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THE LINEAR MODEL OF TECHNOLOGICAL INNOVATION: BACKGROUND AND TAXONOMY

SUMMARY

"Basic Research, Applied Research and Development - R&D", collectively, make up a structure referred to here as the Linear model of innovation. For almost half a century, this formation has played a decisive role in the evolution of the tacit technology strategies of most industrial nations.

R&D does not mean exactly the same to all the organizations which deal with it. This report compares the definitions of R&D by the following organizations: US National Science Foundation, US Department of Defense, OECD's Frascati Manual, Statistics Canada and Revenue Canada.

The major shortcomings of the Linear model of innovation are being discussed under six main headings: 'Lack of a common definition for R&D', 'Confining technological innovation to R&D', 'Lack of attention to design and production', 'Lack of attention to feedbacks, incremental innovation and reverse engineering', 'Using the expenditures on R&D as an input proxy for innovation', and 'Assumption that technology always follows science'.

PRELUDE

For over four decades, R&D has been praised in numerous disciplines; from industrial and economic development to social and political studies. Text books on management, economics and engineering, among so many other disciplines, have cited R&D, over and over again. In the second half of the twentieth century, R&D is not just a set of activities, it is also a myth.

The starting point in the R&D system is "Basic Research" which has been primarily the purview of universities, government research institutes and the central laboratories of some very large firms. "Applied Research" is the typical entry point of industry and "Development" is the last major stage in the R&D model, leading directly to "Commercialization".

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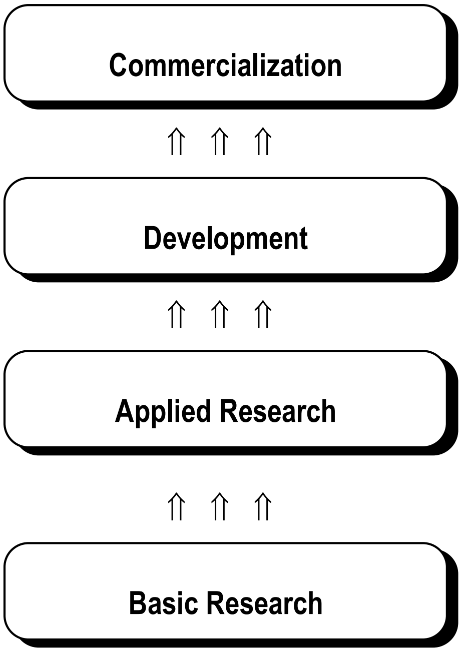
The two categories of Basic and Applied research are so much fused into a continuum that any line of demarcation would be largely arbitrary. Perhaps the distinction is more closely related to considerations of status, prestige, and social ideology than to objective characteristics of the work done. What may be applied research to a university scientist may be considered very basic by an engineer desiring to utilize the results. The distinction between basic and applied may also be but a matter of time[1]. The same is also applicable to applied research and development.



The Linear Model of Innovation

Development has further been classified into “product development” and “process development”. However, there may be no clear distinction between them. In fact the same technical advance may be viewed as a product development by its producers and as a process development by those using it. The vast majority of product development in the service sector, in particular, is process development for the manufacturing sectors.

The R&D model of innovation has been used to explain the link between knowledge and economic performance. In this model, knowledge is discovered in universities, passed on to firms through publications, patents, and other forms of scientific correspondence, and to final customers in the form of a product or service. This model represents innovation as a linear process in which technological change is closely dependent upon, and generated by, prior scientific research. Consequently the R&D model is named “The Linear Model of Innovation”, denoting serial events in time and not linearity in the sense of a linear equation[2]. In addition to the Linear, the R&D model has also been referred to as the “Assembly-line model,”[3] “Pipeline model,”[4] [5] “Ladder model,”[6] and the ‘Bucket model’.

The Linear model is a framework for categorizing the process of knowledge creation according to their application aims. When research is conducted with little or no regard to commercial applications it is ‘basic research’. When commercially useful methods are the subject of examination, the activity is called ‘applied research’. When specific products or processes are being designed and tested, the process is called ‘development’.

The Linear model is also a theory of knowledge production. Each level in the linear model produces outputs that are transferred to the next level as inputs. For example, basic research outputs, its theories and findings, are inputs to applied research. In keeping with the sequential nature of the model, the flow is ‘unilateral’; later stages do not provide inputs for earlier stages.

Finally, the Linear model is a theory of epistemology. It characterizes the transfer of knowledge as involving refinement and adaptation from universal principles to particular instances, from comprehensive theory to specific applications[7].

According to the Linear model, innovation takes place in distinct and sequential phases. Research is considered to be the initiating step and the source of all innovations. The Linear model suggests that the sequence from research through development to production is a standard and predominant path of innovation in both firms and national economies, and no feedback role is built into the system. The Linear model has also been used as a justification for doing basic science research in the US[8] and provides the conventional wisdom which underlies most policy thinking about technology development and economic growth.

The Linear model is the foundation of present models for collecting statistical information on research activities, for organizing economic research on the social benefits of scientific research, and for explaining the role of science in industrial innovation[9].

Consistent with the Linear model of innovation, science and technology (S&T) policies have evolved which have long focused primarily, perhaps exclusively, on government-funded R&D, whether conducted at government laboratories or in universities. Combined with the economic rationale of ‘market failure’ and Keynesian economic policies, which justified government intervention to lift and sustain the level of output and employment[10] and to prevent another depression, government grants for research and development remain a popular policy in keeping with the Linear model.

Nonetheless, there is growing criticism of Linear model. As a framework for categorizing the process of knowledge creation, the Linear model diverts attention from the economic and social determinants of scientific research activity. As a theory of knowledge production, the Linear model ignores the role of technology in shaping the aims, methods, and productivity of science and neglects the non-scientific origins of many technological developments. As epistemology, the Linear model creates distinctions that closer examinations of scientific and technological activity fail to confirm[11]. In addition, the Linear vision of innovation dominates also the regional innovation capability evaluations[12].

The Linear model has often been used implicitly, making it even more important in our thinking than explicitly understood models. An implicit model is used without thinking about it, and is not subject to correction through experience, as we tend to think it is the “truth” and not a model. Moreover, even when a new model is presented, it is a slow and difficult process to readjust our thinking and conclusions[13].

Fumio Kodama[14] believes ‘Most descriptions of the process of technology development have employed the pipeline metaphor: new technology emerges from the successive steps of basic research, applied research, exploratory development, engineering and manufacturing.’ Then he adds ‘For years it has been said that innovation is achieved by breaking through the boundaries of existing technology. Recent innovations make it more appropriate to view innovation as the *fusion* of different types of technology rather a series of technical breakthroughs. Fusion mean more than a combination of different technologies; it invokes an arithmetic in which one plus one makes three. While breakthroughs are often associated with defense policies, fusion is promoted through industrial policy. The shift in innovation patterns - from breakthroughs to fusion is implicit in the other dimensions of the techno-paradigm shift.’

BACKGROUND

Up to a century ago organized innovation was rare, and innovation was a slow process. Before 1900, there was little, if any, organized research anywhere, and individual inventors dominated the course of technological progress. The principal exception was the in-house R&D by German chemical firms, and a few major US corporations. In the nineteenth century, much of engineering remained a craft, empirically based and with little direct connection to science.

Freeman[15] believes that science was already important in the First World War - more important than most people realized at the time - but it was the Manhattan Project and its outcome at Hiroshima which impressed on people throughout the world the power of science and especially, as it seemed, Big Science. Many other developments on both sides, such as radar, computers, rockets and explosives, resulted from large R&D projects, mobilizing both government, industrial and academic engineers and scientists.

The experience with the scientific community in World War II was pivotal in establishing the widespread belief that science could make major contributions to industry[16]. World War II was a midwife to a distinct role for the application of science in war, as well as in production.

