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NON-LINEAR MODELS OF TECHNOLOGICAL INNOVATION

"Linear Model of Technological Innovation" another report of this series studied the origin, taxonomy and deficiencies of the Linear (R&D) model of technological innovation in the wake of the Second World War. The present report briefly studies the following non-linear innovation models.

- **Stephen Kline's Chain-Linked model**
- **Ralph Gomory's Circle model**
- **Alic-Branscomb's model**
- **OECD's Oslo manual**
- **John Ziman's Neural Net model**

John Alic argues that four closely related themes characterize a non-linear understanding of the technological process: the importance of "downstream" or non-R&D technical activities, the pertinence of alternatives to the so-called pipeline view of technology generation and application, the convergence of science and engineering, and the importance of borrowing and adapting technology as well as generating it[1]. However, as the "Linear Model of Innovation" indicated, the deficiencies of the Linear model go beyond the above four points

STEPHEN KLINE'S CHAIN-LINKED MODEL

The Chain-Linked Model, the most cited non-linear innovation model, was first reported in "Research, Invention, Innovation and Production: Models and Reality", Report INN-1, March 1985, Mechanical Engineering Department, Stanford University. Dr. Stephen Kline, an emeritus professor of Mechanical Engineering, has further developed and revised the Chain-Linked model in "An Overview of Innovation[2]", "Models of Innovation and Their Policy Consequences[3]". In "Styles of Innovation and Their Cultural Basis [4]" Kline further elaborated the Chain-Linked model. The Chain-Linked model has also been referred to in many other documents, for instance in the Oslo Manual[5], the OECD's Technology/Economy Program[6] and "Canada and the National System of Innovation[7]".

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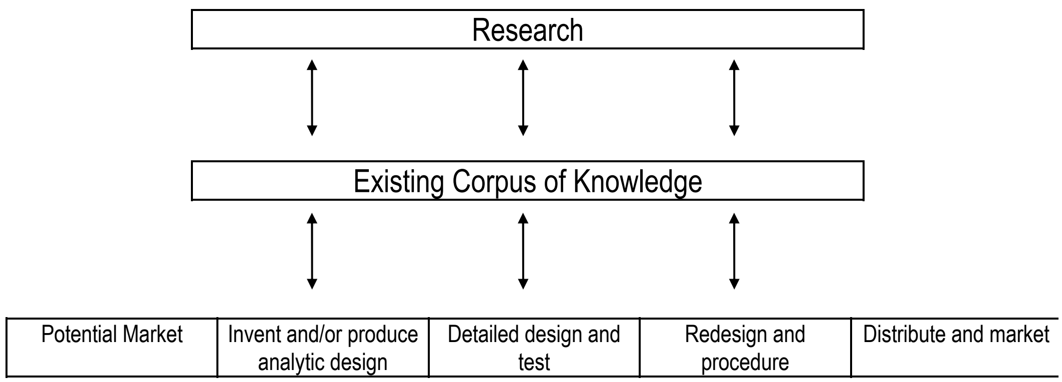
Kline argues that the Chain-Linked model is consistent with a detailed evaluation of the nature of technology, the concept of innovation, and the failures of a simple linear model which are often assumed, and the necessity that the linear model be replaced with a more complex model in order to understand the nature of innovation. The Chain-Linked method emphasizes the socio-technical nature of industry and technology and the necessity to look at it as a complex system. In the model the first path of innovation process, central chain-of-innovation, begins with design and continues through development and production to marketing. The second path is a series of feedbacks[8].



THE CHAIN-LINKED MODEL

In the Chain-Linked model, the general process starts with a market-finding phase followed by design, production, marketing and distribution, and use phases. It differs from the Linear model in a number of ways: there are multiple paths from which innovations may arise and many forms of feedback. Research is not normally considered to be the initiating step (in fact, research occurs in and contributes to all phases in the innovation process), and the primary source of innovation is now held to be stored knowledge and technological paradigms[9]. It appears this model more closely corresponds to the Japanese perception of the innovation process[10].

The Technology/Economy Program - TEP by OECD (Organization for Economic Cooperation and Development) addresses also the need to integrate policies for science and technology with other aspects of government policy, particularly economic, social, industrial, energy, education and labor policies. 'Technology and the Economy; the Key Relationships[11]', which is an outcome of TEP and published in 1992, also refers to the Chain-Linked model. This report underlines that the Chain-Linked model combines two somewhat different types of interaction. One concerns processes within a given firm (or possibly a group of firms working in a tightly-knit network). The second expresses the relationships between the individual firm and the wider science and technology system within which it operates.

