Innovation Based Economic Models

Or how technology and technological change can be contextualized

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"Le XXe siècle a inventé les grandes organisations,
le XXIe siècle sera celui des réseaux hétérogènes."
("The 20[th] century invented large organisations,
the 21[th] century will live in heterogeneous networks.")
(Callon/Laredo/Rabeharisoa, 329)

This paper attempts to show how to expand the concept of linear innovation process that is proposed by neoclassical economic models, into a complex, feedback-driven, continuous system within the context of science, economics and society. With the help of different models on technology and its environment (social constructivists, Hughes's technological system, Rosenberg's technology within economics and Callon's actor-network model), some aspects of technology constitution and its impacts are examined: they cannot be strictly separated from each other, technology is a system that incorporates engineering, social, economic and political values, and technology is a result of a continuous negotiation process within society.

Introduction

In our time when the social, economic and political weight of technology is increasing, when social participation is expanding and several disciplines emphasize the relevance of different social groups and are working out methodologies to incorporate them into political and economic decision-making processes and when complex, high-risk technological systems are evolving, some basic understanding of the evolution of this system and the "occurring" of innovations within this system should be proposed by innovation studies. Furthermore, technology and knowledge become "indexed", that is to say, extra information on information, or metadata, or indices verify the information (conditions where and when the specific piece of information becomes true, reliable and relevant), the importance of context-dependence of information has definitively drawn attention to the analysis of the system that contains information (e.g. closed systems of scientific theories – free information flow among scientists; Manhattan project – controlled information flow). Considering the enormous amount of scientific analysis in this field, this paper focuses on the concept of linear innovation process proposed by the neoclassical economic model and then investigates some technology based models from different disciplines that may provide some further aspects for technology constitution and contextualization. In order to obtain a better understanding, both a historical review and a methodological, scientific review will be provided. The critical analysis focuses on the introduction of some "reality experts", sociologists, innovation researchers, practical managers on the one hand, and the analysis of background sciences: innovation research, sociology (social constructivists), history of technology (Hughes), history of economics (Rosenberg), economic policy (ecole des mines) on the other.

1. Neoclassical economic model

The basic elements of neoclassical economics (using Newton's gravitational system as a pattern) elaborated by the work of Smith, Marshall, and Keynes are rational market actors seeking to maximize their profits, own defined resources and technologies and select among them based upon pre-defined decision mechanisms.

Market is in a state of equilibrium, or if it is not, then it aspires to it through the process of an adjustment mechanism. The economists' main task is to analyse market coordination and adjustment processes using advanced mathematics in the name of certainty of prediction. The framework is holistic but provides an analytic approach only from within. Market price as the result of equality of supply and demand is the signalling system for market actors. They obtain information on input and output prices and thus can decide upon an optimal production function. Consumer preferences and technology are constant in the short term (whenever new technology is needed, the company just takes it 'off the shelf' and then uses it), and is not linked to microeconomic factors in the long term. The impacts of technology choice alone are analysed, the constitution of technology is not explained. In the case of perfect market conditions, when all the actors possess all the information concerning the market and when none of the actors can influence the market better than the others, individual actors can reach the maximum efficiency. The role of the state is to preserve the legal and external conditions for perfect competition and to interact if monopolies or dumping prices or any other external factors threaten to disturb the free movement of market prices. The aggregation of individual self-interest finally leads to common good (invisible hand concept). In the long term, markets reach the final equilibrium state and become static.

