, p. 143).

The model was not without its detractors. Perhaps the most critical was Leontief who, in the late 1960s, would argue that "elaborate aggregative growth models can contribute very little to the understanding of processes of economic growth, and they cannot provide a useful theoretical basis for systematic empirical analysis" (Leontief, 1970, p. 132). Regular users like Griliches were also critical: "the concept of a production function, frontier, or possibilities curve [is] a very unsatisfactory tool of analysis" (Griliches, 1962, p. 348). The criticisms generally centered around two lines of argument. First, how do we measure input and output with regard to science and technology? Second, what is the relationship between input and output?

These questions were discussed at length by Griliches, Kutznets, Machlup, Schmookler and researchers from RAND,[4] among others, at the NBER conference. Defining invention and understanding the process of invention was an issue addressed by almost every speaker. To a certain extent, the issue relied on appropriate statistics for measuring input and output. But almost all available statistics were criticized. In one of two introductory papers to the conference, Sanders, from the Patent, Trademark, and Copyright Foundation of George Washington University, declared: "none of the measures used to date is satisfactory even as a crude measure of inventiveness as such or inventive activity" (Sanders, 1962, p. 53). With regard to input measures, Sanders argued that labour devoted to inventive activity was badly measured, as were expenditures on R&D, because they were limited to institutions and subject to judgment. All in all, "neither the quality nor the completeness of the information which we now have, nor our conceptual understanding of the functional relationship between input and inventions, are such as to enable us to determine from apparent trends in input the trends in inventions" (Sanders, 1962, p. 63). With regard to output, Sanders was equally critical: "We have devised no objective yardstick for the measurement of this quantity and may never be able to devise one (. . .). Substituting in its place some measurable end product far removed from the initial act of inventing (. . .) may be the nearest we shall ever be able to come to measuring invention" (Sanders, 1962, p. 65). Schmookler did not entirely agree, particularly on patent statistics: "No one will dispute that accurate measures of a thing are always better than an uncertain index of it (. . .). In the meantime, much as we might prefer caviar, we had better settle for plain bread when that is all we can get. The question, therefore, is not whether to use statistics of aggregate patents granted or applied, but how" (Schmookler, 1962, p. 78).

Kuznets was as pessimistic as Sanders, particularly with regard to the new data series on R&D coming out of the National Science Foundation's (NSF's) recently launched series of surveys, because it included development – an activity Kuznets qualified as adjustment, not original invention – and excluded the efforts of individuals and independent inventors (Kuznets, 1962). The NSF representative, Liebling, accused Kuznets of applying "somewhat more rigorous standards to the R&D series than he does to the national income category we have learned from him" (Liebling, 1962, p. 89). To Liebling, "in the construction of any complex set of statistics, attention must be given to its operational requirements in obtaining a successful measure, often requiring the adoption of certain conventions" (Liebling, 1962, p. 88). For the NSF, he added, the "series on R&D expenditures is designed [mainly] to measure the scope of the scientific effort for government policy purposes" (Liebling, 1962, p. 90).

Defining input and output was only one of the two issues addressed during the conference. The other was the relationship between input and output. "Our economy operates on the belief that there is a direct causal relationship between input and the frequency and extent of inventions", recalled Sanders.[5] "No doubt there is a direct relationship of some kind, but we have no evidence that this relationship does not change" (Sanders, 1962, p. 55). Griliches asked the participants "whether an increase in inputs in the knowledge producing industry would lead to more output" (Griliches, 1962, p. 349). Machlup's answer was: "a most extravagant increase in input might yield no invention whatsoever, and a reduction in inventive effort might be a fluke result in the output that had in vain been sought with great expense" (Machlup, 1962b, p. 153). To Griliches, "none of [the] studies [from the conference: J.R. Minasian, R.R. Nelson, J.L. Enos, A.W. Marshall and W.H. Meckling] comes anywhere near supplying us with a production function for inventions", and when they establish a relationship between input and output, these relationships "are not very strong or clear" (Griliches, 1962, p. 350).

---

[4] K.J. Arrow, C.J. Hitch, B.H. Klein, A.W. Marchall, W.H. Meckling, J.R. Minasian, and R.R. Nelson.

[5] For a highly lucid analysis on the same topic at about the same time, see Shapley (1959).

The problem with regard to the relationship between input and output was threefold, the last part of which several participants discussed at the conference. First, there was the well-known problem of causality. Although Minasian, from RAND Corporation, concluded his study by affirming that "beyond a reasonable doubt, causality runs from research and development to productivity, and finally to profitability" (Minasian, 1962, p. 95), what the production function demonstrated was a correlation between input and output, rather than any causality. The production function is "only an abstract construction designed to characterize some quantitative relationships which are regarded as empirically relevant", stated Machlup (Machlup, 1962b, p. 155). Second, there was the problem of lags between invention and its diffusion, which complicates measurements and was rarely addressed by econometricians. Related to this problem, and finally, there were difficulties in accounting correctly for returns on R&D. To Machlup, there were two schools of thought here: "According to the acceleration school, the more that is invented the easier it becomes to invent still more – every new invention furnishes a new idea for potential combination (. . .). According to the retardation school, the more that is invented, the harder it becomes to invent still more – there are limits to the improvement of technology" (Machlup, 1962b, p. 156). To Machlup, the first hypothesis was "probably more plausible", but "an increase in opportunities to invent need not mean that inventions become easier to make; on the contrary, they become harder. In this case there would be a retardation of invention (. . .)" (Machlup, 1962b, p. 162), because "it is possible for society to devote such large amounts of productive resources to the production of inventions that additional inputs will lead to less than proportional increases in output" (Machlup, 1962b, p. 163).

From the conference and its participants, we can conclude that the semantics of input and output, and a model linking the two, were definitely in place by the early 1960s, at least in economists' prose. The model was far from perfect, but economists would make extensive use of it in the following decades: calculating social and private rates of return of R&D (Griliches, 1958; Mansfield, 1965; Minasian, 1969; Mansfield et al., 1977), estimating multifactor productivity and economic growth (Denison, 1962, 1967; Jorgensen and Griliches, 1967), measuring sectoral flows of technology (Maestre, 1966; Scherer, 1982; Pavitt, 1984; Robson et al., 1988), as extension to input–output tables (Leontief, 1953a,b, 1966/1986).

Two years after the NBER conference, Machlup published what was the first collection of multiple statistics on science, or knowledge as he called it: education, R&D, communication, information.[6] The whole work was based on an accounting framework. In his chapter on R&D, Machlup constructed a much quoted table where a list of indicators on input and output were organized according to stages of research (basic research, applied research, development, innovation) and to whether they were tangible or intangible, and measurable (Machlup, 1962a, pp. 178–179) (see Appendix A).[7] Machlup's table marked a transition here. From a theoretical and "abstract construct", the production function became a "practical" tool as well: official statisticians would follow Machlup and adapt the input–output semantic to their efforts at measuring science. To understand how the input–output framework got into official statistics and indicators on science and technology, one has to turn to the OECD and UNESCO, and the work of an economist as consultant, Chris Freeman.