The historical period following the Second World War has been referred to as the ‘postwar’ or the Cold War. The Cold War period commenced at the end of the World War II (1945), and continued up to the late 1980s, terminated symbolically with the fall of the Berlin Wall on November 11, 1989; actually phased out with the disintegration of the Soviet Union in 1991.

During the Cold War, the wide application of science further accelerated. Scientists and engineers assumed prominent roles. Professional economists had been prominent in the World War II mobilization. Having served in the Second World War with evident success, they so served in the postwar[17] One of the advantages of a democracy is that when it is engaged in a war, no one feels that everything should be controlled by the military. There are great areas where civilian organizations can operate to better advantage[18].

The Linear model of innovation, with its three consecutive stages of basic research, applied research and development (R&D), became the principal model for innovation and R&D began to be used also as an interchangeable term for ‘technological innovation’, even ‘innovation’.

‘Science - The Endless Frontier[19]’, a report prepared in July 1945 by Vannevar Bush, the director of the Office of Scientific Research and Development during World War II, is the founding stone of the US National Science Foundation - N.S.F. Although ‘Science - The Endless Frontier’ is usually credited as the origin for classification of R&D, but surprisingly no part of this report explicates the R&D classification. However, the ‘Report of the Committee on Science and the Public Welfare[20]’ to Vannervar Bush, prepared in April 1945 under the chairmanship of Isaiah Brown, divided scientific research into three main categories: (1) pure research, (2) background research, and (3) applied research and development.

The differentiation of ‘applied’ from ‘pure’ science may go back to the nineteen century, however, Bernal[21] suggested that the 19th century scientist deliberately distanced himself from the industrial application of discovery, a self-removal that Bernal saw as a 'sign of the scientist aping the don and the gentleman'

Limited clues exist regarding the exact birthplace of the classification of R&D (basic research, applied research and development). Probably this classification evolved gradually during the Second World War in the US military-oriented projects.

Freeman[22] continues that it was, therefore, hardly surprising that in the climate which existed after the Second World War, the prestige of organized, professional R&D was very high. the R&D system was seen as *the* sources of innovations - an impression that was reinforced by the system measurement which was adopted, first by the National Science Foundation in the United States and later during the 1950s and 1960s by all other OECD countries. This was standardized by the so-called 'Frascati Manual , OECD - 1963). Despite the fact that the authors pointed out that technical change did not depend just on R&D but on many other related activities, such as education, training, production engineering, design, quality control, etc. etc., nevertheless R&D measures were very frequently used as a surrogate for all these activities which helped to promote new and improved products and processes. Furthermore, the importance of all the feedback loops from the market and from production into the R&D system was often overlooked or forgotten. The simple fact that the R&D measure were the only ones that were available reinforced these tendencies.

During the Cold War, R&D as a classification and model played a decisive role in the evolution of U.S. tacit technology strategy and consequently in the studies on innovation and technology development in world academic systems. Many Cold-War era concepts about the nature of technological innovation still dominate political thinking[23].

The Linear model of innovation places excessive emphasis on originality, in the sense of newness to the universe as opposed to newness in context. In other words, the collection of statistics about science and technology is focused primarily on R&D, often leading policy-makers to equate innovation policy with R&D policy. It leads them as well to overemphasize the significance of originality of "newness to universe" as the sole source of the economic and social benefit arising from R&D or scientific technological activity more broadly[24].

Consistent with the R&D model, postwar US federal policy for science and technology had two parts: government support for basic research, and active development of advanced technology by federal agencies in pursuit of their statutory missions[25].

Whatever other thinking may be behind the efforts of many scientists to impress upon the public the uniqueness of basic research, it is clear that one major reason today is the desire to influence public policy for science with respect to the federal budget, and the R&D classification has worked as the main tool. Some scientists are adopting a political strategy of demanding a separation of basic research from other components of R&D. This model was used as a base to explain to the public the substantive connections that make research essential to technological development, and not vice versa [26].

Consistent with the Linear model, for the first several decades after 1945, the United States emphasized the generation of new knowledge, other nations its application and diffusion. The Linear model of innovation had also deep influence in the organizational patterns of U.S. private industries. In the 1950s and 1960s, consistent with the linear approach, an internal and hierarchical organization developed that was based on central corporate research laboratories to development to manufacturing engineering. In the 1980s that approach started being changed to a decentralized organization with carefully managed division of responsibility among R&D and engineering groups; simultaneous product and process development where possible; greater reliance on suppliers and contract engineering firms.

During the 1950s and 1960s, the overseas activities of American multinationals centered on exports and direct investment. Newer technology went abroad embodied in goods. Overseas affiliates typically got older technology. Multinational corporations kept the latest knowledge at home, where it could be protected more easily[27].

THE TAXONOMY OF THE LINEAR MODEL OF INNOVATION

Previous chapter underlines the background of the Linear model of innovation. Sundry academic books and papers, as well as numerous non-academic articles, have referred to, and praised the R&D. However, a very limited number of them correlates the different definitions for R&D, as well as contemplates the R&D classification as a model to scrutinized its purpose, domain, application and interpretation. A comparative study of all sources on the classification and definition of R&D is, certainly, beyond the scope of this report. However, this paper covers some main sources on classification and definitions of the three main stages of the Linear model: Basic Research, Applied Research and Development. As in all taxonomic schemes, there is certain fuzziness around the edges of the categories of R&D. It appears, however, R&D does not means the same to the main organizations which deal with it.

US National Science Foundation - NSF

'National Patterns of R&D Resources'[28], by the US National Science Foundation, is considered to be the, original source for the classification of R&D. According to NSF, "Research and Development (R&D) - basic and applied research in the sciences (including medical sciences) and in engineering, and activities in development" , covers as following:

Basic Research: Within the U.S. Federal government, university, and non-profit sectors, basic research is defined as research directed toward increase in knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific application toward processes or product in mind. For the industry sector, basic research projects are defined as original investigations for the advancement of scientific knowledge which do not have specific commercial objectives, although they may be in fields of present or potential interest to the reporting company.

Applied Research: Within the Federal, university, and nonprofit sectors, applied research is defined as research directed toward gaining knowledge or understanding necessary for determining the means by which a recognized and specific need may be met. The applied research definition for the industry sector is modified to include research projects which represent investigations directed to discovery of new scientific knowledge and which have specific commercial objectives with respect to their products or processes.

Development: Development is the systematic use of the knowledge or understanding gained from research directed toward the production of useful materials, devices, systems or methods, including the design and development of prototypes and processes. It excludes quality control, routine testing, and production.

US Department of Defense - DoD

DoD uses a more finely graduated system, designated by numbers ranging from 6.1 (Research) to 6.6 (Operational Systems Development), tied to DoD's procedure for approving and funding the weapons program[29]. When DoD compiles R&D spending statistics for National Science Foundation surveys, it reports category 6.1 as basic research, 6.2 as applied research and the remaining categories taken together as development.

6.1 **Research** in DoD parlance, emphasizes fundamental knowledge for long-term national security needs. Most 6.1 work is organized according to the scientific and engineering discipline.

6.2 **Exploratory Development**: At the 6.2 stage, funding is organized into broad areas of military applications such as "aerospace propulsion" and "surface ship technology". 6.2 funding supports applied work up to and including construction of breadboard hardware for exploring feasibility. But 6.2 stops short of supporting large experiments involving special-purpose hardware.

6.3A **Advanced Technology Development**: Category 6.3 is divided into two stages. In category 6.3A, funding begins to be organized by military system or by particular mission. Expensive hardware and full scale testing are supported under 6.3A, but test articles do not necessarily resemble anything that would eventually end up in the field.

6.3B **Advanced Development**: Category 6.3 typically funds technology demonstrators or prototypes developed in response to identified mission needs. The hardware begins to resemble a weapons system that might actually go into the field, and effort turns to working out the details necessary to move from a laboratory demonstration to something that will work under operational conditions. Contractors may explore competing designs.

6.4 **Engineering Development**: Funds in this category pay for designing, building, and testing production-model prototypes and for working out the details of manufacturing, operations, and maintenance. Final products are clearly identified (e.g. "Midgetman missile" or "C-17 transport aircraft".

