The Culture of Numbers:
From Science to Innovation

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Many thanks for inviting me to this distinguished roundtable. It is an honor to share some food for thought with you tonight. Since you are attending the dinner instead of going in the sun and heat, you must think statistics (or mathematics) is very cool. I totally agree with you. [1]

Many others do think so. In 1994 the OECD Directorate for Science, Technology and Industry stated that, "if the OECD were to close its doors tomorrow, the drying up of its statistics would probably make a quicker and bigger impact on the outside world than would the abandonment of any of its other activities". This is certainly a self-congratulatory statement. However, it also reflects the fact that measuring science has become an "industry". Dozens of surveys and thousands of statistics are produced yearly by academics and governments, and then used for varying purposes.

When, how and why did science come to be measured in the first place? How did a "cultural" activity – science – long reputed to be not amenable to statistics, come to be measured? I suggest that we are not measuring science correctly … and that we are therefore not making correct decisions. I shall explain how we arrived at this situation.

Eugenics

Statistics on science began to be collected in the mid-nineteenth century in a context of eugenics. In the view of many at that time, the stock of the population and the quality of the race were deteriorating, and those groups that contributed more to civilization, namely eminent men including scientists, were not reproducing enough. The "unfits" were far more fertile – and some suggested policies of sterilization. This gave rise to the idea of measuring the number of available scientists. No-one at the time considered sterilizing scientists who publish bad papers, although this would have solved many problems currently plaguing science and the scientific journal system.

In 1869, British statistician Francis Galton (1822-1911) conducted the first measurements of science from the perspective that the progress of civilization depends on great men,

[1] This paper has benefited considerably from comments by Gerald Barnett (Washington University, USA), Ron Freeman (Impact Group, Canada), Loet Leydersdorf (University of Amsterdam), Manfred Moldashi (Chemnitz University of Technology, Germany) and Alain-Marc Rieu (University of Lyon 3, France). The precise references to texts cited in this paper may be found in the various papers available at www.csii.ca.

and that their numbers were in decline. According to Galton, there were only 233 eminent British men for every one million population, while "if we could raise the average standard of our race one grade" there would be ten times more. Analysis of the antecedents of men of science from questionnaires sent to fellows of the Royal Society revealed that men of science were not "productive" enough, having less children than their parents had. The number of their living children between the ages of 5 and 50 was on average 4.7, compared to 6.3 in the families these men of science were born into. To Galton, the numbers revealed a clear "tendency to an extinction of the families of men who work hard with the brain", "a danger to the continuance of the race".

The Advancement of Science (or Scientists?)

In 1895, the American psychologist James McKeen Cattell (1860-1944), a student of Galton and an early sympathizer of eugenic doctrines, acquired the weekly journal *Science*, established in 1880 by Alexander Graham Bell and Gardiner G. Hubbard. Besides editing *Science* and other journals for 40 years, Cattell turned to the "scientific" study of science. To Cattell, applying statistics to the study of men of science was highly desirable: "the accounts of great men in biographies and histories belong to literature rather than to science (…). It is now time that great men should be studied (…) by the methods of exact and statistical science".

Between 1902 and 1906, Cattell compiled a directory (called *American Men of Science*) for a contract granted by the newly-created (1902) Carnegie Institution of Washington "to discover the exceptional man in every department of study whenever and wherever found", and to fund their research. The first edition contained about 4,000 biographical sketches of men of science. By 1944, the last year Cattell edited the directory before he died, the document contained biographical information on over 34,000 men of science. From the directory, Cattell constructed statistics which he published regularly until his death.

Two concepts were fundamental to his work, and still guide current measurements. The first was productivity (or quantity), defined as the number of men of science a nation produces. Cattell compared American states and institutions in terms of both absolute and relative (per million population) numbers of men of science. He found concentrations of origin in a few regions: Massachusetts and Boston were identified as the intellectual center of the country, while the South “remains in its lamentable condition of scientific stagnation”. To Cattell, “methods should be devised by which scientific work will be rewarded in some direct proportion to its value to society”.

To this end, Cattell elected a second concept, that of performance (or quality). Cattell asked leading representatives of each of the disciplines to arrange the men of science whose names appeared in the directory in order of merit (rank). A star was assigned to each of the thousand best. Cattell frequently compared his (novel) statistical procedure to that used in elections to a scientific society, or in filling chairs at a university: “the Academy [of Sciences] has no method of comparing performance in different sciences”. In Cattell’s view, his method was more accurate, and “it might seem that publishing such a list [of scientists by ranks] would be as legitimate as publishing any list of eminent men selected by other methods, but perhaps its very accuracy would give it a certain brutality”.