3. The economics of science

Official statistics on science emerged in the early 1920s, but we had to wait until the 1950s for the first systematic surveys to appear, and for real methodological works to be conducted (Godin, 2005). In these efforts, the NSF had a strong influence on academics' analyses, as Nelson reported during the NBER conference: "the establishment of the NSF has been very important in focusing the attention of economists on R&D (organized inventive activity), and the statistical series the NSF has collected and published have given social scientists something to work with" (Nelson, 1962, p. 4). The NSF also had a strong influence on other countries' statistical offices as regard methodology (NSF, 1959), as did the OECD. To the latter we owe the first international standards for measuring inputs devoted to R&D as well as the first discussion on the input–output framework for official statistics on science.

It was at the European Productivity Agency (EPA), created in 1953 as part of the OEEC – the predecessor to the OECD – that the international measurement of science began. Measurement of science at the EPA started with the measurement of qualified human resources and shortages of these resources, since human resources lie at the heart of economic growth and productivity issues. On the initiative of the United States, recently shaken by

---

[6] For a very early collection of several statistics on science (patents, inventions, discoveries) used for measuring knowledge (*sic*) and its growth, see Ogburn and Gilfillan (1933, p. 126).

[7] The table, with an acknowledgement to Machlup, first appeared in Ames (1961).

Sputnik, the OEEC created the Office of Scientific and Technical Personnel (OSTP) in 1958 as part of the EPA. The OSTP conducted three large surveys of scientific and technical personnel in member countries (OEEC, 1955, 1957; OECD, 1963d). These surveys were the first systematic international measurements of science, and they were guided by what would become the repeated *lacunae* of current statistics: "Few member nations had adequate statistics on current manpower supply; fewer still on future manpower requirements. Furthermore, there were no international standards with regard to the statistical procedures required to produce such data" (OEEC, 1960, p. 7).

At about the same time, the EPA's Committee of Applied Research (CAR) began to convene meetings to discuss methodological problems concerning R&D statistics.[8] An *ad hoc* group of experts was set up to study existing surveys of R&D. The secretary of this group, Gerritsen (consultant to the OEEC), prepared two case studies on definitions and methods. One was in 1961 (United Kingdom and France) (OEEC, 1961),[9] and the other in 1962 (United States and Canada) (OECD, 1963b).

These exercises were motivated by two factors. First was the will to measure gaps between European countries and the United States in terms of innovation (Godin, 2002). Second was the creation of the OECD in 1961 and its focus on policy questions. Science was now becoming recognized as a factor in economic growth, at least by OECD bureaucrats. In order that science might optimally contribute to progress, however, science policies had to be developed. And to inform the latter, statistics were essential, so thought the organization: "Informed policy decisions (. . .) must be based on accurate information about the extent and forms of investment in research, technological development, and scientific education", argued the OECD's Piganiol report (OECD, 1963e, p. 24).

That statistics came to occupy an early place at the OECD was also the consequence of a third factor: the economic orientation of early OECD reflections on science policy. In 1962, the Committee for Scientific Research (CSR) recommended that the OECD Secretariat "give considerable emphasis in its future program to the economic aspects of scientific research and technology" (OECD, 1962b, p. 1). This orientation was in line with the 50% economic growth target advocated by the OECD for the decade (OECD, 1962d). The committee recommendation would be reiterated during the first ministerial conference on science in 1963 (OECD, 1963c) and during the second conference held in 1966 (OECD, 1966).

The committee proposal was based on the fact that there "is an increasing recognition of the role played by the so-called third factor [technical progress] in explaining increases in GNP" (OECD, 1962b, p. 2). But, so the committee continued, "the economist is unable to integrate scientific considerations into his concepts and policies because science is based largely on a culture which is anti-economic" (OECD, 1962b, p. 5). Thus, the OECD gave itself the task of filling the gap. To this end, the organization developed a research program on the economy of science that led to a statement on science in relation to economic growth as a background document for the first ministerial conference held in 1963 (OECD, 1963c). The document contained one of the first international comparisons of R&D efforts in several countries based on existing statistics, conducted by Freeman et al.[10] The document concluded that "most countries have more reliable statistics on their poultry and egg production than on their scientific effort and their output of discoveries and inventions". (. . .) The statistics available for analysis of technical change may be compared with those for national income before the Keynesian revolution" (OECD, 1963f, pp. 21–22).[11] A pity, since the Piganiol report stated: "Provision for compilation of data is an indispensable prerequisite to formulating an effective national policy for science" (OECD, 1963e, p. 24).

The committee went further than simply recommending the collection of statistics. It also suggested that the OECD conduct studies on the relationships between investment in R&D and economic growth. Indeed, "comprehensive and comparable information on R&D activity are the key to [1] a clearer understanding of the links between science, technology and economic growth, [2] a more rational formulation of policy in government, industry and the universities, [3] useful comparisons, exchange of experience, and policy formation internationally" (OECD, 1963a, pp. 4–5). Again, the main obstacle to this suggestion was identified as being the inadequacy of available data (OECD, 1962b, p. 10). To enlighten policy, the committee thus

---

[8] Two meetings were held: one in June 1957 and a second in March 1960.

[9] Missing from the OECD archives.

[10] The year before, Dedijer (Sweden) had published the first such comparison (Dedijer, 1962). Two other international statistical comparisons, again based on existing statistics, would soon follow: Kramish (1963) and Freeman and Young (1965).

[11] The same citation (more or less) can be found on p. 5 of the first edition of the Frascati manual.

supported the development of a methodological manual (OECD, 1962a, p. 19):

> The main obstacle to a systematic study of the relationship between scientific research, innovation and economic growth is the inadequacy of available statistical data in member countries on various aspects of scientific research and development. (. . .). The Secretariat is now preparing a draft manual containing recommendations defining the type of statistical data which should be collected, and suggesting methods by which it can be obtained.

Christopher Freeman was the ideal person to work on such a manual because he was one of the few people at that time with hands-on experience of designing and analyzing a survey of R&D. In 1960, while he was assigned, seconded by the National Institute of Economic and Social Research (London), to improving the methodology of the survey on industrial R&D conducted by the Federation of British Industries (FBI), E. Rudd, from the British Department of Scientific and Industrial Research (DSIR), suggested to the OECD that Freeman be invited as consultant to work on what would become the Frascati manual.

The first edition of the manual was prepared by Freeman – who visited the main countries where measurements were conducted – and was adopted and discussed by member countries at a meeting in Frascati (Italy) in 1963. It proposed standardized definitions, concepts and methodologies for conducting R&D surveys and measuring inputs, namely money devoted to R&D and scientific and technical personnel. The manual's proposed standards were mainly concerned with four topics. Firstly, norms were proposed for defining science as "systematic" research and as composed of three major categories of research (basic/applied/development). Secondly, activities were demarcated for statistical inclusion/exclusion: research/related scientific activities, development/production, research/teaching. Thirdly, economic sectors (university, government, industry, non-profit) were precisely delineated for specific surveys and statistical breakdowns. Finally, standards were suggested for surveying the units of research and measuring their activities.

In the following decades, the manual served as the basis for surveying R&D in member countries, for collecting international data at OECD, and for analyzing trends in science. The manual also gave official statisticians their main indicator on science: Gross Expenditures on R&D, or GERD – the sum of expenditures devoted to R&D by the four above economic sectors.

The first edition of the Frascati manual set the stage for an input–output approach as a framework for science statistics. The manual was entirely concerned with proposing standards for the measurement of inputs. Despite this focus, the manual discussed output and inserted a chapter (section) specifically dedicated to its measurement because "in order really to assess R&D efficiency, some measures of output should be found" (OECD, 1962c, p. 11). However, stated the manual, "measures of output have not yet reached the stage of development at which it is possible to advance any proposals for standardization" (OECD, 1962c, p. 37). "It seems inevitable that for some time to come it will not be possible to undertake macro-economic analysis and to make international comparisons on the basis of the measurement of output (. . .). This is an important limitation" (OECD, 1962c, pp. 37–38).