Historically, one main feature of the development of this neoclassical model should be considered from the point of view of technology: the issue of economic growth and how it is related to technological growth. Based upon the pressure of economic reality (economic crisis of 1929 and then permanent market disequilibria), the issue of business cycles and then the issue of economic growth gained a central focus in the 1950s and 1960s. In the analytical framework, the concept of long-term growth was first explained by either the supply or the demand side (concept of push versus pull). The most remarkable growth model of the 1950s is the Solow model, that has the following logic: part of the income (savings) is used for investment leading to the increase of capital stock within the economy, and a higher level of capital stock and steadily increasing work provides a higher level of income. Thus, investments maintain a steady growth level within this static model. Concerning macroeconomic predictions, the Solow model states that under the principle of decreasing returns and the evaluation of production factors based on their marginal productivity, a higher capital stock level (in developed countries) leads to a lower interest rate level than in the underdeveloped countries, thus, capital should flow into underdeveloped countries. In the long term this would mean that underdeveloped countries would receive a significant capital inflow allowing them to catch up with their development. This theory did not prove to be true in real life conditions. Further factors affecting economic growth were then added to the analysis, namely the special state of technology and work production factors and the concept of knowledge. Romer and Lucas stated at the end of the 1980s that both technology and work (called the human factor) are special goods that can be protected via intellectual property rights and can be monopolized by certain market actors, once they are diffused in the market, they act as public goods – they can be considered as exogenous factors in both cases. On the micro level, market actors bring in their individual decisions based on consumption saving and knowledge or production-investment and knowledge. The optimisation of the level of knowledge is thus another objective of individual market actors. On the macro level, there is a case when these public goods increase productivity (economic growth) without any changes in the other production factors.

Overall, neoclassical economics managed to consider knowledge or knowledge based production factors as "exogenous" for economic models, thus it does not focus its analysis on the real cause of economic growth.

2. The old model of innovation

The linear model of innovation focuses on the four or six stages of the diffusion process of innovation. The logic behind this is that scientific discovery leads to invention in applied sciences and then to production and marketing of the invented product or process. This process consists of stages strictly separated in space and time. It is ideal for the analysis of the impact of a new scientific theory or new knowledge and for the description of innovation within and among separate institutions. Two main problems are the weak points of this model: 1, not the entire impact of the diffusion of innovation can be calculated based upon traditional cost-benefit analysis. 2, it does not allow the analysis of the constitution of technology. It answers the question how technology is diffused but not why it is diffused or how it is created. Thus it does not allow a prediction for innovation, which makes it mainly static, descriptive.

3. Innovation research

The process and complexity of innovation research grew out of segmented, statistical analyses into a linear model and then developed into a complex ecological understanding of innovation supported by project research. Starting from inventor biographies and then going on to statistical analyses, it progressed to a deep economic model within Schumpeter's work that focused on the disequilibria function of the innovator-entrepreneur. After further articulation of the stages of innovation, different projects deal with unsuccessful innovations (Sappho Project) and the complex, multidisciplinary approach of innovation (Georgia Tech Project). Innovation is an implementation of a new tool of technology: (1) introduction of a new and different product to the market; (2) implementation of a new production process; (3) exploration of new markets. Its basic features are: 1, born as a reaction to needs or to opportunities (context-dependent); 2, based on a creative effort and if successful with an element of novelty; 3, induces further changes; 4, uncertain; 5, technological knowledge is partly tacit (not explicit); 6, both the knowledge base and research processes are continuously changing; 7, and human – genial insights and mistakes may both occur equally.

4. Innovation based sociotechnological models

4.1 Socio-constructivist model

Linking sociology and technology studies, the social constructivist view is based on the concept that "all knowledge and all knowledge claims are to be treated as being socially constructed" (Pinch/Bijker, p.18). Thus technological artefacts are open to social analysis, not only their usage but also their design and technical content. They attack the "black box" concept of economics on technology. "Similarly, in the economic analysis of technological innovation everything is included that might be expected to influence innovation, except any discussion of the technology itself" (Pinch/Bijker, p.21). They use two concepts to describe their model, the EPOR (Empirical Programme of Relativism) and SCOT (Social Construction of Technology). Focusing on scientific controversies, EPOR distinguishes three stages for explaining scientific findings: 1, interpretative flexibility (when scientific findings are open to more than one interpretation); 2, social mechanisms limiting interpretative flexibility; 3, closure mechanisms or a growing degree of stabilization of the different artefacts, when the problem is redefined. SCOT is a multidirectional model describing the developmental process of a technological artefact. Relevant social groups see an artefact differently, because they see some of the problems and some of the solutions to their problems.

Linking these two concepts, in the stage of interpretative flexibility, technological artefacts are culturally constructed and interpreted, incorporating social, ethical, technological, etc. values. The same artefact can have radically different interpretations by different social groups. The closure and stabilisation stage brings out all kinds of conflicts: technical requirements, solutions and moral conflicts. Or equivalent to this, it gives place to a negotiation process among the social groups involved. The problem redefinition stage is successful when relevant social groups see the problem as being solved, and it leads to the stabilization of artefacts.

