Measuring the Impacts of Science : Beyond the Economic Dimension [1]

Benoît Godin
and
Christian Doré

Introduction

For over fifty years, governments have funded research and development (R&D) because of the impact (or outcome) it has – or we think it has – on society. Although scientific policy has for a time been driven by the "policy for science" philosophy or ideology, there has never been any doubt in the minds of policy-makers that the ultimate aim for funding science and technology was socio-economic goals such as national security, economic development, welfare and the environment.

The socio-economic goals of public funding were so pronounced that, from the beginning, academic researchers and statistical offices measuring science and technology discussed how to measure output and outcome of scientific research and developed several indicators to this end. Now, one has historical series of output indicators on patents, technological balance of payments and high-technology trade, for example. We also have multiple studies linking science and technology to productivity and economic growth. OECD countries have also adopted a standard classification to measure and break down public R&D expenditures by socio-economic objectives.

Despite these efforts, however, we still know very little about the impact of science. First, most studies and indicators are concerned with economic impact. While economic impact is important and, above all, non negligible, it represents only a small fraction of the whole which extends to the social, organizational, and cultural spheres of society. As S. Cozzens argued recently: "The majority of [the measurement effort] has studied the process of innovation and not its outcomes. Traditional innovation studies still focus narrowly on making new things in new ways, rather than on whether the new things are necessary or desirable, let alone their consequences for jobs and wages" (Cozzens, 2002: 101). Second, the few discussions and measurements that go beyond the economic dimension concentrate on indirect rather than ultimate impact. We still have, forty years after the first demands for impact indicators, to rely on case studies to quantify, very imperfectly, dimensions other than the economic one.

This paper provides a framework to assess the contribution of science to society. It is divided into three parts. The first reviews the indicators of the impact of science available

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in the literature and explains why economic indicators dominate the field. It also discusses some recent exercises that try to extend the discussions and measurements of impact to more intangible dimensions, and shows that these interesting results nevertheless fail to properly address the issue. The second part develops a typology of impact covering eleven dimensions. Beyond the economic dimension, the typology concentrates on more intangible ones. The third part discusses the challenges confronting social scientists and statisticians interested in measuring the impact of science.

Measuring the Quantifiable

In the literature, most if not all measured impact of science concentrates on the economic dimension. In the 1950's, economists began integrating science and technology into their models, and focused on the impact R-D had on economic growth and productivity. Solow's (1957) approach has been the dominant methodology for linking R-D to productivity. He was the first to formalize accounting growth (decomposing GDP into capital and labour), and equated the residual in his equation with science and technology – although he included more than just science and technology. Denison (1962; 1967) and Jorgenson and Grilliches (1958), among others, later improved on Solow's approach.

Following Solow's initial work, many cost/benefit analyses were conducted and econometric models developed that tried to measure what the economy owed to science (Table 1). Many studies concentrated on estimating the rate of return to investment in R-D. They took two forms: return to publicly funded R&D and return to privately funded R-D. Since then, studies on the economic impact of science have focused on two topics: productivity and spillovers (from university and government funding of research, and across sectors and industries).

One topic that also deserved early attention was the impact of science on international trade. As early as the 1960's, economists began integrating science into models on international trade (Posner, 1961; Vernon, 1970). Using R&D as a factor to explain international trade patterns, the authors discussed why some countries led in terms of trade while others lagged.

The literature on the non-economic impact of science is far less abundant. Impact on science itself is probably the most studied in the literature. Citation count has been used for more than 30 years to measure the impact of scientific publication on other researchers. The contribution of the Science Policy Research Unit (SPRU) in Sussex, England and the Center for Science and Technology Studies (CWTS) in Leiden, Netherlands has been especially important.

The impact on technological innovation has also received a lot attention from researchers (Gibbons and Johnston, 1974; Mansfield, 1991; 1998; Rosenberg and Nelson, 1996). For instance, several authors, among them E. Mansfield, have illustrated the importance of academic research to the advance of industrial innovation. They argued that a large proportion of firms would not have developed products and processes in the absence of academic research.