Nevertheless, from its very first edition, the Frascati manual suggested that a complete set of statistics and indicators, covering both input and output, was necessary to properly measure science. The two output indicators suggested were patents and payments for patents, licensing and technical know-how.[12] From 1981, the manual discussed five indicators: (1) output: innovation, patents; (2) impacts: technological receipts and payments, high-technology trade, and productivity.

Freeman continued to advocate an input–output framework in the following years, to UNESCO's officials among others. "There is no nationally agreed system of output measurement, still less any international system", repeated Freeman in 1969 in a study on output conducted for UNESCO. "Nor does it seem likely that there will be any such system for some time to come. At the most, it may be hoped that more systematic statistics might become possible in a decade or two" (Freeman, 1969, p. 8). The dream persisted, however, because "it is only by measuring innovations (. . .) that the efficiency of the [science] system (. . .) can be assessed", continued Freeman (Freeman, 1969, p. 25). "The output of all stages of R&D activity is a flow of information and the final output of the whole system is innovations – new products, processes and systems" (Freeman, 1969, p. 27).

To Freeman, "the argument that the whole output of R&D is in principle not definable is unacceptable (. . .). If we cannot measure all of it because of a variety of practical difficulties, this does not mean that it may not be useful to measure part of it. The GNP does not mea-

---

[12] An early statistical analysis of two indicators was conducted by the director of the OCED statistical unit and presented at the Frascati meeting in 1963 (Fabian, 1963).

sure the whole of the production activity of any country, largely because of the practical difficulties of measuring certain types of work. The measurement of R&D inputs omits important areas of research and inventive activity. But this does not mean than GNP or R&D input measures are useless" (Freeman, 1969, pp. 10–11). And what about the relationship between input and output? "The argument that the input/output relationship is too arbitrary and uncertain in R&D activity to justify any attempts to improve efficiency or effectiveness (. . .) rests largely on the view that unpredictable accidents are so characteristic of the process that rationality in management is impossible to attain (. . .). The logical fallacy lies in assuming that, because accidental features are present in individual cases, it is therefore impossible to make useful statistical generalizations about a class of phenomena" (Freeman, 1969, p. 11).

Armed with such a "convincing" rationale, the Frascati manual continued, edition after edition, to suggest an input–output framework of science (under paragraph 4) as well as offering its readers an Appendix A on discussing output indicators. It also continued to argue for the development of output indicators as follows: "Problems posed by the use of such data should not lead to their rejection as they are, for the moment, the only data which are available to measure output" (OECD, 1981, p. 131). "At present, only R&D inputs are included in official R&D statistics and, thus, in the body of this manual. This is regrettable since we are more interested in R&D because of the new knowledge and inventions which result from it than in the activity itself" (OECD, 1981, p. 17).

The 1993 edition of the manual innovated, however, by adding a table presenting the OECD "family" of methodological manuals on measuring science, among them three manuals on output indicators.[13] What happened that could explain such a sudden development on output indicators (Table 2)?[14]

Table 2
The OECD R&D family of manuals

1963	*The Measurement of Scientific and Technical Activities: Proposed Standard Practice for Surveys of Research and Development* (Frascati manual)
1990	*Proposed Standard Practice for the Collection and Interpretation of Data on the Technological Balance of Payments*
1992	*Proposed Guidelines for Collecting and Interpreting Technological Innovation Data* (Oslo manual)
1994	*Data on Patents and Their Utilization as Science and Technology Indicators*
1995	*Manual on the Measurement of Human Resources in Science and Technology* (Canberra manual)

In 1973, the NSF published the first edition of *Science Indicators*, a compendium of statistics on science covering both input and output (Godin, 2003). What characterized the NSF publication, besides the fact that it was the first of a regular series that systematically collected a large number of statistics on science, was that it carried an input–output framework. Despite the quality of the publication, this framework was rapidly criticized by academics in conferences held in 1974 and 1976[15] and by other public organizations: *Science Indicators* is "too constricted by an input–output framework. In this approach, science and technology are seen as resources which go into, and tangible results which come out of, a black box", complained the US General Accounting Office (GAO, 1979, p. 19).

Be that as it may, the publication caught the attention of the OECD and its second *ad hoc* review group on science statistics: output could be measured. The publication served as a catalyst to OECD efforts on measuring output. After more than 20 years devoted almost exclusively to collecting and analyzing data on inputs (OECD, 1967, 1971, 1975a,b, 1979), the OECD organized a large conference on output indicators in 1980, launched experimental studies, and convened workshops concerned with specific output indicators: patents, technological receipts and payments, high-technology, and innovation. These activities produced two results.

First, an analytical series entitled *Science and Technology Indicators* was started in 1984. Three editions were published, then replaced by *Main Science and Technology Indicators* (MSTI) in 1988, a collection of statistics on science for each member country, covering both input and output series: GERD, R&D personnel, patents, technological balance of payments, and high-technology trade. MSTI was complemented, in the mid 1990s, by a series entitled *Science, Technology and Industry Scoreboard*, containing a larger set of statistics, and ranking countries accordingly. The second result from the OECD work was a series of methodological

---

[13] This was a small innovation, however, compared to the proposal, made 15 years before, about transforming the Frascati manual into a manual on indicators. See OECD (1978).

[14] To this table, we could add a working paper on bibliometrics (Okubo, 1997). This document, however, was not really a methodological manual.

[15] Papers from the conferences can be found in Elkana et al. (1978) and Zuckerman and Balstad-Miller (1980).

manuals on measuring output, and intended for official statisticians (Table 2).

From the start, national statisticians vehemently criticized the indicators on output. The main point of controversy related to methodology. Every indicator was said to measure the phenomenon improperly, a point already made by Sanders and Kuznets, because of the limitation of the concepts underlying the indicators: patents measured only part of innovations; technological receipts and payments did not consider non-market exchanges of technology; high-technology minimized embodied technology and diffusion. To the OECD, however, these limitations were manageable. On patents, for example, the OECD argued: "There has been continuing controversy over the use of patent statistics. (. . .). But, as J. Schmookler wrote, we have a choice of using patent statistics continuously and learning what we can from them, and not using them and learning nothing. (. . .). All progress in this field will come ultimately from the reasoned use of this indicator which, while always taking into account the difficulties it presents, works to reduce them (OECD, 1983, p. 11). Similarly, for the indicator on high-technology: "Obviously, one has to be very careful in making policy conclusions on the basis of statistically observed relationships between technology-intensity measures and international competitiveness. Yet, as emphasized by one participant, to deny that policy conclusions can be made is to ignore some of the most challenging phenomena of the last decade" (OECD, 1980, p. 18).

The main reason for criticizing output indicators, however, rarely avowed, had to do with the fact that the data came from other sources than the official survey, sources over which the official statisticians had no control. Nevertheless, one output indicator gained rapid and widespread consensus among national statisticians: innovation. From the beginning, science policy was definitively oriented towards economic goals and technological innovation. In fact, to policy-makers, innovation was always considered to be the final output of the science system, as suggested by Freeman. What helped achieve this consensus view on innovation indicators was the fact that official statisticians could develop a tool they controlled: the survey of innovation activities.