6.5 **Management and Support**: Category 6.5 is really an overhead account that supports test ranges, test vehicles, laboratory maintenance, and management studies of the R&D complex. Costs of laboratory personnel and of special-purpose test facilities come from program budgets.

6.6. **Operational Systems Developmen**t: Once a system has been approved for production, R&D funding shifts out of 6.4 into 6.6, which supports testing of operational hardware and any modifications to the design approved during manufacturing or after the system enters the inventory. Much work of this sort in the commercial world would probably not be considered R&D at all.

Frascati Manual

'Measurement of Scientific & Technical Activities - Proposed Standard Practice for Surveys of Research and Experimental Development'[30], code named as "Frascati Manual", is an important document prepared by the Organization for Economic Cooperation and Development - OECD in Paris. This document intends to coordinate the activities on measuring scientific & technical activities between OECD member countries. The first edition of the Frascati Manual goes back to 1963. The fourth edition of the manual, which appeared in 1980, does not reflect major changes in concepts, definitions or basic classifications for R&D, compared to the first edition.

According to Frascati Manual, Research and Experimental Development (R&ED) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications. R&ED covers three activities: 'Basic research', 'Applied research' and 'Experimental development'.

Basic (or fundamental) research is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view.

Applied research is also original investigation undertaken in order to acquire knowledge. It is, however, directed primarily towards a specific practical aim or objective.

Experimental development is systematic work, drawing on existing knowledge gained from research and /or practical experience that is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed.

R&D activities in the mechanical engineering industry often have a close connection with design and drawing work. Usually there are no special R&D departments in small and medium size companies. In this industry R&D problems are mostly dealt with under the general heading "design and drawing".

Statistics Canada

Statistics Canada, in 'Industrial Research and Development - 1993'[31], defines R&D as follows: Research and development (R&D) is systematic investigation carried out in the natural and engineering sciences by means of experiment or analysis to achieve a scientific or commercial advance. Research is the original investigation undertaken on a systematic basis to gain new knowledge. Development is the application of research findings or other scientific knowledge for the creation of new or significantly improved products or processes. If successful, development will usually result in devices or processes which represent an improvement in the "state of the art" and are likely to be patentable.

Research and development may be carried out either by a permanent R&D unit (e.g. R&D division) or by a unit generally engaged in any non-R&D activity such as engineering or production. In the first case, the R&D unit may spend part of its time on routine testing or trouble shooting or on some other activities which should not be included in R&D. In the second, only the R&D portion of such units' total activity should be considered.

Revenue Canada

The federal department of Revenue Canada administers the Scientific Research and Experimental Development (SR&ED) incentive program where taxpayers can earn federal investment tax credits on current and capital SR&ED qualifying expenditure at rates of 35 percent for Canadian-controlled private corporations and 20 percent for all other taxpayers. Corporate credits are refundable in cash while 20 percent credits are non-refundable and may only be used to reduce federal corporation income-taxes payable[32]. Canada's system of R&D incentives is considered one of the best in the world.

The definition of scientific research and experimental development is set out in Section 2900 of the Income Tax Regulations. In relatively simple terms, a project is eligible for SR&ED if its objective is an advancement in technology, with a technological uncertainty resolved in a systematic manner by individuals who are skilled in the technologies involved[33].

The three criteria for characterizing eligibility for SR&ED include:

- Scientific or technological advancement
- Uncertainty
- Content

Scientific or technological advancement: Scientific or technological advancement is the discovery of technical knowledge that advances the understanding of scientific relations or technologies. The taxpayer is expected to know information that is common knowledge, at the time of the work[34].

Novelty, innovation, uniqueness, feature enhancement or increased functionality in the product or process is not sufficient to demonstrate technological advancement. It is how such attributes arise (i.e. whether or not they arise through the process of SR&ED) that is important. An effort to achieve a technological advance will be accompanied by experimentation or analysis that is a non-trivial departure form the usual established technical practice of software development. It results from a situation where there is a technological uncertainty about whether or how the technological advancement can be achieved.

It is the attempt to achieve a technological advancement that is important in determining eligibility. A failure can increase knowledge by showing that a particular technological approach will not succeed. Thus, a failed SR&ED project can meet the technological advancement criterion.

The scientific or technological uncertainty: A scientific or technological uncertainty arises when the solution, or the method of arriving at the solution, is not readily apparent to appropriately skilled and experienced developers after they have analyzed the problem using generally known techniques. Generally, technological uncertainties are identified in the feasibility phase of an SR&ED project. However, they may become apparent at any time during the course of a project. The work to resolve the technological uncertainty or uncertainties can be an SR&ED project.

One type of technological uncertainty is "system uncertainty" which uncertainty exists only if the integration is not achieved through routine engineering and involves interactions between components or technologies that were unknown or unpredictable before the integration. System uncertainty is not necessarily related to the size of a system: it is possible for very large systems to be built using proven technologies or for a system of only two components to have technological uncertainty associated with the integration. The concept of system uncertainty does not justify a claim for the work of developing an entire system when the technological uncertainty only affects part of the system.

The scientific and technical content: This criterion has both methodological and personnel aspects. A systematic investigation or search by experiment or analysis must be demonstrated. This means that a systematic investigation or search must have been performed and that the taxpayer must have documentation or records to substantiate the work claimed. The personnel responsible for directing and performing the SR&ED project must have the professional skills or experience commensurate with the requirements of the project.

According to Revenue Canada - 1991[35], in any assessment of the issues of uncertainty or advancement, judgment must be exercised on the merits of each individual case, and must be dependent on the resource base of the company and availability of knowledge. The objective of this incentive is not to **duplicate knowledge** that is **openly** available to the taxpayer. If, however, it not generally available, eligibility may exist. Reverse engineering would not be eligible, but experimental development in association with the application of the technology could be.

According to Revenue Canada - 1994[36], SR&ED, generally speaking, is intended to result in an invention which may subsequently become a technological innovation. An essential requirement is that the outcome of the work is uncertain, i.e. that the possibility of obtaining a given technical objective cannot be known in advance on the basis of current knowledge or experience. Hence much of the work done by scientists and engineers is not SR&ED, since they are primary engaged in 'routine' production, engineering, quality control or testing. Although they apply scientific or engineering principles, their work is not directed towards the discovery of new knowledge or the development of new products and processes. However, work elements which are not considered SR&ED by themselves but which directly support SR&ED projects, should not be included with SR&ED in these cases. Examples of such work elements are design and engineering, shop work, computer programming, and secretarial work.

If the primary objective is to make further technical improvement to the product or process, then the work comes within the definition of SR&ED. If however, the product, process or approach is substantially set and the primary objective is to develop markets, to do pre-production planning or to get a production or control system working smoothly, then the activity can no longer be considered as part of SR&ED even though it could be regarded as an important part of the total innovation process. Thus, the design, construction and testing of prototypes, models and pilot plants are part of SR&ED. But when necessary modifications have been made and testing has been satisfactorily completed, the boundary of SR&ED has been reached. Hence, the costs of tooling (design and try-out), construction drawings and manufacturing blueprints, and production start-up are not included in development costs.

Pilot plants may be included in development only if the main purpose is to acquire experience and compile data. As soon as they begin as normal production units, their costs can no longer be attributed to SR&ED. Similarly, once the original prototype has been found satisfactory, the costs of other ‘prototypes’ built to meet a special need or fill a very small order are not to be considered as part of SR&ED.

Revenue Canada emphasizes that although the definition of “Scientific Research and Experimental Development” is considered to be the same as R&D, certain expenditures for scientific research cannot be claimed for income tax purposes (e.g., land, building). Section 37, Regulation 2900 of the Income Tax Act, specifically excludes the following:

1. Market research, sales promotion
2. Quality control or routine analysis and testing of materials, devices or products
3. Research in the social science or the humanities
4. Prospecting, exploring or drilling for or producing minerals, petroleum, or natural gas
5. The commercial production of a new or improved material, devices or product for the commercial use of a new or improved process
6. Style change, or routine data collection

Britannica

‘Knowing How and Knowing Why’[37]. of Britannica covers another perception about R&D Customary, science, or the scientific hierarchy, is divided into four categories. Pure, or academic, oriented fundamental, applied and development.