Table 1 – Sample of Studies on the Economic Dimension of Science

Impact of R-D on output and productivity growth	**Impact on rate of return to investment**		
Coe and Helpman (1995)	Bernstein (1988, 1989)	Jaffe (1986)	Schankerman-Nadiri (1986)
Cuneo-Mairesse (1984)	Bernstein and Nadiri (1988, 1989a, 1989b, 1991)	Lichtenberg-Seigel (1991)	Scherer (1982, 1984)
Englander-Mittelstadt (1988)	Clarck-Griliches (1984)	Link (1978.1981,1983)	
Griliches (1980a, 1980b,1986)	Englander-Mittelstadt (1988)	Mansfield (1977, 1980)	Sterlacchini (1989)
Lichtenberg (1992)	Evenson (1968)	Minasian (1962,1969)	Suzuki (1993)
Mansfield (1988)	Evenson et al. (1979)		Sveikausas (1981)
Mairesse-Cuneo (1985)	Goto and Suzuki (1989)	Möhnen-Nadiri-Prucha (1986)	Terleckyj (1974,1980)
Mairesse-Hall (1996)	Globerman (1972)	Nadiri (1993)	Wolff-Nadiri (1993)
Nadiri (1980)	Griliches (1958,1973,1980a,1980b,1986)	Nadiri-Prucha (1990)	
Nadiri-Prucha (1990)	Griliches-Lichtenberg (1984a,1984b)	Odagiri (1983,1985)	
Verspagen (1995)	Griliches-Mairesse (1983,1984,1986,1990)	O'Mahony (1992)	
	Hall -Mairesse (1995)	O'Mahony-Wagner (1996)	
	Hanel (1988)		
		Schankerman (1981)	

Studies of other types of impact are rather scarce. Certainly, one can find some empirical studies on the impact of new technologies (computers) on jobs and work division (for examples, see OECD, 1996), or measures of the return on investment in health research on the burden of disease – incidence, prevalence, hospital days, mortality, years of life lost (Comroe and Dripps, 1976; Hanney et al., 1999; Gross and al., 1999; Grant, 1999). One can also find several evaluation of specific public programs that deal with socioeconomic impacts, for example at the European Commission level. But most of the literature is concerned with the definition of the right approach to be used in the evaluation of impact or simply with the description of the available methods to do so (for recent examples, see: Garrett-Jones, 2000; Meulen van der meulen and Rip, 2000; Roessner, 2000; Caulil et al., 1996; Kostoff, 1994). Many authors acknowledged the difficulty of measuring impact, first due to the fact that it is indirect rather than direct, and second because it is diffused in space and time. For many, the concern in measuring non-economic impact depends on a better knowledge of the mechanisms of research transfer. One can indeed find several models in the literature that proposed analytical frames for transfer mechanisms (Hanney, Davies and Buxton, 1999; Caulil et al., 1996; Cozzens, 1996).

Several factors contributed to focusing on statistics and indicators, above all official statistics, in the economic dimension of science. One relates to the mission of the first organization that got involved systematically in measuring science, namely the OECD. Most of the OECD's work dealt with indicators of an economic nature, because from the start the mandate of its Committee on Scientific Research was to "give considerable emphasis in its future program to the economic aspects of scientific research and technology". The OECD was very influential on national statistical offices in regard to the methodology for measuring science, and its philosophy considerably influenced the statistics collected and the indicators developed (Godin, 2002).

Secondly, economists have been the main producers and users of statistics and indicators on science – and have constituted the bulk of national and OECD consultants because they were, until recently, among the only analysts that worked systematically with statistics. R. Nelson once argued that: "one would have thought that political science, not economics, would have been the home discipline of policy analysis. According to some, the reason it was not was that the normative structure of political science tended to be squishy, while economics possessed a sharply articulated structure for thinking about what policy ought to be" (Nelson, 1977: 30). I would suggest that it is the mystique of numbers that was at play here. Numbers have always seduced bureaucrats, and it was the economists, not the sociologists or political scientists, who were reputed to produce them, who were hired as consultants, and emulated.

The third reason for focusing on economics was that the economic dimension of reality is the easiest to measure. Most of the output and impact of science are non-tangible, diffuse, and often occur with important lags. Although difficult to measure, the economic dimension of science and technology remains the least difficult of all.

Aware of these limitations, some researchers in recent years have identified new ways in which science, and above all (basic) research, influences society. Among them are K. Pavitt and B. Martin. The latter, B. Martin – who built on the work of Pavitt – and A. J. Salter argued recently that econometric studies provided few hints on the real economic benefits of publicly funded (basic) research. These studies use models that face too many methodological limitations to capture all the benefits of basic research. They lack reliable indicators and they do not explain the link between research and economic performance (Salter and Martin, 2001: 514)

Salter and Martin recognise at least six categories for the benefits derived from publicly funded research, and these categories require special attention:

- Increasing the stock of useful knowledge.
- Training skilled graduates.
- Creating new scientific instrumentation and methodologies.
- Forming networks and stimulating social interactions.
- Increasing the capacity for scientific and technological problem-solving.
- Creating new firms.