Having measured input and output, the OECD could next turn to the task of relating them. It did so precisely on the same topic as that studied by economists in the 1950s – productivity – and with the same methodology: the production function and multifactor productivity (Godin, 2004). In the 1990s, as part of the OECD Growth Project on the New Economy, the Directorate for Science, Technology and Industry (DSTI) analyzed productivity trends and the role that information and communication technologies (ICT) play in it. Economists from the Industry Division conducted several analyses at the national, industrial, and firm level. The measurements showed only a weak correlation between ICT and productivity. "Ten years or so from now," concluded the OECD, "it should be easier to assess, for instance, the impacts on growth deriving from ICT, other new technologies and changes in firm organization" (OECD, 2001, p. 119). Yet, the OECD made a non-ambiguous plea for (industrial) science and its benefits to the economy. The political message was one of publicly supporting research and technologies.

4. An accounting framework

Linking input to output came quite late in official statistical work on science. As a matter of fact, no I/O ratio has even been constructed by national bureaus of statistics to measure efficiency in science. The one and only ratio in the official literature is GERD/GDP.[16] Certainly, one could argue that GDP accounts for (economic) output. But the ratio GERD/GDP rather measures intensity or efforts (that part of economic activities devoted to R&D), not efficiency.

Nor can one find any trace of input–output accounting in recent scoreboards of statistics. Certainly, the very first editions carried some elements, in the sense that indicators were grouped into categories corresponding, among others, either to inputs or outputs, the latter with this precise label (OECD, 1999). The following editions, however, reorganized the groupings and re-labeled the categories without any trace of the input–output semantics. Scoreboards are actually simple collections of statistics, where ranking of countries is the (very indirect and only) measure of efficiency.

We have, then, to look elsewhere for traces of accounting in official statistics on science. The very first edition of the Frascati manual suggested classifying R&D by dimension. One of the central dimensions was concerned with economic sectors. In line with the system of national accounts (SNA), and following the practice of the NSF (Arnow, 1959; Stirner, 1959), the manual recommended collecting and classifying R&D according to the following main economic sectors: business, government, and private non-profit.[17] To these three sectors, however, the OECD added, following the NSF's practice, a fourth one: higher education. The following rationale was offered

---

[16] And variants on this measure, see Godin (2004b).

[17] Households, as a sector in the SNA, was not considered by the manual, but was included in the non-profit sector.

for the innovation: "The definitions of the first three sectors are basically the same as in national accounts, but higher education is included as a separate main sector here because of the concentration of a large part of fundamental research activity in the universities and the crucial importance of these institutions in the formulation of an adequate national policy for R&D" (OECD, 1962c, p. 22).

This alignment to the system of national accounts gave us the Gross Expenditures on R&D (GERD), which is the sum of R&D expenditures in the four economic sectors, and the matrix of R&D flows between economic sectors of the System of National Accounts. Why align R&D statistics with the system of national accounts? The system, now in its fourth edition, was conventionalized at the world level by the United Nations in the 1950s (United Nations, 1953; OEEC, 1958). At that time, R&D was not recognized as a category of expenditures that deserved a specific mention in the national accounts.[18] The same holds true today: during the revision of the system of national accounts in the early 1990s, the United Nations rejected the idea of including or recognizing R&D "because it was felt that it opened the door to the whole area of intangible investment" (Minder, 1991, p. 3). R&D is not part of the accounting system of nations, despite the many efforts of statisticians for whom "being part of the National Accounts [would] raise the importance and visibility of R&D statistics and statisticians" (OECD, 2003, p. 4).[19]

The reason for using the system of national accounts framework in statistics on science was however given in the very first edition of the Frascati manual: the classification of R&D data by economic sector "corresponds in most respects to the definitions and classifications employed in other statistics of national income and expenditure, thus facilitating comparison with existing statistical series, such as gross national product, net output, investment in fixed assets and so forth" (OECD, 1962c, p. 21). The GERD/GDP indicator is an example of such a comparison.

Yet, this "accounting" is not real accounting. First, with regard to inputs: despite its alignment to the system of national accounts, GERD is not really a national budget, but "a total constructed from the results of several surveys each with its own questionnaire and slightly [I would say rather, importantly] different specifications" (Bosworth et al., 1993, p. 29). Some data come from a survey (industry), others are estimated with different mathematical formulas (university), and still others are simply proxies (government). Second, outputs are measured via proxies rather than actual outputs, and are constructed from different sources that do not share any common framework. Third, very few, if any, official statistics exists that link input to output as measures of efficiency. In retrospect, the accounting in official statistics on science is rather a symbolic or conceptual framework based on an accounting metaphor within which numbers are discussed and presented.

What then are the virtues of this framework? A framework is a representation. It provides meaning and organization. The accounting framework was part of the understanding of science policy that developed after World War II. The measurement of science emerged within a background and an intellectual context composed of ideas and models all concerned with efficiency and accounting.[20] The production function was one such, as was the System of National Accounts (Studenski, 1958; Ruggles and Ruggles, 1970; Fourquet, 1980; Vanoli, 2002; Maddison, 2003) and the input–output tables (Leontief, 1966/1986). But there were also operations research, cybernetics, system analysis, and the new positive political science, all concerned with rational choice and costs-benefit analyses (Wildavsky, 1966; Hoos, 1972).[21] This whole "philosophy" of accounting spread rapidly to official statistics: social indicators (UNESCO, 1952; US Department of Health, Education, and Welfare, 1970; United Nations, 1975, 1989), education (OECD, 1992), environment (Bartelmus et al., 1991), health (OECD, 2000), human capital (OECD, 1996, 1998) and . . . science.

In this context, the accounting framework as metaphor served discourses on science policy in the sense that it contributed to making sense of (already made) decisions. Freeman is a good example of such argumentation: "As long as governments or enterprises were spending only very small sums on scientific research, they could afford to regard this outlay in a very similar way to patronage of the arts, using prestige criteria rather than attempting to assess efficiency. But it is one thing to endow an occasional eminent scien-

---

[18] Only institutions primarily engaged in research are singled out as a separate category.

[19] The current revision of the system promises some changes, however.

[20] On this context, see Miller and O'Leary (1987).

[21] RAND, one of the pioneers on the economics of technical change, was part of this movement (see the paper from RAND researchers for the NBER conference). However, the focus at RAND was generally on allocating resources to science and technology rather than with an input–output framework *per se*. See Hounshell (2000).

tist; it is quite another to maintain laboratories regularly employing thousands of scientists and technicians on a continuous basis. The increased scale of scientific activities led inexorably to an increased concern with their effectiveness" (Freeman, 1969, p. 7).

If there was any real accounting in science policy, it did not owe anything to official statistics and its accounting framework. It was conducted elsewhere than in statistical offices – in government departments – and with other statistics: administrative data. Official statistics, because they were "too macro", were usually not appropriate to such tasks. They were what Godin has called "contextual" data (Godin, 2005). As the OECD admitted recently: "Monitoring and benchmarking are not coupled with policy evaluation (. . .). They are seldom used for evaluation purposes (. . .) but to analyze [countries'] position vis-à-vis competing countries and to motivate adaptation or more intense policy efforts (. . .)" (OECD, 2005, p. 64).