Pure, or academic research is the pursuit of knowledge for its own sake. It is mainly the work of an individual, or of the group that he leads. The pure scientist has to justify himself only before a jury of his peers. He is judged not by the usefulness but by the integrity of his work. He is the Maker Possible.

Oriented fundamental research is still basic science, that is to say, the scientist is still questioning nature, seeking to extend knowledge and understanding, but he is not a free agent indulging his curiosity. He is restrained within a frame of reference. He is compiling data that will be important in a general field and will likely have some foreseen applications. In the big corporations, this is called “speculative research”. Such a scientist is likely to have adequate research facilities, endowments, contracts. He is the Maker Probable.

Applied research is programmed research. The target is specified, and results are expected. The predicted yield is the measure of the support. The scientist is held accountable in the annual report. He is Maker to Happen.

Development is really technology, but coupling it with research (R&D) keeps it in the scientific hierarchy and away from the "rude mechanical." It is the transfer of laboratory results, through the pilot plant, to the production line. R&D is far and away the most expensive scientific bracket. The R&D scientist is the Maker to Work.

The Nature of Scientific Research

Isaiah Brown, in the **Report of the Committee on Science and the Public Welfare**[38], provides a classification for scientific research.

Scientific research may be divided into the following broad categories: (1) pure research, (2) background research, and (3) applied research and development. The boundaries between them are by no means clear-cut and it is frequently difficult to assign a given investigation to any single category. On the other hand, typical instances are easily recognized, and study of them reveals that each category requires different institutional arrangements for maximum development.

Pure Research: Pure research is research without specific practical needs. It results in general knowledge and understanding of nature and its laws. This general knowledge provides the means of answering a large number of important practical problems, though it may not give a specific solution to any one of them. The unpredictable nature of pure science makes desirable the provision of rather special circumstances for its pursuit.

Background Research: The preparation of accurate topographic and geologic maps, the collection of meteorological data, the determination of physical and chemical constants, the description of species of animals, plants, and minerals, the establishment of standards for hormones, drugs, and X-ray therapy; these and similar types of scientific work are here grouped together under the term background research. Such background knowledge provides essential data for advances in both pure and applied science. It is also widely used by the engineer, the physician and the public at large. In contrast to pure science, the objective of this type of research and the methods to be used are reasonably clear before an investigation is undertaken. Thus comprehensive programs may be mapped out and the work carried on by relatively large number of trained personnel as a coordinated effort.

Applied Research and Development: Applied research and development differs in several important respects from pure science. Since the objective can often be definitely mapped out beforehand, the work lends itself to organized effort. If successful, the results of applied research are of a definitely practical or commercial value. The very heavy expenses of such work are, therefore, undertaken by private organizations only in the hope of ultimately recovering the funds invested.

The distinction between applied and pure research is not a hard and fast one, and industrial scientists may tackle specific problems from broad fundamental viewpoints. But it is important to emphasize that there is a perverse law governing research: Under the pressure for immediate results, and unless deliberate policies are set up to guard against this, *applied research invariably drives out pure.* The moral is clear: It is pure research which deserves and requires special protection and specially assured support.

THE DEFICIENCIES OF THE LINEAR MODEL OF INNOVATION

Contemporary studies stress the Linear model's shortcomings. It has been argued that the simple pipeline model - in which research leads naturally to development and then to the introduction of new products and processes into the marketplace - has been repeatedly discredited; it fits neither past not present. The linear process of technological innovation no longer applies (if it ever did), and raises a concern with a larger set of 'barriers to innovation' which R&D effort alone cannot address. Recent studies on the technology development process have suggested that innovation should not be limited to a linear process which is an indispensable result of expenditure on R&D[39].

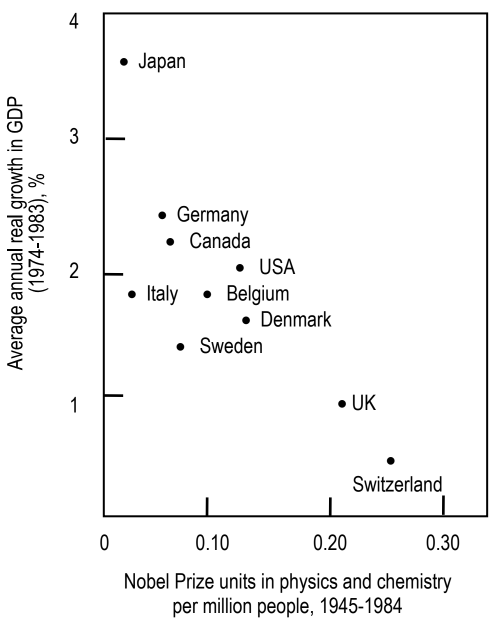


Figure 1: Growth in gross domestic product and Nobel Prize winning in physics and chemistry

Figure 1 plots the rate of Growth Domestic Product - GDP per person versus Nobel awards in physics and chemistry for most of the industrial nations. If the Linear model were true, we ought to find a positive correlation: the graph shows just the opposite. Indeed, it would be hard to find a more complete disconfirmation of the idea that leadership in physical science guarantees economic growth. It would seem we grow rich, and then do high science - not the other way around[40].

Equating innovation with R&D, consistent with the exogenous approach towards technology development in the neoclassical economics, overvalues the pursuit of original knowledge relative to excellence in production, and limits innovation strategies to science and technology policies. Integration of knowledge in economics and development of economic policies to be linked with innovation require the development of non-linear innovation models. Consequently, the introduction and development of new innovation models will create a domino effect in economic, financial, as well as scientific systems.

The Linear model distorts the reality of innovation in several ways and most serious scholars of innovation have now come to recognize those distortions[41]. Of the main deficiencies of the Linear model of innovation, the following points appear to be of great importance. The shortcomings of the Linear model should not disqualify it as a heuristic for examining the relation between basic research and industrial innovation. Moreover, alternative theories are at an early stage of development.

Lack of a Common Definition for R&D

The previous chapter revealed the wide differences among the definition of R&D stages in just some major references. All of those sources refer to R&D, but they do not seem to articulate the same process or phenomena! It appears each source tacitly defines its objectives under a general term called “R&D”.

“Industrial R&D”, which concentrates on the development side of R&D is not the same as or confined to the “Academic R&D” which inclines more to basic research. There is justification to believe that fewer than a dozen Canadian industrial enterprises are able to perform basic research, although according to most recent data on ‘Science and Technology Statistics’ by Industry Canada, 3566 Canadian businesses have performed R&D, which corresponds to 0.4% of total businesses[42]. Even in the context of industry, the R&D classification is basically suitable for large firms[43].

Innovation Is Much Broader than R&D

R&D, mainly concentrated on product development, is aimed at introducing genuine invention and major or radical innovations. The process of R&D has often been equated with innovation. If this were true, understanding innovation would be far simpler than it truly is, and the real problems would be far simpler and less interesting than they truly are[44]. Successful innovation requires the coupling of the technical and the economic in ways that can be accommodated by the organization while also meeting market needs, and this implies close coupling and cooperation among many activities in the marketing, R&D, and production functions[45].

An R&D system differs in several ways from an innovation system. Reported formal R&D expenditures are only a part of the innovation-related outlays made by firms. Formal R&D data ignore the complex processes of technological accumulation whereby tacit, partly un-codified knowledge is built up and transmitted from one generation to the next within institutions, firms and sometimes whole industries. Formal R&D captures nothing of the linkages between organizations, the feedback processes, or the alliances and relationships of power between agencies and firms. An R&D system is at best a poor proxy for an innovation system[46].