As evident from this list, Salter and Martin's study still concentrates on specific benefits or impact from research. The authors, in fact, stated explicitly that: "the study focuses on the economic benefits from basic research rather than social, environmental or cultural benefits". However, and this is where they innovated, they considered "less direct economic benefits [than usually discussed] such as competencies, techniques, instruments, networks and the ability to solve complex problems" (Salter and Martin, 2001: 510).

The problem with Salter and Martin's suggestions is that they are still far from looking at the ultimate impact of science on society. What one expects today is measures of the impact of science on human lives and health, on organizational capacities of firms, institutional and group behaviour, on the environment, etc. What Salter and Martin are looking at is the intermediate impact of science. Although a move in the right direction, much remains to be done to extend the range of indicators to real social dimensions.

A Multi-Dimensional View of Science

To sum up the previous discussion, it appears that most measures of the impact of science are concerned with the economic impact such as economic growth, productivity, profits, job creation, market share, spin-offs – and there are very few indicators as such that link science and technology directly to these economic pay-offs. Systematic measurements and indicators on impact on the social, cultural, political, and organizational dimensions are almost totally absent from the literature.

In order to better identify the scope of impact, we conducted a series of interviews with researchers (several of them acting as directors) from 17 publicly funded research centres[2], and above all, with actual and potential users of research results in 11 social and economic organizations. The interviews had two principal objectives. First, it was a matter of delimiting the diverse types of research done by researchers : fundamental, applied and strategic. Second, it was a question of identifying the entire spectrum of the potential impact of research by collecting information on the results stemming from research activities and imagining potential uses. The interviews were carried out with the help of a short questionnaire that served as a guide for the interviewer. The interviews were of a semi-guided nature, offering thus freedom in dealing with the themes broached. From this material, we constructed a typology with eleven dimensions corresponding to as many categories of impact of science on society (Table 2).

The first three dimensions are the most well known. The first concerns scientific impact. The research results (at time 1) have an effect on the subsequent progress of knowledge (at time 2) – theories, methodologies, models and facts -, the formation and development of specialties and disciplines, and training. They can also have an effect on the development of research activities themselves : interdisciplinarity, intersectionality, internationalisation.

[2] Ten were from the natural sciences and engineering, four from the health sciences, and three from the social sciences and humanities.

Table 2: Impact of Science

Science

- Knowledge
- Research activities
- Training

Technology

- Products and processes
- Services
- Know-how

Economy

- Production
- Financing
- Investments
- Commercialisation
- Budget

Culture

- Knowledge
- Know-how
- Attitudes
- Values

Society

- Welfare
- Discourses and actions of groups

Policy

- Policy-makers
- Citizens
- Public programs
- National security

Organisation

- Planning
- Work organization
- Administration
- Human resources

Health

- Public health
- Health system

Environment

- Management of natural resources and the environment
- Climate and meteorology

Symbolic

- Legitimacy/credibility/visibility
- Notoriety

Training

- Curricula
- Pedagogical tools
- Qualifications
- Graduates
- Insertion into the job market
- Fitness of training / work
- Career
- Use of acquired knowledge

The second dimension refers to the technological impact. Product, process and service innovations as well as technical know-how are types of impact that we owe partly to research activities. Beyond patents, however, there are actually very few indicators to properly assess this dimension. The innovation survey, for example, measures innovation activities rather than output (counting innovations) and impact.

The third dimension is the most well known: economic. It refers to the impact on an organization's budgetary situation (operating costs, revenue, profits, the sale price of products), sources of finance (action capital, risk capital, contracts), investments (human capital – hiring and training, physical capital – infrastructure and material, operating and expansion), production activities (types of goods and service products) and the development of markets (diversification and export).

The other eight dimensions are somewhat new for statisticians, for they are often less tangible. The impact on culture refers to what people frequently call public understanding of science, but above all to the four following types of knowledge: know what, know why, know how, and know who (Lundvall and Johnson, 1994). More specifically, it refers to the impact on an individual's knowledge and understanding of ideas and reality. It also includes intellectual and practical skills, the attitudes and interests (on science in general, scientific institutions, scientific and technological controversies, scientific news and culture in general) and values and beliefs (Godin and Gingras, 2000).

Social impact refers to the impact knowledge has on welfare, and on the behaviors, practices and activities of people and groups. For people, social impact concerns well being and quality of life. It also concerns the customs and habits of life (consumption, work, sexuality, sports and food). For groups, new knowledge can contribute to changing discourse on and conceptions of society, or help "modernize" their way of doing "business".