Official statistics mainly served discourse purposes, and in this sense the accounting framework and the statistics presented within it were influential because they fit perfectly well with the policy discourse on rationality, efficiency and accountability: it aligns and frames the science system, by way of statistics, as goal-oriented and accountable. As it actually is, the accounting in official statistics on science is a metaphor, not an accounting exercise as such.[22]

5. Conclusion

Accounting of a certain type exists in science. For decades, firms have constructed I/O ratios to assess rates of return on their investments (Johnson and Kaplan, 1987), including investments in R&D (Olsen, 1948). Governments have conducted their evaluation exercises with data dealing both with investments and results (Office of Technology Assessment, 1978). The input–output framework used to frame official statistics on science is part of this movement, as were other official "accounting" exercises such as the measurements on the technological balance of payments, the balance between types of research (fundamental and applied), and human capital.

Academics were very influential in these accounting developments. The first were economists, above all Freeman, author of the first edition of the OECD Frascati manual. Very early on, Freeman conducted statistical studies linking input to output (Freeman, 1962; Freeman et al., 1963), and remained a fervent advocate of the input–output framework for decades (Freeman and Young, 1965; Freeman, 1967, 1969, 1974, 1982). This framework came directly from mainstream economics, and Machlup has been very influential here. By the end of the 1960s, however, few traces of the production function remains in statistics on science, except in econometric studies on productivity. The input–output framework now had a life of its own. Price, an historian of science and one of the founders of scientometrics and bibliometrics (Price, 1963), was an influential person here. He generally collected several indicators to measure science as a system, presented them into an input–output framework, and suggested all sort of input–output ratios (Price, 1967a,b, 1978, 1980a,b). The NSF, with its series of indicators published every 2 years from 1973 and after, was equally influential. In the following decades, most researchers would use an input–output framework to conduct "accounting" or evaluation exercises of investments in science.

A second historical source for the input–output framework has to be mentioned, namely the management of industrial research and the control of costs. Establishing a relationship between input and output at the national level, that is the level that interests governments most, is in fact the analogue to the firms' ratio on "returns on investment" (ROI). For decades, managers have constructed such ratios in order to evaluate their investments (Chandler, 1977; Johnson, 1978; Johnson and Kaplan, 1987; Hounshell and Smith, 1988). Very early on, the ratios came to be applied to R&D activities. By the 1950s, most companies calculated ratios like R&D as a percentage of earnings, as a percentage of sales, or as a percentage of value-added (Olsen, 1948; Abrams, 1951; Anthony and Day, 1952; Quinn, 1960), and a whole "industry" developed around studying the "effectiveness" of research (Hogan, 1950; Pelz, 1956; Quinn, 1959; Kaplan, 1960; Lipetz, 1965; Seiler, 1965; Yovits et al., 1966; Pelz and Andrews, 1966; Dean, 1968; The Institution of Chemical Engineers, 1963). Very few administrative decisions really relied automatically on metrics,[23] but it was not long before performance ratios

---

[22] For a reading of accounting as symbolic and metaphoric, see Carruthers and Espeland (1991). Some authors prefer talking of accounting as a "social and organizational" practice for naming the ideology of efficiency by numbers. It includes all types of accounting that are implicated in economic activities such as costing, budgeting, cost-benefit analysis, risk assessment, censuses, samples, etc. See Hopwood and Miller (1994) and Power (1994).

[23] For evidence, see NSF (1956b), Rubenstein (1957), and Seeber (1964).

came to be applied to aggregated statistics on industrial R&D (Sherman, 1941; US National Association of Manufacturers, 1949; US Bureau of Labor Statistics, 1953a,b; Dearborn et al., 1953; Compton, 1941; NSF, 1956a, 1960)[24] and national R&D expenditures (Bernal, 1939/1973; Ewell, 1955; NSF, 1956a,b). In the latter case, GDP served as denominator and gave the famous GERD/GDP ratio as the objective of science policies.

There are currently two explanations or rationales offered for statistics and accounting on science. The most common rationale is "controlling" science, in the sense of limiting expenses for example. The very first edition of the Frascati manual assigned two main goals to this practical side of statistics: managing research and assessing returns on R&D (OECD, 1962c, pp. 9–11). Management of research (or management control) consists of "the optimum use of resources" and involves concepts like the productivity of research and the balance between types of research. Assessment of returns deals with the effectiveness of research. Yet science policy is full of statistics used not to control science, but to make a case for providing increasing resources to science, such as in the current official literature on the knowledge-based economy.

A second rationale relates to the theoretical use of statistics and the accounting framework – and it was indeed mentioned in the first edition of the Frascati manual.[25] The accounting framework is a kind of "model" that explains science activities. It is centered on a specific kind of "mechanisms" and has a certain truth: inputs come first, and without money and personnel there would be no output. It is an administrative or accounting view, and is concerned exclusively with accounting of an economic type. Another understanding, developed by academics with the same semantics, started with suggesting that science is a complex phenomenon, or system as Price suggested. To measure science properly, one therefore needs to take account of several dimensions: inputs, but also outputs and outcomes (Pavitt, 1982; Martin and Irvine, 1983). This "philosophy" is known as multiple converging indicators.

A third rationale, or use, is for accounting on science to act as "rhetoric". We have seen how accounting in official statistics on science is a representation. By representation, we do not mean just an idea. A representation, like an imaginary or ideology, is an ideal. It is a "common understanding that makes possible common practices and a widely shared sense of legitimacy" (Taylor, 2004, p. 23). It incorporates expectations and norms about how people or things behave and fit together, and suggests courses of action. By definition, the representation carried by official statistics is (usually) that of its patron, the State. Whether or not the representation really serves accounting as such does not matter. It suffices that the rhetoric (of efficiency) appears to be real, for rationalizing and justifying decisions to the nation rest in large part on a web of discourses that look coherent and seem to make sense with decisions taken at the organizational level where accounting is real.

---

[24] For Great Britain, see Federation of British Industries (1952) and DSIR (1958). For Canada, see Dominion Bureau of Statistics (1956).

[25] Information and description, evolution, comparison.

Appendix A

The Flow of Ideas through the Stages of Research, Invention, and Development to Application

	INPUT			OUTPUT	
Stage	Intangible	Tangible	Measurable	Intangible	Measurable
I "Basic Research"	1. Scientific Knowledge (old stock and output from I-A)	Scientists Technical aides Clerical aides	Men, man-hours Payrolls, current and deflated	A. New scientific knowledge: hypotheses and theories	Research papers and memoranda; formulas
[Intended output: "Formulas"]	2. Scientific problems and hunches (old stock and output from I-B, II-B and III-B)	Laboratories Materials, fuel, power	Outlays, current and deflated Outlay per man	B. New scientific problems and hunches	___
				C. New pratical problems and ideas	___
II "Inventive Work" (Including minor improvements but excluding further development of inventions)	1. Scientific Knowledge (old stock and output from I-A)	Scientists Non-scientist inventors Engineers Technical aides Clerical aides	Men, man-hours Payrolls, current and deflated	A. Raw inventions: technological recipes	
	2. Scientific problems and hunches (old stock and output from II-A and III-A)	Laboratories Materials, fuel, power	Outlays, current and deflated Outlay per man	a. Patented inventions	a. Patent applications and patents
[Intended output: "Sketches"]	3. Practical problems and ideas (old stock and output from I-C, II-C, III-C and IV-A)			b. Patentable inventions, not patented but published	b. Technological papers and memoranda
				c. Patentable inventions, neither patented nor published	c. ___
				d. Non-patentable inventions, published	d. Papers and memoranda
				e. Non-patentable inventions, not published	e. ___
				f. Minor improvements	f. ___
				B. New scientific problems and hunches	___
				C. New pratical problems and ideas	___
III "Development Work"	1. Scientific Knowledge (old stock and output from I-A)	Scientists Engineers Technical aides Clerical aides	Men, man-hours Payrolls, current and deflated	A. Developed inventions: blueprints, specifications, samples	Blueprints and specifications
[Intended output: "Blueprints and Specifications"]	2. Technology (old stock and output from III-A)	Laboratories Materials, fuel, power	Outlays, current and deflated Outlay per man	B. New scientific problems and hunches	___
	3. Practical problems and ideas (old stock and output from I-C, II-C, III-C and IV-A)	Pilot plants	Investment	C. New pratical problems and ideas	___
	4. Raw inventions and improvements (old stock and output from II-A)				
IV "New-type Plant Construction"	1. Developed inventions (output from III-A)	Entrepreneurs Managers Financiers and bankers Builders and contractors Engineers		A. New pratical problems and ideas	New-type plant producing a. novel products b. better products c. cheaper products
[Intended output: "New-type plant"]	2. Business acumen and market forecasts				
	3. Financial resources		$ investment in new-type plant		
	4. Enterprise (venturing)	Building materials Machines and tools			