According to the Frascatti Manual[47], the R&D (comprising basic research, applied research and experimental development) ‘is an activity which is related to a number of others with a scientific and technological base’. Consistent with this outlook, R&D is not equal to technology development.

The notion that innovation is initiated by research is incorrect most of the time. There are a few instances in which research sparks innovation, and these are often important, revolutionary innovations, as in semiconductors, lasers and current genetic developments; but even then, the innovation must pass through a design stage and must be coupled to market needs if it is to reach completion[48] and be of commercial value.

By equating innovation with R&D and overvaluing the pursuit of original knowledge relative to excellence in execution, many engineering schools have helped to create, or at least to sustain, dysfunctional walls between research and other downstream technological activities in American industry[49].

However, the rate of innovation in any country and the effectiveness of companies in world competition in international trade in goods and services, does not depend simply on the scale of R&D and other technical activities. It also depends upon the way in which the available resources are managed and organized, both at the individual enterprise and the national level[50].

Any model that describes innovation as a single process, or attributes its sources to a single cause, or gives a truly simple picture, will therefore distort the reality and thereby impair our thinking and decision making[51].

Lack of Attention to Design Engineering and Production

One of the most serious deficiencies of the Linear model is the narrow outlook towards innovation, as R&D represents a relatively small part of the innovation cycle[52]. This defect with the Linear model flows from the fact that the central process of innovation is not science but design. Contrary to much common wisdom, the initiating step in most innovations is not research, but rather a design. The term "design" is used to denote a study of new combinations of existing products and components, rear-arrangement of processes, and planning of new artifacts within the existing state of the art[53].

A design in some form is essential to initiating technical innovations, and redesigns are essential to ultimate success, for the reasons just stated concerning the need for several types of feedbacks. The problems that are thrown up by the processes of designing and testing new products and new processes often spawn research - true science - and have in some instances even given rise to new branches of mathematics. Moreover, science often is dependent, in an absolute sense, on technological products and processes for its advances. Over the course of history thus far, it is moot whether science has depended more on technological processes and products than innovation has depended on science[54].

Engineering design, on the other hand, is currently a main practice on the part of engineers, is little understood by the public at large. Engineering design consists of analysis of various arrangements of existing components or of modifications of designs already within the state of the art to accomplish new tasks or to accomplish old tasks more effectively or at lower cost. Design is not invention in the usual sense. However, analytical design is currently a more common initiator of the central-chain-of-innovation than invention. Given current computer capabilities, it is nearly certain that we will see in the coming decades a merging of analytical design and invention that will constitute a more powerful method for initiating technical innovations than anything we have known in the past[55].

Another important step in understanding innovation is related to the recognition that when the science is inadequate, or even totally lacking, we still can, do, and often have created important innovations, and innumerable smaller, but cumulatively important evolutionary changes[56].

It is insufficiently appreciated that successful innovation even in high technology industries often is not so much a matter of invention, as a patent examiner would define invention, as it is a matter of design, in the sense of trying to devise a product or process that will achieve a desirable cluster of performance characteristics, subject to certain cost constraints. This engineering design capability is a very sophisticated and costly business. Moreover, determining where "design" ends and "research" begins is a matter of some real difficulty as soon as one deals with relationships that cannot be optimized by referring to the codified data in the engineering handbooks[57].

Lack of Attention to Feedbacks, Incremental Innovation and Reverse Engineering

The R&D model assumes a close tie between basic discovery and industrial supremacy, which does not always exist. The picture of the Linear model is that put expenditure on R&D here and innovation pops out there. Linear in this context denotes sequential (not linear in the sense of linear equations). The Linear model has been invoked in nearly all the arguments for the support of science to governments right up to the present time. We all know well the references to science as the "seed corn" on which technology draws[58].

The linear metaphor sees new technology emerging from successive steps of basic research, applied research, exploratory development, engineering and manufacturing. The pipeline model is not a bad approximation for radical innovations in which new science develops unprecedented technological capabilities. But such breakthroughs are rare exceptions even in high-technology sectors[59].

In the Linear model, research is safely separated from the free market. These accepted U.S. federal roles are mirrored in the agencies most active in technology: The Department of Defense (DoD), the Department of Energy, NASA, and the National Science Foundation for basic research[60].

The Linear model places too much emphasis on breakthroughs and mistakenly identifies rare case of how product innovations are initiated for the common occurrence and outcome. Innovation originates not from formal R&D, but from informal learning by doing, by using, and by interacting. Engineering skills, product know-how and understanding customers' requirements are the major sources of incremental innovations and product customization[61].

Feedbacks are an inherent part of development processes and innovation demands feedback. Effective innovation demands rapid, accurate feedback with appropriate follow-on actions. In the Linear model, there are no feedback paths within the ongoing work of development processes. Nor are there feedbacks from sales figures or from individual users[62].

Reverse engineering involves trying to manufacture a product similar to one already available on the world market but without direct foreign investment or transfer of blueprints for product and process design. Reverse engineering requires understanding of the basic mechanism behind products and the skills to imitate and adapt technologies[63].

Reverse engineering involved activities that sensed the potential needs in the market, activities that located knowledge or products that would meet the market needs, and activities that would infuse these elements into a project. Reverse engineering also involved purposive research of relevant information, effective interactions among technical members within a project group and with marketing and production departments within the firm, effective interactions with other organizations such as suppliers, customers, local research institutes and universities, and trial and error in developing a satisfactory result. Adaptation, a feedback based procedure in technology development, is a process of further development of existing innovations and producing more competitive or higher quality products. Unlike R&D which concentrates on product development, adaptation concentrates on strong process development. Adaptation, a gradual innovation process, includes activities like design engineering which are largely outside R&D.

Since many skills and activities required in reverse engineering are also the same in R&D, activities that had been called reverse engineering have easily been transformed in Korea into activities called R&D, as that country approached the technological frontier[64].

R&D in the formal sense of the term was not important for Korea during the 1960s and 1970s, in the stage of imitating mature technologies. Industries in fact reveres the sequence of R,D&E: it started with engineering (E) for products and processes imported from abroad, and then progressively evolved into the position of undertaking substantial development (D). But research (R) was not relevant to Korea's industrialization through the 1970s. Several studies conducted in other countries also provide a similar evidence. Studies on Japanese industrial history show that its industries went through a similar pattern. The United States also reversed the sequence of research, development and engineering, that is, it started with practical technologies imported from Britain, then slowly evolved into the present position of conducting substantial research[65].

Any study about Japan's technology development, both pre- and postwar, as well that of Korea and Taiwan, is not complete without addressing the crucial role of reverse engineering in this process. In Taiwanese firms, activities such as imitating, copying, or limited improvements on the existing foreign product (i.e. various reverse engineering tactics) were the major sources of acquiring foreign technologies[66].

After World War II, when Japanese industry was vastly devastated, the method of assimilating and improving upon imported technology was mainly some form of 'reverse engineering'. The Japanese approach to product and process design, often originally developed through reverse engineering, created a new style of innovation management, with engineering design, procurement, production and marketing even in the largest organizations.

According to Freeman-1987, the widespread use of reverse engineering in the 1950s and 1960s had several major consequences for the Japanese system of innovation[67]. First, Japanese management, engineers and workers grew accustomed to thinking of the entire production process as a system and of thinking in an integrated way about product and process design. This capability to redesign an entire production system has been identified as one of the major sources of Japanese competitive success in industries as diverse as shipbuilding, motor vehicles and color television. Whereas Japanese firms made few original radical product innovations, they did make many incremental innovations and they did redesign many processes in such a way as to improve productivity and raise quality. The motor vehicle industry is probably the most spectacular example.