Political impact has to do with the way knowledge influences policy-makers and policies: the interest and attitudes of politicians, administrators and citizens towards a question of public interest involving science and technology, public action (law-jurisprudence-ethics, policies, programs–regulation-norms, standards) and citizen participation in scientific and technological decisions.

Organizational impact is impact on the activities of institutions and organizations like planning (objectives, administrative organization), the organization of work (sharing and the quality of tasks, automation, computing), administration (management, marketing, distribution, purchasing, accounting), and human resources (the workforce, the qualifications of the employees, work conditions).

The health dimension refers to the impact of research on public health (life expectancy, prevention and prevalence of illness) and on the health care system (health care and costs, health care professionals, medical infrastructure and equipment, products – medication, treatment). The environmental dimension refers to the impact on managing the environment, notably the management of natural resources (conservation and bio-diversity plan) and of environmental pollution (pollution surveillance tools and the sources of pollution). It also refers to the impact of research on climate and meteorology (climatic surveillance methods and climatic and meteorological forecasting models). Indicators on the state of health and the state of the environment already exist in several organizations and countries. The problem is, like economic growth and productivity, linking this impact to research activities and output.

The last two types of impact deserve specific comments. Symbolic impact is an important impact that was identified by the users of research results that were interviewed. In fact, a company, for example, often gains credibility for conducting R&D or from being associated with university research and academics. For several firms, this is probably an impact as important as the economic one – and has itself probably an economic impact. No attempt seems to have been made, however, to systematically measure such impact.

The last type of impact, training, could have been placed under the first one – scientific. It has been treated separately here because of its importance in regards to the mission of universities. It refers to curricula (training programs), pedagogical tools (educational manuals), qualifications (acquired competence in research), entry into the workforce, appropriateness between training and work, career path and of the use of acquired knowledge.

The above typology provides a check-list to remind statisticians that research has an impact on several dimensions of reality besides those usually identified and measured in the literature. The obstacle to measuring these impacts should not be minimized, however, and the next section attempts to set out some guidelines to conduct appropriate measurements.

Challenges

At least three challenges must be met before one conducts any measurement of the types of impact presented above. One is to distinguish conceptually between output and impact (or outcome). The second is to identify specifically the transfer mechanisms by which science translates into impact. The last is to develop appropriate and reliable instruments and indicators.

Distinguishing Output and Impact

Output and impact are frequently dealt with under the same term – output. In fact, output is often understood to mean impact. There has always been confusion between the two[3]. Some clarification is necessary. While output is the direct result or product of science – production or mere volume of output as economists call it – impact is the effects that this output has on society and the economy. Patents are real output indicators, for example, but other so-called output indicators from the OECD are in fact measures of impact (or outcome) of science and technology: technological balance of payments, high-technology trade.

[3] For exceptions, but without any consequences, see OECD (1980) and Falk (1984).

Conceptually, output is a direct result of research activity while impact is the indirect but ultimate effect of science on society. The output of research activities is, for example knowledge (measured by papers), innovations, new trained people. Impact is rather the effects of this output and its use on one or several dimensions of reality. Take, for example, the case of poverty. Output, namely knowledge or guidelines for public programs produced by social scientists can have an impact on society when integrated into public policies, which in turn affect poverty. The direct impact of scientific knowledge here is its effect on policies, while the indirect effects on poverty are due to numerous factors, among them knowledge integrated into policies.

Another example of confusion regarding output concerns innovation. Eurostat and the OECD's methodological work in the early 1990s marked the beginning of standardization in the field of innovation measurement. The main objective was to develop output indicators, which, as statisticians and policy analysts firmly declared, would measure innovation by measuring the products, processes and services that arise from innovation activities. But subsequent developments strayed significantly from this initial goal. Instead, with time, national and international surveys focused on innovation activities. Without really noticing that they had departed from their original goal, national governments and the OECD ended up measuring innovation the way they measured R&D, i.e.: in terms of input and activities (Godin, 2003). This is simply another influence of the linear model that has guided policy-makers since 1945. According to this model, innovation is what comes out (output) of basic research. Consequently, whenever statisticians measured innovation, they called it output. But having focused on innovation activities, innovation surveys fell far short of measuring innovative output (products and processes) and its impact (or outcome). Although there are some survey questions on the impact of innovation on sales, for example – which were recognized as key questions as early as 1991[4] - most of these are only qualitative questions with yes/no answers. Therefore, "it is impossible to quantify these impacts" within the innovation survey as it is constructed (Guellec and Pattinson, 2001: 92).