Source: Machlup (1962a, pp. 178–179).

References

Abramovitz, M., 1989. Thinking About Growth. Cambridge University Press, New York.

Abrams, A., 1951. Contribution to the session on measuring the returns from research, in Engineering Research Institute. In: Proceedings of the Fourth Annual Conference on the Administration of Research, University of Michigan, September 11–13, 1950. University of Michigan, pp. 22–24.

Ames, E., 1961. Research, invention, development and innovation. American Economic Review 51 (3), 370–381.

Anthony, R.N., Day, J.S., 1952. Management Controls in Industrial Research Organizations. Harvard University, Boston, pp. 286–300.

Arnow, K., 1959. National Accounts on R&D: The National Science Foundation Experience, in NSF. Methodological Aspects of Statistics on R&D, op. cit. pp. 57–61.

Bartelmus, P., et al., 1991. Integrated environmental and economic accounting framework for a SNA satellite system. Review of Income and Wealth 2, 111–148.

Bernal, J.D., 1939/1973. The Social Function of Science. MIT Press, Cambridge, MA.

Bosworth, D.L., Wilson, R.A., Young, A., 1993. Research and Development, Reviews of United Kingdom Statistical Sources Series, vol. XXVI. Chapman and Hill, London.

Carruthers, B.G., Espeland, W.N., 1991. Accounting for rationality: double-entry bookkeeping and the rhetoric of economic rationality. American Journal of Sociology 97 (1), 31–69.

Chandler, A.D., 1977. The Visible Hand: The Managerial Revolution in American Business. Belknap Press, Cambridge.

Cobb, C.W., Douglas, P.H., 1928. A theory of production. American Economic Review 18, 139–165.

Compton, K.T., 1941. Industrial Research Expenditures, 124–125.

Dean, B.V., 1968. Evaluating, Selecting, and Controlling R&D Projects. American Management Association.

Dearborn, D.C., Kneznek, R.W., Anthony, R.N., 1953. Spending for Industrial Research, 1951–1952.

Dedijer, S., 1962. Measuring the growth of science. Science 138, 781–788.

Denison, E.F., 1962. The Sources of Economic Growth in the United States and the Alternatives Before us. Committee for Economic Development, New York.

Denison, E.F., 1967. Why Growth Rates Differ. Brookings Institution, Washington.

Dominion Bureau of Statistics, 1956. Industrial R&D Expenditures in Canada, 1955. Reference paper no. 75. Ottawa.

Douglas, P.H., 1948. Are there laws of production? American Economic Review 38, 1–41.

DSIR, 1958. Estimates of Resources Devoted to Scientific and Engineering R&D in British Manufacturing.

Elkana, Y., et al., 1978. Towards a Metric of Science: The Advent of Science Indicators. John Wiley, New York.

Ewell, R.H., 1955. Role of research in economic growth. Chemical and Engineering News 18, 2980–2985.

Fabian, Y., 1963. Note on the Measurement of the Output of R&D Activities. DAS/PD/63.48. OECD, Paris.

Federation of British Industries, 1952. R&D in British Industry. FBI, London.

Ferguson, C., 1969. Microeconomic Theory. Richard D. Irwin Inc., Homewood.

Fourquet, F., 1980. Les comptes de la puissance: histoire de la comptabilité nationale et du plan. Encres, Paris.

Freeman, C., 1962. Research and development: a comparison between British and American industry. National Institute Economics Review 20, 21–39.

Freeman, C., Poignant, R., Svennilson, I., 1963. Science, Economic Growth and Government Policy. OECD, Paris.

Freeman, C., Young, A., 1965. The Research and Development Effort in Western Europe, North America and the Soviet Union: An Experimental International Comparison of Research Expenditures and Manpower in 1962. OECD, Paris.

Freeman, C., 1967. Research comparisons. Science 158 (3800), 463–468.

Freeman, C., 1969. Measurement of Output of Research and Experimental Development. ST/S/16. UNESCO.

Freeman, C., 1974. The Economics of Industrial Innovation. Penguin Books, London.

Freeman, C., 1982. Recent Developments in Science and Technology Indicators: A Review. SPRU, Mimeo, Brighton.

GAO, 1979. Science Indicators: Improvements Needed in Design, Construction, and Interpretation. USGPO, Washington.

Godin, B., 2002. Technological gaps: an important episode in the construction of S&T statistics. Technology in Society 24 (4), 387–413.

Godin, B., 2003. The emergence of science and technology indicators: why did governments supplement statistics with indicators? Research Policy 32 (4), 670–690.

Godin, B., 2004a. The new economy: what the concept owes to the OECD. Research Policy 33 (5), 679–690.

Godin, B., 2004b. The obsession for competitiveness and its impact on statistics: the construction of high-technology indicators. Research Policy 33 (8), 1217–1229.

Godin, B., 2005. Measurement and Statistics on Science and Technology: 1920 to the Present. Routledge, London.

Godin, B., 2007. The linear model of innovation: the historical construction of an analytical framework. Science, Technology, and Human Values 31 (6), 639–667.

Godin, B., 2006. The value of science: changing conceptions of productivity, 1869-circa 1970. In: Communication Presented at the SPRU Conference "The Future of Science, Technology and Innovation Policy: Linking Research and Practice", Brighton, September 11–13.

Griliches, Z., 1958. Research costs and social return: hybrid corn and related innovations. Journal of Political Economy 66 (5), 419–431.

Griliches, Z., 1962. Comment on W.R. Mueller's paper. In: NBER. The Rate and Direction of Inventive Activity. Princeton University Press, Princeton, pp. 343–346.

Hogan, R.M., 1950. Productivity in research and development. Science 112 (2917), 613–616.

Hoos, I.R., 1972. Systems Analysis in Public Policy: A Critique. University of California Press, Berkeley.

Hopwood, A.G., Miller, P. (Eds.), 1994. Accounting as Social and Institutional Practice. Cambridge University Press, Cambridge.

Hounshell, D.A., 2000. The medium is the message, or how context matters: the RAND corporation builds an economics of innovation, 1946–1962. In: Hughes, A.C., Hughes, T.P. (Eds.), Systems, Experts, and Computers: The Systems Approach in Management and Engineering, World War II and After. MIT Press, Cambridge, MA, pp. 255–310.