Cattell then ranked the various institutions, constructing the first league table, or scoreboard, of the universities. “I give this table with some hesitation, but it appears in the end it will be for the advantage of scientific research if it is known which institutions obtain and retain the best men (...). A table such as this might have some practical influence if the data were made public”. The table showed Harvard, Columbia and Chicago as the leading universities in terms of their share of the top thousand scientific men. All in all, Cattell calculated that about half of the best scientific men were connected with just 18 institutions.

At about the same time as Cattell’s work, psychologists started collecting a new statistics in order to contribute to the advancement of that discipline. While the yardstick in America for comparing the natural sciences was Europe, renowned for its chairs, laboratories and public support, in the science of psychology it was its status *vis-à-vis* the other sciences, experimental in nature, that served as the benchmark. Several psychologists developed a rhetoric on progress in psychology in which measures of growth were constructed like the number of psychologists, geographical distribution, degrees, doctorates conferred, laboratories, journals and … publications. In fact, psychologists were the first to use the counting of scientific papers (bibliometrics) systematically, in order to demonstrate that the discipline was really a science, namely a discipline producing scientific knowledge.

Accounting

These early measurements were only the precursors of a long series of statistics produced by governments and their agencies. From the 1940s onward, it was public organizations that produced most of the statistics, and these soon had a "monopoly" on the measurement of science, partly because they had the financial resources to conduct systematic surveys. It took four years for Cattell to construct his directory on men of science from which he drew his statistics. Such investments in time and money are rarely practicable to individual researchers today; governments have far more resources.

We owe a large part of the development of official (or institutional) measurement of science in western countries to the United States. It was there that the first experiments emerged in the 1920s. The very first official measurement of science activities was by the US National Research Council, a body of the National Academy of Sciences, which compiled many directories, above all on industrial laboratories involved in research and development (R&D). However, from the 1940s onward, it was primarily governments and their statistical bureaus that collected statistics, and these focused on a new type of statistics: the money spent on research. What has changed since Cattell is that counting men of science is no longer considered the measurement *par excellence.* Money devoted to R&D is now the preferred statistics.

Two factors explain this measurement. The first was accounting in order to control (government) expenses on R&D which were, according to the American Bureau of Budget, growing too fast. Secondly, and on a more positive note, statistics on money spent were developed as policy targets for scientific development, and were thus used to convince institutions to devote more money to R&D.

These efforts coalesced into the OECD Frascati manual. In 1963, OECD member countries adopted standards for the measurement of R&D expenditures. The GERD (Gross Expenditures on R&D) is the main statistics originating from the Frascati standards. The concept developed from the American Department of Defense and its consultant, the accountant R. N. Anthony from Harvard University, and from the National Science Foundation and its early experiments, preceded by J. D. Bernal in England and V. Bush in the United States. GERD is the total money spent on R&D by the following four economic sectors: industry, university, government and non-profit. However, the GERD is not in fact a statistics compiled on a national basis, but rather “a total constructed from the results of several surveys each with its own questionnaire and [significantly] different specifications”. Some (industry) data come from a survey, other (university) data is estimated using various mathematical formulas, and other data represents proxies (government). For this reason, as Statistics Canada admitted recently, “The GERD, like any other social or economic statistic, can only be approximately true (…). Sector estimates probably vary from 5 to 15% in accuracy. The GERD serves as a general indicator of S&T and not as a detailed inventory of R&D (…). It is an estimate and as such can show trends (…)”.

However, GERD, and its derivative GERD/GDP, is currently the most cherished indicator. Over the last fifty years, the indicator has been used for several purposes, from rhetorically displaying national performance to lobbying for more funds for science. In every statistical publication, the indicator is calculated, discussed, and countries ranked according to it, because, as the OECD once said, “it is memorable”, and is “the most popular one at the science policy and political levels, where simplification can be a virtue”. As the US economist W. C. Mitchell suggested in 1919: “Secure a quantitative statement of the critical elements in an official’s problem, draw it up in concise form, illuminate the tables with a chart or two, bind the memorandum in an attractive cover tied with a neat bow-knot (…). The data must be simple enough to be sent by telegraph and compiled overnight”.