Integrating Transfer Mechanisms

The linear or input-output model does not really allow one to link science to impact because between the two lie transfer mechanisms and activities that are usually considered a black-box, and because direct and indirect impact is rarely distinguished.

We can presently distinguish two trends in the literature concerning the transfer of research results. First, works of a historical nature have been done for a long time within the framework of debate on the relationship between science and technology. They aim to retrace the scientific foundations of specific technologies with the goal of illustrating or demonstrating the role of new knowledge in technological development. Typical cases of this type of study were produced at the end of 1960's by the National Science Foundation

[4] Sales are not really an impact of an innovating firm for example. An economic impact would rather be profits coming out of innovations, effects of a new process on the innovative firm's performance, or of a new product on other firms' performance (productivity, costs) or on the economy as a whole.

or the American Department of Defence (Mowery et Rosenberg, 1979). Since, apart from economists, several researchers have abandoned work on the question, on the pretext that the research benefits only materialise in the long term, that exploiting research is a diffuse phenomenon, hard to seize and generally not measurable.

A second trend in the studies done on transfer looks more directly at mechanisms of transfer : transfer between businesses or between university and business, etc. These studies have the advantage of often being empirical (cf. Lee, 1997), but they are also limited in being descriptive more than theoretical. A theoretical model enabling the understanding of the links between knowledge and socio-economic progress is still lacking. Moreover, these studies generally stop at the sole transfer of knowledge, still leaving in the dark the effect or the real impact of such transfers. At the present moment, the links of "causality" between research results (output) and impact are postulated more than demonstrated. The transfer mechanisms are literally ignored and one must be generally content with either correlations – often produced thanks to econometric models – or, as the OECD has done, with putting together a series of statistics whose implicit objective is to produce in the reader a sense of causality (OECD, 1999): simply putting numbers together leads one to believe that the first numbers (relative to research activities) are the cause of the second ones (relative to economic growth). One can forget that between the two there are transfer mechanisms that are determining factors of the exploitation and use of research results. "What the research evaluation community lacks, we maintain, is not data, but rather a logic connecting concrete S&T policies and programs to the available data on outcomes" (Cozzens, 2002: 105).

It is important to distinguish the diffusion from the appropriation (use) of knowledge. Diffusion generally occurs by way of paper, communication, goods (embodied technology), and /or people. But whoever says diffusion, has yet to say anything on appropriation. It is one thing to spread or, for a potential user, to know that some specific knowledge exists because someone has told them of its existence, another to decide to acquire it. Transfer is the group of activities intended to further the appropriation of knowledge. Thus defined, the transfer consists of the following four points, and each has to be properly measured in order to link science to its impact:

- Transmission/diffusion
- Acquisition
- Introduction or integration
- Use

Measuring and Developing Indicators

Appendix 1 is a tentative and very preliminary list of impacts and indicators for each of the eleven dimensions of our typology. Some simply build on existing statistics, but most of them need proper and systematic surveys.

Surveys on impacts need to have certain characteristics as follows. Firstly, a definition of impacts: an impact is measured by a changed situation. One can collect two measures of change : 1) the existence or not of a change in one or the other of the eleven dimensions of reality, 2) the importance of this change. Generally, one measures the presence or the existence of a change by a nominal type indicator. The nominal indicators are frequently used by statistical organizations. OECD countries particularly use this type of measure within the scope of surveys on innovation. Nominal indicators are usually presented in the form of binary data such as “yes/no”. From an analytical point of view, the interpretation of the binary data that is possible is clearly limited by the fact that no quantification of the importance of impact is possible. The nominal indicators, however, find their usefulness in the fact that they allow for a counting of the presence (or not) and of the type of impact.

The measurement of the importance of the change allows for a qualitative (ordinal) or quantitative (numerical) appreciation of the said change. The main ordinal measurement is the rank, for example, scales of pertinence (1 to 5) or of importance (from very important to not important at all). The main numerical measurements are: the quantity (number or rate), the duration and the frequency.