Hounshell, D.A., Smith, J.K., 1988. Science and Corporate Strategy: Du Pont R&D, 1902–1980. Cambridge University Press, Cambridge.

Johnson, H.T., 1978. Management accounting in an early multidivisional organization: general motors in the 1920s. Business History Review 52 (4), 490–517.

Johnson, H.T., Kaplan, R.S., 1987. Relevance Lost: The Rise and Fall of Management Accounting. Harvard Business School Press, Boston.

Jorgensen, D.W., Griliches, Z., 1967. The explanation of productivity change. Review of Economic Studies 34 (3), 249–283.

Kaplan, N., 1960. Some organizational factors affecting creativity. IEEE Transactions of Engineering Management 30, 24–30.

Klamer, A., McCloskey, D., 1992. Accounting as a master metaphor of economics. European Accounting Review 1, 145–160.

Kramish, A., 1963. Research and Development in the Common Market vis-à-vis the UK, US and USSR. Report prepared by the RAND Corporation for the Action Committee for a United Europe (under the chairmanship of J. Monnet).

Kuznets, S., 1962. Inventive activity: problems of definition and measurement. In: NBER. The Rate and Direction of Inventive Activity. Princeton University Press, Princeton, pp. 19–43.

Leontief, W., 1936. Quantitative input–output relations in the economic system of the United States. Review of Economics and Statistics 18 (3), 105–125.

Leontief, W., 1953a. Domestic production and foreign trade: the American capital position re-examined. Proceedings of the American Philosophical Society 97 (4), 332–349.

Leontief, W., 1953b. Studies in the Structure of the American Economy. Oxford University Press, Oxford.

Leontief, W., 1966/1986. Input–Output Economics. Oxford University Press, Oxford.

Leontief, W., 1970. Comment on J.S. Chipman's paper. In: Vernon, R. (Ed.), The Technology Factor in International Trade. Columbia University Press, New York, pp. 132–138.

Liebling, H.I., 1962. Comment on S. Kuznets' and B.S. Sanders' papers. In: NBER. The Rate and Direction of Inventive Activity. Princeton University Press, Princeton, pp. 85–90.

Lipetz, B.-A., 1965. The Measurement of Efficiency of Scientific Research. Intermedia, Carlisle.

Machlup, F., 1962a. The Production and Distribution of Knowledge in the United States. Princeton University Press, Princeton.

Machlup, F., 1962b. The Supply of Inventors and Inventions. In: NBER. The Rate and Direction of Inventive Activity. Princeton University Press, Princeton, pp. 143–169.

Maddison, A., 2003. The World Economy: Historical Statistics. OECD, Paris.

Maestre, C., 1966. Vers une mesure des échanges intersectoriels entre la recherché et l'industrie. Progrès scientifique 102, 2–45.

Mansfield, E., 1965. Rates of return from industrial R&D. American Economic Review 55 (2), 310–332.

Mansfield, E., 1968. The Economics of Technological Change. Norton, New York.

Mansfield, E., et al., 1977. Social and private rates of return from industrial innovations. Quarterly Journal of Economics, 221–240.

Martin, B.R., Irvine, J., 1983. Assessing basic research: some partial indicators of scientific progress in radio astronomy. Research Policy 12, 61–90.

Miller, P., O'Leary, T., 1987. Accounting and the construction of the governable person. Accounting, Organizations and Society 12 (3), 235–265.

Minasian, J.R., 1962. The economics of research and development. In: NBER. The Rate and Direction of Inventive Activity. Princeton University Press, Princeton, pp. 93–141.

Minasian, J.R., 1969. R&D, production functions, and rates of return. American Economic Review 59 (2), 80–85.

Minder, J.F., 1991. R&D in National Accounts. DSTI/STII (91) 11. OECD, Paris.

National Science Board, 1973. Science Indicators 1972. National Science Foundation, Washington.

Nelson, R.R., 1962. Introduction. In: NBER. The Rate and Direction of Inventive Activity. Princeton University Press, Princeton, pp. 2–16.

NSF, 1956a. Expenditures for R&D in the United States: 1953. Reviews of Data on R&D 1. NSF 56-28. NSF, Washington.

NSF, 1956b. Science and Engineering in American Industry: Final Report on a 1953–1954 Survey, NSF 56-15. NSF, Washington.

NSF, 1959. Methodological Aspects of Statistics on Research and Development: Costs and Manpower, NSF 59-36. NSF, Washington.

NSF, 1960. Funds for R&D in Industry: 1957. NSF 60-49. NSF, Washington.

OECD, 1962a. Draft 1963 Programme and Budget. SR (62) 26. OECD, Paris.

OECD, 1962b. Economics of Research and Technology. SR (62) 15. OECD, Paris.

OECD, 1962c. The Measurement of Scientific and Technical Activities: Proposed Standard Practice for Surveys of Research and Development. DAS/PD/62.47. OECD, Paris.

OECD, 1962d. The 50 Per Cent Growth Target. CES/62.08. OECD, Paris.

OECD, 1963a. A Progress and Policy Report. SR (63) 33. OECD, Paris.

OECD, 1963b. Government Expenditures on R&D in the United States of America and Canada. DAS/PD/63.23. OECD, Paris.

OECD, 1963c. Ministers Talk about Science. La Documentation française, Paris.

OECD, 1963d. Resources of Scientific and Technical Personnel in the OECD Area. OECD, Paris.

OECD, 1963e. Science and the Policies of Government. OECD, Paris.

OECD, 1963f. Science, Economic Growth and Government Policy. OECD, Paris.

OECD, 1966. The Technological Gap. SP (66) 4. OECD, Paris.

OECD, 1967. A Study of Resources Devoted to R&D in OECD Member Countries in 1963/64: The Overall Level and Structure of R&D Efforts in OECD Member Countries. OECD, Paris.

OECD, 1971. R&D in OECD Member Countries: Trends and Objectives. OECD, Paris.

OECD, 1975a. Changing Priorities for Government R&D: An Experimental Study of Trends in the Objectives of Government R&D Funding in 12 OECD Member Countries, 1961–1971. OECD, Paris.

OECD, 1975b. Patterns of Resources Devoted to R&D in the OECD Area, 1963–1971. OECD, Paris.

OECD, 1978. General Background Document for the 1978 Meeting of the Group of National Experts on R&D Statistics. DSTI/SPR/78.39 and annex. OECD, Paris.

OECD, 1979. Trends in Industrial R&D in Selected OECD Countries, 1967–1975. OECD, Paris.

OECD, 1980. Preliminary Report of the Results of the Conference on Science and Technology Indicators. SPT (80) 24. OECD, Paris.

OECD, 1981. The Measurement of Scientific and Technical Activities: Proposed Standard Practice for Surveys of Research and Experimental Development. OECD, Paris.

OECD, 1983. State of Work on R&D Output Indicators. SPT (83) 12. OECD, Paris.

OECD, 1992. Education at a Glance: OECD Indicators. OECD, Paris.

OECD, 1996. Measuring What People Know: Human Capital Accounting for the Knowledge Economy. OECD, Paris.

OECD, 1998. Human Capital Investment: An International Comparison. OECD, Paris.

OECD, 1999. The Knowledge-based Economy: A Set of Facts and Figures. OECD, Paris.