The main consequence of such an orientation was twofold. First, statistics came to be packaged in an accounting framework. Statistics on science concentrated on costs, aligning themselves with the System of National Accounts, and were collected within an input or efficiency approach that assumed increased investment produced increased results. The second consequence was a focus on economic growth and productivity. Certainly the concept of scientific productivity arose from scientists themselves. In Galton's hands productivity meant biological reproduction: the number of children a scientist had. To Cattell it corresponded to the number of scientists a nation produced. Then in the mid-twentieth century, scientific productivity came to mean efficiency with regard to the quantity of output of a scientific (papers) or technological (patents) type, and later, outcomes such as economic growth and productivity. The statistics are still eugenic in style, but the nature of what is "fit" and "unfit" has changed. It is no longer a matter of increasing reproduction among the best minds, which takes generations, but rather increasing immediate output: counting the volume of activity and its fluctuations, and those responsible for this production.

Today, it is the organizations (and the economic sectors to which they belong) that are measured, above all firms (think of the innovation surveys). The people in our society who are supposed to benefit from science and public funding are not measured – and have never been. In spite of decades, even centuries, of discourse on the social benefits of science, you would look in vain for systematic indicators on outcomes other than productivity. Most current statistics and indicators are economic in type: expenditures on research, technological balance of payments, patents, trade in high-technology products, marketed innovation, etc. In fact, in "accounting", it is the economics that is significant, is made visible and demands action. The social aspect is the residual and is relegated to the periphery. The culture of numbers is in fact the cult of (economic) efficiency.

If I were the President of the United States, and a President serious about measuring the many benefits of science to society, not just the economic benefits, I would become a eugenicist and sterilize the economists. In their current form, statistics do not play a meaningful role in identifying and encouraging great, leading and emerging science. GUIRR should invest in developing statistics that can be believed in, and for that, one has to look at science that is innovative or transformative, rather than safe or usual or expected, or which confirms the status quo and calms public and government nerves.

Competition and Technological Innovation

But statisticians think otherwise, and have turned, all together and at the same time, toward a very restrictive idea of innovation. Until recently, innovation was excluded from the measurement of science, although it has been the central objective of science policy from the very beginning of the latter (I like to say that there has never been a "policy for science" golden age; science has always been funded for its applications or useful inventions). Innovation has been a contested category since antiquity (as science was in its early days). Until the nineteenth century, innovation was understood as "introducing change" into religion and politics. The term had nothing to do with originality or creativity. Innovation was subversive and forbidden. Such negative views on innovation would continue until the mid-nineteenth century. This is a fascinating story. We could come back to it during our discussion.

Innovation as a category was 'de-contested' over the twentieth century. Today, the quest for innovation is so strong that some researchers even suggest that drugs such as Ritalin and Adderall, normally used to treat psychiatric and neurological conditions, should be prescribed to the healthy as a "cognitive enhancement technology" to improve the innovative abilities of our species. Biologists have also started talking of animal innovation. Fundamentally, innovation owes its 'de-contestation' to the contribution of inventions to the progress of societies: innovation is invention turned useful. And to governments (supported by economists as experts and consultants), usefulness means competitiveness or competition through the commercialization of technological invention (US Department of Commerce). From the 1960s onward, innovation came to be seen as restricted to technological and marketed innovation, and efforts were devoted to its measurement: lags between discoveries and commercialization, gaps between countries in their capacity to innovate, contribution of technological innovation (or rather R&D as proxy) to economic growth, etc.

Innovation remains difficult to measure. There are two traditions here. One is American and concentrates on innovation as the introduction (adoption) of technology in industrial processes, i.e.: technological change. This tradition is that of the mainstream economists, and it relies on econometrics. Few people believe in these statistics except economists. The other tradition is European (and/or institutional). Here, innovation is seen not as the use of technological inventions in industry, but as the generation of new technological inventions or products for the market. The statistics produced in this tradition are descriptive statistics. They are called indicators, and they cover, to varying degrees, the steps from research to commercialization. However, most of these indicators are proxies.

Each of these two traditions ignores the other, with few exceptions. However, and I will conclude my talk with the following thoughts, both traditions share similar assumptions. Innovation is the affairs of businesses, and the benefits derived from (technological) innovation are growth in productivity and in market share. The measurement of innovation continues on the same path or bias (the cult of efficiency) as that of the measurement of science. We are still waiting for innovative 'statisticians'.

Summary Table

The Historical Development

of Statistics on Science

(19^{th} -20^{th} Centuries)

Stages	**Source**	**Main statistics**	**Objectives**
Emergence (1869-circa 1940)	Scientists (Galton, Candolle, Cattell)	Number of scientists	Eugenics Advancement of Science
Institutionalization (1940-circa 1970)	Governments and national statistical offices (pioneering role of the United States)	Monetary expenditures (and rates of return)	Management and policy (Economic growth)
Internationalization (1960 and after)	International organizations (UNESCO, OECD, European Commission)	Technological innovation (indicators) International comparisons	Competition