<u>Indicators of change</u>

→ The presence of a change

<u>Indicators of importance of the change</u>

→ Quantity
→ Duration
→ Frequency

Two methodological points of order are of foremost importance and must be recalled for leading inquiries on the impact of science. An inquiry on impact must always make appeal to a particular research result or to a well defined group of results. In effect, one does not survey an organization on the impact of research in general, but on the impact of one or several precise scientific results. And this is the complexity – and the weight – of inquiries on the impact of science. First, it is necessary to know (or inquire about) research output. Then, one has to imagine the principal sectors and potential users of these results. Last, one must build questionnaires that identify if there is or is not a use for the results of science and to measure its impact. Moreover, the questionnaires can vary according to the category of user surveyed and to the use of research results.

The second methodological point of order concerns the interpretation of the measurement of impact. The consideration and inclusion of questions on transfer are necessary to explain the presence or absence of measured impact in an inquiry to this end, and go beyond mere statistical correlations. In fact, the absence of the impact of research is not necessarily the sign of research that is “too” fundamental – or useless. It may be that the transfer is not achieved. It is necessary therefore to question on the conditions, the context and the efforts of the organization’s appropriation to appreciate the impact of science on it. One related difficulty is to measure the changes that take place in certain organizations by mimetism or contagion. It will often be difficult to recount the origin of this change.

All these suggestions should solve one of the main problems of current statistical analyses: the attribution problem. It is a well-known fact that the econometric models linking science to productivity, for example, fails to properly explain the relation between the two variables. The problem stems from the fact that most economists work with two separate and independent data sets – one on R&D and another on economic growth or GDP – that they correlate statistically. Once a survey proper is conducted, the problem of attribution disappears: the data on output and impacts come from the same organization.

Conclusion

There is a huge demand for quantitative studies and indicators on the impact of science. This demand not only comes from governments that need to evaluate the performance of their investments, but also from researchers for theoretical purposes: what is the scope of science's impact on society? By what mechanisms does research transfer to society?

Answering such questions requires that surveys on specific types of impact be conducted. Actually most quantitative studies on the impact of science are based on econometric models that correlate R&D expenditures to economic variables such as GDP. Social scientists have rarely entered the field with their own methodologies. Most seem to follow NSF's early statement that "the returns [of science] are so large that it is hardly necessary to justify or evaluate the investment" (NSF, 1957: 61).

This paper has suggested several dimensions of society, beyond the economic one, on which science has an impact. It has also identified three areas for further work if one wants to properly measure and evaluate the impact of science on society. The measurement of impact is actually at the stage where the measurement of R&D was in the early 1960s: data have to be constructed from scratch. Certainly, challenges are numerous, and adequate solutions still have to be developed to properly address the methodological issues. But actually it seems as if most researchers have given up without really trying. S Cozzens was right when she suggested : "We need to link back more to fundamental social problems and issues, rather than focusing narrowly on immediate payoffs from a particular program or activity" (Cozzens, 2002 : 75).

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Appendix 1. Indicators on the Impact of Science

The table below presents a preliminary list of indicators susceptible of measuring each of the eleven dimensions of the impact of science and technology. It has three columns. The first column presents the sub-dimensions of reality for which impact indicators are suggested. For each of the eleven dimensions retained in the framework of the study, we also encounter sub-dimensions.

The second column presents the indicators that allow measurement of 1) the presence of a change produced by the result or results of research on a given sub-dimension of reality, 2) the quantitative or qualitative importance of this change on the sub-dimension. For each of the sub-dimensions, we find at least one of the two following types of indicators. The first is an indicator of the presence of a change. It is always identified by the letter "a". This indicator is generally qualified by a nominal measurement. The second is *an indicator on the importance (quantitative or qualitative) of change*. It is always identified by the letter "b". It is measured thanks to a statistic of a cardinal or ordinal nature.

Impact on science **Sub-dimension :** **Advances in knowledge**	**Indicators**
Specialties	1.a) The appearance of a new training program 1.b) The enrolment in this new program The number of new journals and related articles
Theories	2.a) The invention of a new theory 2.b) The use of this theory (citations)
Methodologies	3.a) The conception of a new methodology 3.b) The use of this new methodology (citations
Facts	4.a) The discovery of a new fact 4.b) The use of this fact (citations)

Impact on science **Sub-dimension :** **Advances in knowledge (cont.)**	**Indicators**
Models	5.a) The construction of a new model 5.b) The use of this mode (citations)

Impact on science **Sub-dimension :** **Research activities**	**Indicators**
Contributions to research	6.b) The number of new publications
Type of research	7.a) The intensification or diversification of the type of research done (fondamental/applied/strategic)
Interdisciplinarity	8.b) The growth in the number of publications in interdisciplinary collaboration and citations between disciplines
Intersectoriality	9.b) The growth in the number of publications in intersectorial collaboration
Internationalisation	10.b) The growth in the number of publications in international collaboration

Impact on science **Sub-dimension :** **Training of researchers**	**Indicators**
Research competence	11.a) The presence of research competence : definition of a research problem, organizing a project, strategies for collecting data, methods of analyzing.
Related competence	12.a) The presence of competences such as writing, communication, computing, management.