Second, Japanese engineers and managers grew accustomed to the idea of 'using the factory as a laboratory'. The work of the research and development department was very closely related to the work of production engineers and process control and was often almost indistinguishable. The whole enterprise was involved in a learning and development process and many ideas for improving the system came from the shop floor. The horizontal flow of information became a characteristic feature of the Japanese style of management. Since almost all studies of the management of innovation in Western Europe and the United States point to the lack of integration between R&D, production management and marketing as a major source of failure, the integrative effect of learning by creative reverse engineering conferred a major competitive advantage in many Japanese firms. It also gave production engineering a much higher status than is usually the case in Europe or the United States.

Third, reverse engineering in such industries as motor vehicles, and machine tools also involved an intimate dialogue between the firm responsible for assembling and marketing the final product and numerous suppliers of components, sub-assemblies, castings, materials and so forth. The habits, attitudes and relationships engendered during this prolonged joint learning process did much to facilitate the high degree of cooperation with subcontractors which finds expression, for example in the 'just-in-time' system.

Fourth, the emphasis on high quality of products which is characteristic of Japanese technology policy also owed much to the experience of reverse engineering.

Brazilian and Argentinean firms began manufacturing with assembly and packaging operations and eventually extended into more intricate operations. Engineering was the initiating portion of the R,D&E spectrum leading gradually to more advanced development and research efforts[68].

A case study for Argentinean systems of innovation also characterizes an important role for reverse engineering in the national overall innovation process. According to Katz 1993, given the highly "localized" nature of Argentinean domestic operation, many of the newly created companies found themselves needing to establish "in house" engineering departments whose basic mission was to adapt foreign product designs and production processes to the local working and regulatory environments. This process of industrial growth had a major impact on the functioning of the national system of innovation supporting technological change in industry. The neoclassical metaphor of complete specification and perfect availability of "from-the-shell" production functions just does not seem to be very useful if one is to make sense of the present case. Rather, evolutionary ideas based on notions of incomplete specifications of production know-how, imperfect information of domestic entrepreneurs, "adaptive" R&D efforts, "technological learning," bottleneck, and disequilibrium seem to fit much better the set of issues we need to examine[69].

This same source (Katz 1993) showed that repair and maintenance induced an early expansion of domestic technological capabilities in areas such as stamping, forging, and machining. This approach is consistent with the classification of the technological activities, which is not limited to linear R&D model.

Katz-1993 emphasizes that, based on a study in Argentina, technological "learning" and domestic engineering efforts gradually acquired significance as explanatory forces of the newly emerging trends. Similar trends reported by other researchers looking at other newly industrialized countries such as India, Brazil, Mexico, Hong Kong, and Taiwan, confirming the fact the technological "learning" from peripheral societies could be expected to have dynamic consequences that had not been previously examined in the development literature.

Consistent with the R&D model of innovation, the often single-minded pursuit of excellence and leadership in basic research within academia spills over into an undervaluation of other types of technical activity in industry, thereby indirectly weakening the ability of U.S. industry to develop, assimilate, and manage technology effectively for economic advantage. The preoccupation with technical originality throughout academic science and engineering and the preoccupation with phenomenological research and development of tools for analysis within engineering have led to an underemphasize on holistic design experience, manufacturing, and technology management in the curricula and research portfolios of U.S. engineering schools, particularly those that tend to be pacesetters[70].

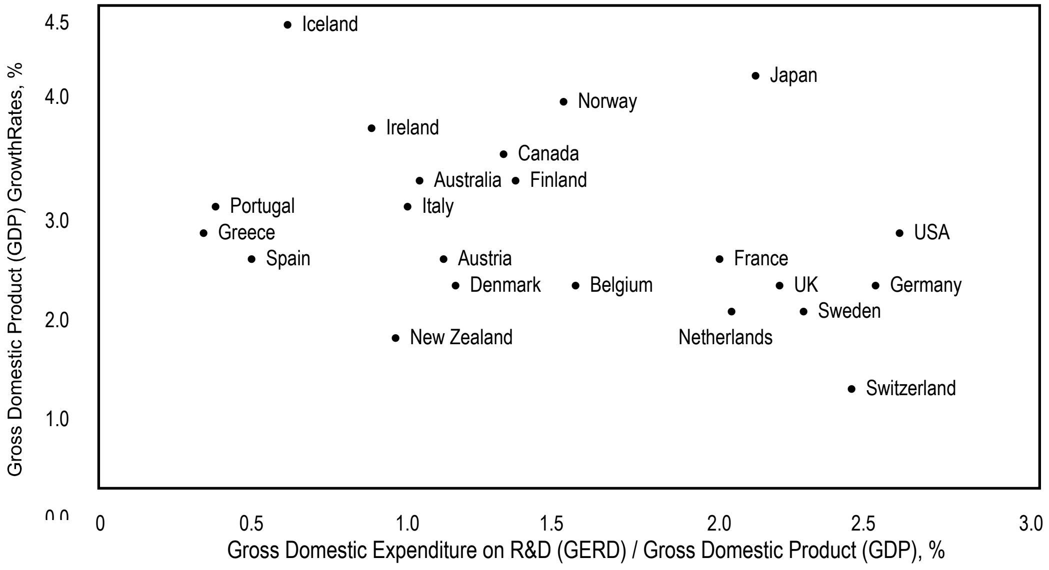
Machine design, a engineering design service mainly in the context of reverse engineering, is a major part of mechanical engineering; as machine design is not as rosy as making a new supersonic airplane every other year. Large portion of mechanical and electrical engineering deal with design engineering of this type. Engineering design is a synergy between forward engineering and reverse engineering. In academic courses, engineers are being familiarized with some aspects of forward engineering as a process being initiated with research, new ideas, or patents. However in the classical disciplines, reverse engineering, which is interwoven with adaptation and is based on the study of existing products and the design of new and better products, has not been as fortunate as forward engineering. Reverse engineering theory and practice have not been examined in detail yet, either in engineering or management courses and text books.

Expenditures on R&D as a Proxy for Innovation

We rely on proxies such as research and development expenditures to measure the inputs or patent counts to measure the output. Consequently we have imperfect measures of both the inputs and outputs of the innovation process. Inputs to R&D - money spent, number of engineers and scientists at work - tell nothing about the outputs of R&D. Those outputs are hard to measure, as every research manager knows[71]. Furthermore, the impact of R&D expenditures may depend critically on the focus or distribution of these resources rather than their aggregate[72]. The analysis of the formal R&D expenditure data yields few insight on how the innovation system really works[73].

The Linear model concerns mainly an activity's expenditure, title or place of origin, rather than the practical output or process of performing the activity. One should bear in mind that in the innovation processes, the outcome of an activity and its process are much more important than the location or title of activity.

Processes of technology development and diffusion are complex. The official figures show that US R&D spending exceeds $ 145 billion annually. Such figures understate the total because official statistics do not capture much design and application engineering in smaller firms, and much manufacturing engineering in firms of all sizes. The great bulk of federal R&D money goes to electronics, aerospace and the biomedical sciences. That distribution is not broad enough to support an economy as vast and diverse as that of the United States. Moreover, federal R&D is focused on the generation - rather that the diffusion and broadest possible utilization - of knowledge[74].



GERD/GDP Percent vs Growth Rate (OECD Countries, 1911-1989)

Empirically, Gross Domestic Expenditure on R&D (GERD) over Gross Domestic Product (GDP) is a poor indicator of the relevance of R&D to economic development, since that ratio shows no statistical correlation with economic growth rate (see below). Logically, the ratio is also obviously deficient because the effectiveness of R&D may depend on the aggregate effort but surely not on its “normalized intensity” - i.e., per unit of the “size” of the economy[75].

Comparison of the available indicators of science and technology activities confirms the astonishing Japanese progress over the past 30 years by comparison with both Europe and North America. This applies as much, and indeed even more, to the so-called “output” indicators (e.g. patent statistics) than the “input” indicators, for instance expenditures on Research and Development[76].The advisory Committee on Science and Technology Statistics at Statistics Canada, announced that R&D expenditures are not adequate to describe the dynamic system of knowledge creation, development, acquisition, and application that determine the inventiveness of the system. Better data on the nature of innovation, its relationship to technological capabilities and the nature of diffusion are required[77].