At the level of the firm, the innovation chain is visualized as a path starting with the perception of a new market opportunity and/or a new science and technology-based invention; this is necessarily followed by the 'analytic design' for a new product or process, and subsequently leads to development, production and marketing. Feedback relations are generated: short feedback loops link each downstream phase in the central chain with the phase immediately preceding it and longer feedback loops link perceived market demand and product users with phases upstream. Problems identified by the processes of designing and testing new products and new processes often spawn research in engineering disciplines but also in science.

The second set of relationships links the innovation process embedded in firms and industries with the scientific and technical knowledge base and with research. In an industry-focused, interactive approach to innovation, a useful analytical distinction can be made between the two different uses of science and technology by firms, the use of available knowledge about physical and biological processes, and the work undertaken to correct and add to that knowledge. Generally, innovation takes place with the help of available knowledge. When corporate engineers confront a problem in technical innovation, they will call first on known science and technology, most often in serial stages. Only when those sources of information prove inadequate does a need arise for research. This analysis of the role of industrial R&D in the innovation process applies directly to large firms. Firms below a certain size cannot bear the cost of an R&D team

RALPH GOMORY'S CIRCLE MODEL

Dr. Ralph Gomory is a retired senior vice president of IBM and the current president of the Alfred Sloan Foundation. Gomory has developed the Circle model of innovation as an alternative to the linear model that he calls the Ladder model. Gomory, in many articles, describes the main aspects of the Circle model[12]

In the Ladder paradigm, new things descend from the realm of science - step by step - into practice and become the genesis of an industry. Well known examples in this respect include transistor and molecular biology. The belief that this kind of scientific dominance should translate into product dominance is probably, in many cases, a residue of the Second World War and the enormous impression made by the science-led, science-developed process of the atomic bomb. After the Second World War, a belief emerged that scientific dominance does translate into economic dominance.

Scientists play the dominant role both in basic research and in the early phases of the industry because they are the only people who understand what's going on in sufficient detail. So, in the early stages of a new industry, the Ladder paradigm predominates. Everything revolves around the new technology. The Ladder paradigm is really a paradigm for getting things started, not for winning the longer race.

Much of the dominant thinking about innovation comes from the Ladder process because it has been so visible and so spectacular, involving the emergence of a new scientific effort and new products. We must make the cyclic development process more visible and to understand it better.

The cyclic process is a second relationship of technology and science. The cyclic development process is a process of repeated, continuous, incremental improvement. It is that process of following up what exists in manufacturing with the next model, which is designed, built and prototyped, tested, redesigned for manufacturing, put into production, and then in turn starts the next generation. This process is characteristic of the later (not the earlier) states of an industry. The type of industry in this case is discrete manufacturing, of which automobiles and transistors are very good examples. It is this cyclic development process that determines in the long run, then, who will be dominant in this industry. It is not as glamorous as the breakthrough type of invention; but, nevertheless, the progress which it causes is enormous.

The cyclic process is very different from the Ladder process. It is not science-based. It is based on what is already there, the existing product and its restrictions. So this type of development is very much restricted, not by a totally new idea, but rather by what is already there, whether that be the plant, or the tools, or the engineering team, or what they understand. And if new technologies are going to be part of this, they must fit into that very special world.

The Ladder model, is the one that has shaped most people's thinking on the subject of science, technology, and product. The Circle is less familiar. The Ladder is characteristic of the early stages of an industry and the Circle is characteristic of later stages. However, it is the Circle, not the Ladder, that has been decisive in the industries in the US which are in trouble - automobiles, semiconductors, and TV. The notion of investing in R&D, consistent with the Ladder approach, is that you put the R&D here and the product pops out there. That is very, very different from what is really encountered if participating in a cycle development process. It is the industrial success which causes the R&D spending, not the other way around.

The wrong mental picture hurts a great deal. Consider the picture brought to mind by the phrase, "Commercialization" of new technology. Most people believe in the notion that commercialization means to take something new and make it commercial, whereas the essence of the cyclic development process rests in defining something which is already commercial. When one talks about the commercialization of scientific discovery, one is relegated to use of phase one, or the Ladder process.

John Alic argues that the Circle approach, compared to the linear model, gives equal weight to technical virtuosity in all of the functions - research, design, production, and marketing - and produces a model that stresses the importance of close coupling among them[13].