Impact on technology	**Indicators**
Products and Processes	13.a) Achieving and improving a product or process 13.b) The value of sales The number of patents (requested and issued) The number of licences issued The number of users and the frequency of use The citations to the scientific literature in patents
Services	14.a) The development of a new service 14.b) Market shares
Know-how	15.b) The number of individuals or organizations that have mastered new know-how.

Impact on the economy **Sub-dimension :** **Budgetary situation**	**Indicators**
Operational costs	16.b) The reduction of operational costs (thanks to the introduction of new technology or new processes)
Revenue	17.b) The level of revenues
Profits	18.b) Profit levels
The sale price of products	19.b) The evolution of prices

Impact on the economy **Sub-dimension :** **Source of finance**	**Indicators**
Action capital	20.b) The level of financing through action capital
Risk capital	21. b) The level of financing through risk capital
Contracts	22.b) The value of the contracts

Impact on the economy **Sub-dimension : Investments**	**Indicators**
Human capital	23.a) The types of jobs and competences in the organisation (diplomas, degrees, disciplines) 23.b) The inventment ($) in on-going training
Physical capital	24.a) The type of fixed assets and material 24.b) The investments ($) in fixed assets and in material
Operating and expanding	25. b) the number of new entreprises created (or eliminated) The number of spin-offs (by students, professors, researchers or graduates)

Impact on the economy **Sub-dimension : Production**	**Indicators**
Goods	26.a) The type of goods produced 26.b) The value of the goods produced
Services	27.a) The type of services produced 27.b) The value of the services produced

Impact on the economy **Sub-dimension : Marketing**	**Indicators**
Market Development	28.a) The diversification of the markets 28.b) The importance of markets ($) The volume of exports (in total sales) The importance of high tech commerce ($)

Impact on Culture **Sub-dimension :** **Knowledge**	**Indicators**
The knowledge and understanding of the ideas and reality by the individuals (acquired through formal or informal mechanisms)	29.b) The rate of university, technical and professional graduation in the sciences Academic results in the sciences The level of understanding of scientific concepts

Impact on culture **Sub-dimension :** **Know-how**	**Indicators**
Intellectual skills	30.a) The development of new skills : creativity, critique, analysis and synthesis 30. b) The level of mastery of the new acquired skills (for example 1) the capacity to apply basic mathematical; 2) the level of autonomy in order to achieve basic economic transaction such as savings or the preparation of a budget; 3) writing a document judged to be complex)
Practical skills	31.a) The ability to identify and solve certain problems of a mechanical or technical nature at work or at home The presence of new technologies at work and at home 31.b) The frequency and duration of use of new technologies at work and at home

Impact on culture **Sub-dimension :** **Attitudes and interests**	**Indicators**
(For science in general, scientific institutions, S&T controversies, scientific news and culture in general)	32.a) The participation in scientific activities 32.b) The number of hours dedicated by an individual listening to or watching scientific programming on the television or radio, to scientific leisure activities (reading, clubs, etc.) The number of hours dedicated to reading newspapers and magazines on science and technology The level of coverage of science news in the media The level of acceptance and innovation of S&T (GMOs, cloning, etc.) The number of visitors to S&T museums

Impact on culture **Sub-dimension : Vision of the world**	**Indicators**
(Values and Beliefs)	33.a) Values (moral, intellectuel and professional) and beliefs (religious, spiritual and family)

Impact on society Sub-dimension : Individuals	**Indicators**
Well being and quality of life	34.a) Improving the social conditions of individuals Improving the economic conditions of individuals 34.b) Revenues of individuals
Social implication	35.a)Engagement within associations working on scientific questions
Practices	36.b) The number of individuals having modified one or several customs or lifestyle habits (food, sexuality, activities)

Impact on society Sub-dimension : Organisation	**Indicators**
(Speeches, interventions and actions)	37.a) The appearance of new discourses on S&T The appearance of new styles of intervention or the solution to social problems

Impact on policy **Sub-dimension :** **Decision maker**	**Indicators**
Alertness, interests, attitudes	38.a) A new interest or attitude towards questions of public interest involving S&T