In the innovation studies, even output indicators like patents should also be used with caution. Studies performed by Gharrity indicate that between 40 and 80 percent of all patents in the United States have never found use[78].

The major limitation of purely quantitative statistical analysis, such as R&D expenditure or patent applications, is that it fails to take into account institutional factors dealing with innovation. National systems of innovation are clearly of the greatest importance in this respect[79].

“Innovation: Turnkey to Competitiveness in the Nineties,” a discussion paper by the federal Department of Industry, Science and Technology Canada- ISTC; of September 1990, underlined that only 3 per cent of the Canadian manufacturing firms had any research [and development] capability and that most had no staff capable of identifying or acquiring best-practice technologies; indeed, about 70 per cent did not employ a single engineer. Looking to the harsh new demands of the global economy, the federal officials said that an “integrated, comprehensive strategy” on innovation was needed and that “decisive national leadership” was essential[80].

Freeman[81] suggests that the picture which emerges from numerous studies of innovation and growth in firms is one of continuos interactive learning. From these results it follows that simple statistical correlation between R&D - intensity of firms and their rate of growth could not be expected to be very strong. Success with innovation depends on many other factors as well as R&D - external relationships, training, integration of design, development, production and marketing functions within the firm, general management quality, the selection of environment and so forth. In some industries such as clothing and footwear, fashion design, which is hardly measured in R&D statistics, may be more important than technical innovation. Moreover, R&D statistics do not measure organizations innovations at all, although recent research has completely vindicated this view.

Technology Always Follows Science

In the academic studies, it is widely postulated that new science gives rise to new technology. Although it has been argued that this is at best an oversimplification. As an example, the industries producing chemical products, or using chemical reactions in the manufacture of other products, long antedated the rise of modern science. Some, such as tanning and dyeing and brewing, are almost as old as civilization itself. However, in the last four or five decades of the nineteenth century, a systematic body of scientific knowledge about chemistry grew up that laid a new basis for chemical-based innovation.

The stories about advances in physics and chemistry as scientific disciplines appear to show scientific development as autonomous, evolving according to a internal logic of its own, with technology being illuminated as a by-product. But appearances are deceiving. Modern chemistry grew out of the ancient discipline of alchemy, which was concerned with finding ways to transform base materials into valuable ones. The advent of new technologies often leads to scientific work aimed at understanding these technologies, so as to enable them to be improved. Sometimes new technology leads to whole new scientific disciplines. Thus saying that new technologies have given rise to new sciences is at least as true as the other way around[82].

Since modern science as we know it is only about 300 years old, and old sciences like astronomy, medicine and geometry are not older than 4000 to 5000 years, but human sociotechnical systems have been evolving for at least 2 million years, it is evident that innovation over all but the most recent epoch was not based on science as the historians of technology have noted. From the very beginning, technological knowledge has been and probably remains more important than scientific knowledge in industrial competitiveness[83].

[1]REFERENCES:

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[1] Reagan M, 1967, **Basic and Applied Research: A Meaningful Distinction?**, Science, Volume 155, 17 March 1967

[2] Kline S, 1991, **Styles of Innovation and Their Cultural Basis**, Chemtech, August 1991

[3] Wise, George, 1985, **Science and Technology**, *Osiris*, 1: 229-46

[4] Alic J, (et al) 1992, **Beyond Spin-off: Military and Commercial Technologies in a Changing World**, Harvard College, Cambridge MA

[5] Fumio Kodama, 1995, **Emerging Patterns of Innovation**, Harvard Business School Press, Boston, MA

[6] Gomory R, Dec. 89, **From the Ladder of Science to the Product Development Cycle**, Harvard Business Review, Cambridge, MA

[7] Steinmuller E, 1994, **Basic Research and Industrial Innovation**. Appeared in Mark Dodgson and Roy Rothwell (Editors), 1994, **The Handbook of Industrial Innovation**, Edward Edgar Publishing, Brookfield, Vermont.

[8] Poncelet E, 1986, **Japanese and American Approaches to Technological Innovation: Cultural Influences.** Appeared in Ralph Landau and Nathan Rosenberg (Editors), 1986, **The Positive Sum Strategy: Harnessing Technology for Economic Growth**, National Academy Press, Washington, DC

[9] Steinmuller E, 1994, **Basic Research and Industrial Innovation**. Appeared in Mark Dodgson and Roy Rothwell (Editors), 1994, **The Handbook of Industrial Innovation**, Edward Edgar Publishing, Brookfield, Vermont

[10] Galbraith J, 1979, **Annals of an Abiding Liberal**, Houghton Mifflin, Boston MA

[11] Steinmuller E, 1994, **Basic Research and Industrial Innovation**. Appeared in Mark Dodgson and Roy Rothwell (Editors), 1994, **The Handbook of Industrial Innovation**, Edward Edgar Publishing, Brookfield, Vermont

[12] Nauwelaers C, and Alasdair Reid, 1995, **Innovative Regions?: A Comparative review of methods of evaluating regional innovation potential**, European Commission, Luxembourg

[13] Kline S, 1991, **Styles of Innovation and Their Cultural Basis**, Chemtech, August 1991

[14] Kodama, F, 1995, **Emerging Patterns of Innovation**, Harvard Business School Press, Boston, MA

[15] Freeman C, 1995, **The 'National Systems of Innovation' in historical perspective**, Cambridge Journal of Economics, 19, February 1995, pp. 5-24

[16] Steinmuller E, 1994, **Basic Research and Industrial Innovation**. Appeared in Mark Dodgson and Roy Rothwell (Editors), 1994, **The Handbook of Industrial Innovation**, Edward Edgar Publishing, Brookfield, Vermont

[17] Galbraith J, 1994, **A Journey Through Economic Time**, Hougton Mifflin, Boston MA

[18] Vannevar Bush, 1946, **Endless Horizon**,

[19] Vannevar Bush, July 1945, **Science - The Endless Frontier: A Report to the President on a program for Postwar scientific Research,** Office of Scientific Research and Development, Washington DC. This report reprinted in 1990 by the NSF.

[20] Brown, Isaiah, April 1945, **Report of the Committee on Science and the Public Welfare**, Office of Scientific Research and Development, Washington DC. (This document reprinted as an appendix to 'Science - The Endless Frontier' reprinted in 1990 by NSF)

[21]Bernal, J. (1939) **The Social Function of Science**, MIT Press, Cambridge, MA. Cited in Edward Steinmuller, 1994, **Basic Research and Industrial Innovation**. Appeared in Mark Dodgson and Roy Rothwell (Editors), 1994, **The Handbook of Industrial Innovation**, Edward Edgar Publishing, Brookfield, Vermont.

[22] Chris Freeman, 1995, **The 'National Systems of Innovation' in historical perspective**, Cambridge Journal of Economics, 19, February 1995, pp. 5-24

[23] Branscomb L, 1993, **Empowering Technology: Implementing a US Strategy**, MIT Press, Cambridge MA

[24] Branscomb L, 1993, **Empowering Technology: Implementing a US Strategy**, MIT Press, Cambridge MA

[25] Branscomb L, 1993, **Empowering Technology: Implementing a US Strategy**, MIT Press, Cambridge MA

[26] Reagan M, **Basic and Applied Research: A Meaningful Distinction?**, Science, Volume 155, 17 March 1967

[27] Alic J, (et al), 1992, **Beyond Spin-off: Military and commercial technologies in a changing world**, Harvard College, Cambridge MA

[28] National Science Foundation (N.S.F.), 1992, **National Patterns of R&D Resources**, Washington, DC

[29] Alic J, (et al), 1992, **Beyond Spin-off: Military and commercial technologies in a changing world**, Harvard College, Cambridge MA

[30] OECD, 1982, **Frascati Manual: Measurement of Scientific & Technical Activities** - Proposed Standard Practice for Surveys of Research and Experimental Development OECD, Paris