ALIC-BRANSCOMB'S MODEL

Dr. John Alic, a senior associate of the Office of Technology Assessment of the US Congress, and Dr. Lewis Branscomb, from Harvard University, have studied the evolution of the tacit US technology policy in the years after the Second World War. In their books, "Empowering Technology: Implementing a US Strategy[14]" and "Beyond Spin-off: Military and Commercial Technologies in a Changing World", they have greatly contributed to the studies related to specification and procedure of evolution of the Linear model which is tied to the post-war tacit US technology strategy. They vividly delineate some characteristics of the new innovation procedures, described below. However, their studies have not gone far enough to articulate a new innovation model.

John Alic regards 'innovation' as a social process involving the application of knowledge, together with other inputs, to design, develop, create, and market some products. The output of innovation can include intangible service products as well as physical objects and systems. The artifactual product should be viewed as derivative, the consequence of research, design, development, production, and marketing activities - of what people and organizations know (declarative knowledge) and can do (procedural knowledge). Technological innovation, especially in the later stages often called commercialization, is an activity pursued by business firms.

The core activity of commercialization and the culminating stage of innovation is engineering design and development - an activity sufficiently different from R&D that we might call it D&D. As an extension of research, as in R&D, development implies reducing new knowledge to practice - verifying and validating experimental results and theoretical predictions, exploring specific cases, and determining the accuracy and limits of mathematical models and methods. But when coupled with design, development implies the steady refinement of concrete products, processes and systems through an iterative process of conceptualization, preliminary design, analysis, testing and redesign. This is the everyday technical work of private firms, often called product development or product engineering (or process development, software development, and so on). Instead of thinking of design and development (activities in which knowledge is applied) as D&D, reserving R&D for activities that generate knowledge, the latter term has entered into common use to stand for either or both. Although practitioners, understanding the distinctions, do not have much trouble communicating among themselves, the broad range of activities encompassed by R&D in its now-common usage sometimes leads to confusion among economists, policy analysts, and other observers.

Innovation results from the artful combination of new knowledge with, typically, a great deal of existing knowledge. New knowledge and methods originating in R&D may be critical. At the same time, a successful innovation, leaving aside exceptions such as defense systems, is one that meets the test of the marketplace. Successful innovation depends more directly on D&D, though not of course to the exclusion of R&D. But the latter may be far removed in time and place from the design and development that precedes marketplace success.

Alic and Branscomb argue that central to the national system of any advanced economy will be mechanisms both for generating new knowledge through R&D and for applying knowledge, new and existing. Less developed economies with fewer needs for new knowledge may nonetheless benefit from R&D tailored specifically to their situation.

OECD'S OSLO MANUAL

"Proposed Guidelines for Collecting and Interpreting Technological Innovation Data", code named the "Oslo Manual", first published in 1991 by OECD, in Paris. Since then the Oslo Manual has been revised and further elaborated.

The Oslo Manual intends to develop new procedures to collect and interpret data on innovation and technology development, and then substitute the Frascati Manual, another element of the Linear model, but it does articulate and depict the model which is going to be used. The Oslo Manual states that 'it is now commonly accepted that the development and diffusion of new technologies are central to the growth of output and productivity. But our understanding of the innovation process and its economic impact is still deficient in many areas.[15]'

While in the context of the Linear paradigm expenditure on R&D was the key to innovation, the Oslo Manual emphasizes that 'despite the considerable efforts of researchers, however, we are still a long way from understanding all of the factors which shape the rate, direction and effects of technological change, at enterprise, industry, regional or country level. There are many reasons for this. Some are theoretical, to do with the difficulties of building technological change into economic theory and analysis'.

The Oslo Manual regards 'design as an essential part of the innovation process. It covers plans and drawings aimed at defining procedures, technical specifications and operational features necessary to the conception, development and manufacturing and marketing of new products and processes'. However, consistent with the Linear model, the Oslo Manual classifies technology development into 'product' and 'process' development and then continues as follows: A Product innovation is the commercialization of a technologically changed product. A process innovation occurs when there is significant change in the technology of the production of an item. This may involve new equipment, new management and organization methods, or both

John Ziman's Neural Net Model

This model of innovation was developed by John Ziman from the Science Policy Research Unit Group in London UK. Using the basic concepts of the Linear model, such as basic and applied research and development, this model seeks to provide a metaphor based on drawing lines to represent causal or interactive linkages between various points in a cognitive space[16].

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[1] Last update: February 10, 1997