Impact on policy **Sub-dimension :** **Public action**	**Indicators**
Law/jurisprudence/ethics	39.a) a new jurisprudence
Policies	40.a) a new law or policy 40.b) The range of the laws (the number of individuals affected, the sanctions)
Programs/ Regulations / Norms	41.a) A new program, regulation or norm 41.b) The range of programs, regulations or norms
Standards	42.b) One or several new standards (standardisation)

Impact on policy **Sub-dimension :** **Citizens**	**Indicateurs**
Political implication	43.a) The presentation of documents to public commissions or to parliamentary commissions on science and technology The participation in public assemblies or municipal or regional council meetings
Civic responsability (laws, responsabilities and duty)	n/a

Impact on organisations **Sub-dimension :** **Planning**	**Indicators**
Objectives	44.a) New strategic orientations, missions or objectives.
Administrative organisation	45.a) An administrative restructuring 45.b) The number of people affected by the restructuring

Impact on organisations **Sub-dimension :** **Organisation of work**	**Indicators**
Tasks (distribution and quality)	46.a) The allocation of staff (work division) 46.b) The degree of specalisation of the jobs
Automation	47.a) Acquisition of advanced production techniques
Computing	48.a) The architecture of the computer network 48.b) The number of computer jobs in the organisation The value ($) of the purchase of computer and automated equipment

Impact on organisations **Sub-dimension : Administration**	**Indicators**
Management	49.b) The level of qualification and the years of experience of management personnel
Marketing	50. a) The adoption of new methods
Distribution	
Purchasing	
Accounting	

Impact on organisations **Sub-dimensions :** **Human resources**	**Indicators**
Workforce	51.b) The number of new employees in R&D
Qualifications of employees	52.b) The level of qualification of the workforce (degrees) The disciplines and specialties available The experience and expertise of the employees
Work conditions	53.a) Implimenting new norms or new equipement related to health and safety Work perspectives 53.b) The rate of employee satisfaction towards general work conditions offered by the organisation The amounts invested in training Salaries

Impact on health **Sub-dimension :** **Public health**	**Indicators**
Health care	54. b) The length of hospitalisation The avilability of different types of treatment and medication The satisfaction rate of beneficiaries
Life expectency and fertility	55.b) Life expectency at birth and after 65 years of age Fertility rate

Impact on health **Sub-dimension :** **Public health (cont)**	Indicators
Prevention and prevelence of illnesses	56.a) A new prevention program (awareness and immunisation) 56.b) The number of individuals benefiting from new prevention programs (awareness and immunisation) The rate of occurrence of contagious diseases (STD, hepatitis, etc.) The rate of occurrence of chronic diseases (arthritis, diabetes, etc.) The prevalence of smoking, alcoholism and drug addiction The prevalence of cancer and cardio-vascular diseases The prevalence of other diseases

Impact on health **Sub-dimension :** **Health system**	**Indicators**
General costs	57.b) Health expences (in relation to GDP, to government spending expenditure or per inhabitant)
Workforce	58.b) The training (and expertise) of the workforce
Infrastructure and medical equipment	59.a) Medical equipment (diagnostic, therapeutic) 59.b) The value ($) of investments in infrastructure and new medical equipment The average age of medical equipment
Products (Medication, treatment and diagnostics)	60.a) Approval of medication 60.b) The number of new medical protocols

Impact on the environment **Sub-dimensions : Management**	**Indicators**
Naturel resources	61. a) A plan for the conservation, protection and restoration of species and the ecosystem A bio-diversity plan A plan for the development of resources in a context of sustainable development
Environment (pollution)	62.a) A surveillance tool for pollution and its causes A methode for detection, reduction ou elimination of threats related to pollutants The development of anti-pollution norms

Impact on the environment **(water, air, soil, forest, fauna and flora, waste)**	**Indicators**
Climate and meteorology	63.a) A climatic and meteorologic surveillance methode A climatic and meteorologic prediction model

Impact on symbolism	Indicators
Legitimacy/ credibility/ visibility	64. a) Invitation to lead or participate in diverse forums 64. b) Level of knowledge of X by Y Level of appreciation de X by Y
Notoriety/ recognition	65.a) A prize, a title, a promotion or a nomination 65. b) Market share

Impact on training	Indicators
Curricula	66.a) Training programs
Pedagogical tools	67 a) Teaching manuals
Qualifications	68. a) Acquired competence
Insertion into the workforce	70.b) The duration of the period between the end studies and the start of a job Fitness between training and job
Career	71.a) Career path 71.b) Salary
Use of acquired knowledge	72.a) The use of knowledge at work or in daily life.