---

[1] Last update: October 16, 1997

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[31] Industry Canada, 1993, **Industrial Research and Development**, Ottawa
[32] EITC, 1996, **State of Innovation Report**, Economic Innovation and Technology Council, Manitoba
[33] Revenue Canada, 1991, **SR&ED Automotive Industry** Application Paper (Information Circular 86-4), Ottawa
[34] Revenue Canada, 1997**, Scientific Research and Experimental Development, Administrative Guidelines for Software Development, Request for Comments**, Ottawa
[35] Revenue Canada, 1991, **SR&ED Automotive Industry Application** Paper (Information Circular 86-4), Ottawa
[36] Revenue Canada, 1994, **Income Tax Act (Scientific Research and Experimental Development)**, Ottawa
[37] Guide P, 1993, **Britannica**
[38] Isaiah Brown, April 1945, **Report of the Committee on Science and the Public Welfare**, Office of Scientific Research and Development, Washington DC.
[39]
[40] Kline S, 1991, **Styles of Innovation and Their Cultural Basis**, Chemtech, September 1991
[41]
[42] Industry Canada, 1993, **Selected Science and Technology Statistics**, Ottawa
[43] OECD, 1991, **Oslo Manual: Proposed Guidelines for Collecting and Interpreting Technological Innovation Data**, OECD, Paris
[44] OECD, 1991, **Oslo Manual: Proposed Guidelines for Collecting and Interpreting Technological Innovation Data**, OECD, Paris
[45]Kline S, and Nathan Rosenberg, 1986, **An Overview of Innovation**. Appeared in: Ralph Landau and Nathan Rosenberg (Editors), 1986, **The Positive Sum Strategy: Harnessing Technology for Economic Growth**, National Academy Press, Washington, DC
[46] Chesnais F, 1993, **The French National System of Innovation**. Appeared in: Nelson R, (Editor), 1993, **National Innovation Systems; A Comparative Analysis**, Oxford University Press, New York
[47] OECD, 1980, **Frascati Manual** (The Measurement of Scientific and Technical Activities - Proposed Standard Practice for Surveys of Research and Experimental Development), OECD, Paris
[48] Kline S, and Nathan Rosenberg, 1986, **An Overview of Innovation**. Appeared in: Ralph Landau and Nathan Rosenberg (Editors), 1986, **The Positive Sum Strategy: Harnessing Technology for Economic Growth**, National Academy Press, Washington, DC
[49] National Academy of Engineering. Committee on Technology Policy, 1993, **Mastering a New Role: Shaping Technology Policy for National Economic Performance**, National Academy Press, Washington, DC
[50] Freeman C, 1982, **The Economics of Industrial Innovation**, Printer Publisher, London
[51] Kline S, and Nathan Rosenberg, 1986, **An Overview of Innovation**. Appeared in: Ralph Landau and Nathan Rosenberg (Editors), 1986, **The Positive Sum Strategy: Harnessing Technology for Economic Growth**, National Academy Press, Washington, DC
[52] Crane D, 1992, **The Next Canadian Century**, Stoddart, Toronto
[53]
[54] Kline S, and Nathan Rosenberg, 1986, **An Overview of Innovation**. Appeared in: Ralph Landau and Nathan Rosenberg (Editors), 1986, **The Positive Sum Strategy: Harnessing Technology for Economic Growth**, National Academy Press, Washington, DC
[55] Lundvall B, (Editor), 1992, **National Systems of Innovation**, Printer Publishers, London
[56] Lundvall B, (Editor), 1992, **National Systems of Innovation**, Printer Publishers, London
[57] Nelson R, and Nathan Rosenberg, 1993, **Technical Innovation and National Systems**. Appeared in: Nelson R, (Editor), 1993, **National Innovation Systems; A Comparative Analysis**, Oxford University Press, New York
[58]
[59]
[60] Alic J, (et al), 1992, **Beyond Spin-off: Military and Commercial Technologies in a Changing World**, Harvard College, Cambridge MA
[61] Malerba F, 1993, **The National system of Innovation: Italy**. Appeared in: Nelson R, (Editor), 1993, **National Innovation Systems; A Comparative Analysis**, Oxford University Press, New York
[62] Kline S, and Nathan Rosenberg, 1986, **An Overview of Innovation**. Appeared in: Ralph Landau and Nathan Rosenberg (Editors), 1986, **The Positive Sum Strategy: Harnessing Technology for Economic Growth**, National Academy Press, Washington, DC
[63] Odagir H, and Akira Got, 1993, **The Japanese System of Innovation**. Appeared in: Nelson R, (Editor), 1993,

---

National Innovation Systems; A Comparative Analysis, Oxford University Press, New York

[64] Kim L, 1993, **National System of Industrial Innovation: Dynamics of Capability Building in Korea**. Appeared in: Nelson R, (Editor), 1993, **National Innovation Systems; A Comparative Analysis**, Oxford University Press, New York

[65]

[66] Hou C, and San Gee, 1993, **National Systems Supporting Technical Advance in Industry: The Case of Taiwan**. Appeared in: Nelson R, (Editor), 1993, **National Innovation Systems; A Comparative Analysis**, Oxford University Press, New York

[67] Freeman C, 1987, **Technology Policy and Economic Performance; Lessons from Japan**, Printer Publishers, London

[68] Kim L, 1993, **National System of Industrial Innovation: Dynamics of Capability Building in Korea**. Appeared in: Nelson R, (Editor), 1993, **National Innovation Systems; A Comparative Analysis**, Oxford University Press, New York

[69] Katz J, and Nestor A. Bercovich, 1993, **National Systems of Innovation Supporting Technical Advance in Industry: The Case of Argentina**. Appeared in: Nelson R, (Editor), 1993, **National Innovation Systems; A Comparative Analysis**, Oxford University Press, New York

[70] National Academy of Engineering. Committee on Technology Policy, 1993, **Mastering a New Role: Shaping Technology Policy for National Economic Performance**, National Academy Press, Washington, DC

[71] Baldwin J, and David Sabourin, 1995, **Technology Adoption in Canadian Manufacturing**, Statistics Canada, Ottawa

[72] Gault F and Martin Wilk, 1996, **Science and technology Measurement - Rhetoric and Reality**, Second International Symposium on Research Funding, Natural Science and Engineering Research Council, Ottawa

[73] Chesnais F, 1993, **The French National System of Innovation**. Appeared in: Nelson R, (Editor), 1993, **National Innovation Systems; A Comparative Analysis**, Oxford University Press, New York

[74] Freeman C, 1988, **Small Countries Facing the Technological Revolution**, Printer Publishers, London

[75] Gault F and Martin Wilk, 1996, **Science and technology Measurement - Rhetoric and Reality**, Second International Symposium on Research Funding, Natural Science and Engineering Research Council - NSEARC, Ottawa

[76] Freeman C, 1988, **National Systems of Innovation: New Technology and International Leadership**, IFIAS Meeting

[77] Baldwin J, and David Sabourin, 1995, **Technology Adoption in Canadian Manufacturing**, Statistics Canada, Ottawa

[78] Kamien, Morton and Nancy Schwartz, 1982, **Market Structure and Innovation**, Cambridge University Press, Cambridge MA

[79] Freeman C, 1992, **The Economics of Hope**; Printer Publishers, London

[80] Crane D, 1992, **The Next Canadian Century**, Stoddart, Toronto

[81] Freeman C, 1994, **Innovation and Growth**. Appeared in Mark Dodgson and Roy Rothwell (Editors), **The Handbook of Industrial Innovation**, Edward Edgar Publishing, Brookfiled, Vermont.

[82] Nelson R, and Nathan Rosenberg, 1993, **Technical Innovation and National Systems**. Appeared in: Nelson R, (Editor), 1993, **National Innovation Systems; A Comparative Analysis**, Oxford University Press, New York

[83] Kline S, 1991, **Models of Innovation and Their Policy Consequences**. Appeared in Kingery, David (ed), 1991, **Japanese/American Technological Innovation**, Elsevier, New York