OECD, 2000. A System of Health Accounts. OECD, Paris.

OECD, 2001. Drivers of Growth: Information Technology, Innovation and Entrepreneurship. OECD, Paris.

OECD, 2003. Summary Record of the Working Party of NESTI. OECD/EAS/STP/NESTI/M (2003) 2. OECD, Paris.

OECD, 2005. Governance of Innovation Systems, vol. 1. OECD, Paris.

OEEC, 1955. Shortages and Surpluses of Highly Qualified Scientists and Engineers in Western Europe. OECD, Paris.

OEEC, 1957. The Problem of Scientific and Technical Manpower in Western Europe, Canada and the United States. OECD, Paris.

OEEC, 1958. Standardized System of National Accounts. OECD, Paris.

OEEC, 1960. Forecasting Manpower Needs for the Age of Science. OECD, Paris.

OEEC, 1961. Government Expenditures on R&D in France and the United Kingdom. EPA/AR/4209, OECD, Paris.

Office of Technology Assessment, 1978. Research Funding as an Investment: Can We Measure the Returns? USGPO, Washington.

Ogburn, W.F., Gilfillan, S.C., 1933 The influence of invention and discovery. Recent Social Trends in the United States. Report of the President's Research Committee on Social Trends. McGraw Hill, New York.

Okubo, Y., 1997. Bibliometric Indicators and Analysis of Research Systems: Methods and Examples. OECD/GD (97) 41. OECD, Paris.

Olsen, F., 1948. Evaluating the results of research. In: Furnas, C.C. (Ed.), Research in Industry: Its Organization and Management. D. Van Nostrand, Princeton, pp. 402–415.

Olson, M., 1969. The plan and purpose of a social report. The Public Interest, 15.

Pavitt, K., 1982. R&D, patents and innovative activities. Research Policy 11, 33–51.

Pavitt, K., 1984. Sectoral patterns of technical change: towards a taxonomy and a theory. Research Policy 13, 343–373.

Pelz, D.C., 1956. Some social factors related to performance in a research organization. Administrative Science Quarterly 1, 310–325.

Pelz, D.C., Andrews, F.M., 1966. Scientists in Organizations: Productive Climate for Research and Development. John Wiley, New York.

Porter, T.M., 1995. Trust in Numbers: The Pursuit of Objectivity in Science and Public Life. Princeton University Press, Princeton.

Power, M. (Ed.), 1994. Accounting and Science: Natural Inquiry and Commercial Reason. Cambridge University Press, Cambridge.

Price, D.J.D., 1963. Little Science, Big Science. Columbia University Press, New York.

Price, D.J.D., 1967a. Nations can publish or perish. Science and Technology, 84–90.

Price, D.J.D., 1967b. Research on research. In: Arm, D.L. (Ed.), Journeys in Science. University of New Mexico Press, pp. 1–21.

Price, D.J.D., 1978. Toward a model for science indicators. In: Elkana, Y., et al. (Eds.), Towards a Metric of Science: The Advent of Science Indicators. Wiley & Sons, New York, pp. 69–95.

Price, D.J.D., 1980a. A theoretical basis for input–output analysis of national R&D policies. In: Sahal, D. (Ed.), Research Development and Technological Innovation. D.C. Heath and Co., pp. 251–260.

Price, D.J.D., 1980b. Towards a comprehensive system of science indicators. In: Paper Presented to the Conference on "Evaluation in Science and Technology: Theory and Practice" (Dubrovnik, July) and to the "Quality Indicators Seminar" (MIT, October).

Quinn, J.B., 1959. Yardsticks for Industrial Research: The Evaluation of Research and Development Output. Ronald Press, New York.

Quinn, J.B., 1960. How to Evaluate Research Output. Harvard Business Review, 69–80.

Robson, M., Townsend, J., Pavitt, K., 1988. Sectoral patterns of production and use of innovations in the UK, 1945–1983. Research Policy 17, 1–14.

Rubenstein, A.H., 1957. Setting criteria for R&D. Harvard Business Review, 95–104.

Ruggles, N., Ruggles, R., 1970. The Design of Economic Accounts. Columbia University Press, New York.

Sanders, B.S., 1962. Some difficulties in measuring inventive activity. In: NBER. The Rate and Direction of Inventive Activity. Princeton University Press, Princeton, pp. 53–77.

Scherer, F.M., 1982. Inter-industry technology flows in the United States. Research Policy 11, 227–245.

Schmookler, J., 1962. Comment on B.S. Sanders's paper. In: NBER. The Rate and Direction of Inventive Activity. Princeton University Press, Princeton, pp. 78–83.

Schumpeter, J., 1939. Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process, vol. 1. McGraw Hill, New York.

Seeber, N.C., 1964. Decision-making on R&D in the Business Firm. Reviews of Data on R&D 44. NSF 64-6. NSF, Washington.

Seiler, R.E., 1965. Improving the Effectiveness of Research and Development. McGraw Hill, New York.

Shapley, W.H., 1959. Problems of definition, concept, and interpretation of research and development statistics. NSF. Methodological Aspects of Statistics on Research and Development: Costs and Manpower. NSF 59-36. Washington.

Sherman, J.V., 1941. Research as a Growth Factor in Industry.

Solow, R.M., 1957. Technical change and the aggregate production function. Review of Economics and Statistics 39, 312–320.

Stirner, H.E., 1959. A National Accounting System for Measuring the Intersectoral Flows of R&D Funds in the United States, in NSF. Methodological Aspects of Statistics on R&D, op. cit. pp. 31–38.

Studenski, P., 1958. The Income of Nations: Theory, Measurement, and Analysis: Past and Present. New York University Press, New York.

Taylor, C., 2004. Modern Social Imaginaries. Duke University Press, Durham.

The Institution of Chemical Engineers, 1963. Productivity in research. In: Proceedings of a Symposium held in London on 11–12 December 1963, London.

UNESCO, 1952. Report of the World Social Situation. UNESCO, Paris.

United Nations, 1953. A System of National Accounts and Supporting Tables. Department of Economic Affairs, Statistical Office, New York, United Nations.

United Nations, 1975. Towards a System of Social and Demographic Statistics. Studies in Methods, Series F, 18. United Nations, New York.

United Nations, 1989. UN Handbook on Social Indicators. United Nations, New York.

US Bureau of Labor Statistics, 1953a. Industrial R&D: A Preliminary Report. Department of Labor and Department of Defense.

US Bureau of Labor Statistics, 1953b. Scientific R&D in American Industry: A Study of Manpower and Costs. Bulletin no. 1148. Washington.

US Department of Health, Education, and Welfare, 1970. Towards a Social Report. University of Michigan Press, Ann Harbor.

US National Association of Manufacturers, 1949. Trends in Industrial Research and Patent Practices.

Valavanis-Vail, S., 1955. An econometric model of growth: USA, 1869–1953. American Economic Review, 208–227.

Vanoli, A., 2002. Une histoire de la comptabilité nationale. La Découverte, Paris.

Wildavsky, A., 1966. The political economy of efficiency: cost-benefit analysis, systems analysis, and program budgeting. Public Administration Review 26 (4), 292–310.

Yovits, M.C., et al. (Eds.), 1966. Research Program Effectiveness. Gordon and Breach, New York.

Zuckerman, H., Balstad-Miller, R. (Eds.), 1980. Science Indicators 1976. Scientometrics 2 (5/6) (Special Issue).