It is important to emphasize that this concept permits an interpretative flexibility of technology and the problem is solved when the relevant social group sees the problem being solved. The main feature of the socio-constructivist approach is that the boundary between science and technology is a matter for social negotiation and does not represent an underlying distinction.

4.2 Hughes's technological system

Starting from the problems of the history of technology (i.e. isolated, chronological analysis of technological inventions and their description for usage), Hughes develops a concept of technological systems to explain why and how inventions occur and become interrelated. "Technological systems contain messy, complex, problem-solving components. They are both socially constructed and society shaping" (Hughes, p.51). These systems contain elements or components broadly defined as system artefacts (these can be physical artefacts, legislative artefacts, or organizations – thus technical, political and social aspects are integrated within a system). These elements are interdependent, so the change is diffused within the whole system. Innovative energy is focused in some part of the system and at certain stages. There are some peculiar elements in the system that "have fallen behind or are out of phase with the others" (Hughes, p.73). They are called reverse salients. They "emerge, often unexpectedly; the defining and solving of critical problems is a voluntary action" (Hughes, p.74). People – financial experts, managers, engineers or inventors – in the system try to solve these critical problems. "When a reverse salient cannot be corrected within the context of an existing system, the problem becomes a radical one, the solution of which may bring a new and competing system" (Hughes, p.75). Thus, some reverse salients never become components.

The role of people in the system is twofold: 1, they are either "system builders", trying to construct unity from diversity, coherence from chaos and to evaluate system performance against predefined goals; 2, or they are "professional inventors" who try to distance themselves from large organizations and focus on problem areas within the system and try to identify and then to solve reverse salients – this may lead to a new system.

Systems have an evolution cycle: they live through invention, development and innovation phases (that are meanwhile reinforced by technology transfer), and subsequently through growth, competition, and consolidation phases. They can be characterized by degrees of freedom: free movement of people versus durability of the system.

Apart from the success of problem-solving, a "major explanation for this growth, and one rarely stressed by technological, economic or business historians, is the drive for high diversity and load factors and a good economic mix" (Hughes, p.72).

Hughes has introduced an important system aspect into innovation studies, namely he focuses on non-system related elements (reverse salients). He succeeds in linking micro and macro levels of technology. And he provides a partial definition of technology as problem-solving systems. The main motivation for technology development is not purely economic: human – problem-solving, engineering – diversity, load factors, economic – good economic mix.

4.3 Rosenberg: history of economics

His main merit is to question the inapplicability of neoclassical economics in innovation studies and to develop an innovation explanation linked to practical observation and economic statistics. "Most thinking about the role of natural resources in economic growth continues to be excessively static. It ignores not only the dynamic interactions between technological change and natural resources, but also a whole range of additional adaptations which are a mixture of pure technological change, redesigning and substitution" (Rosenberg, p.280). He supports practical engineering thinking and restores its knowledge as equal to economic theorizing. Starting from the analysis of "alternative", non-mainstream economists like Babbage, Schumpeter or Marx, he includes time in the interpretation of innovation analysis. There are different time lags for innovation and the most significant short period when theoretical and practical knowledge about a specific problem has accumulated and starts to formulate in a law or a product can be described as "the time of invention". Innovation is based on skills and knowledge (trial-and-error, problem solving process) and he links this knowledge of the micro level to the macro level. In the development of industries, he introduces the concept of "technological convergence": different industries based upon the same pool of skills do benefit from one another and one technological solution can be adapted in several industries (with minor modifications). Technology is a social construction as "it typically also requires some sort of modification in human behaviour, often painful modifications" (Rosenberg, p.281).

4.4 Economic policy: network aspect

The group of L'école des Mines led by Callon developed an actor network model that provides a new type of rationality to evaluate innovative structures and competences among market actors based on the analysis of the role of the state in promoting and supporting innovation more efficiently in the economy.

Their starting point was the dual problem of evaluating state activity in the economy with neoclassical economic tools (cost-benefit analysis and input-output analysis) while the concept of network supported by real life examples was also definitely present and viable as a basis for evaluation. Analysing the strengths and weaknesses of both concepts, they decided to use a combined evaluation method. The production function (the neoclassical concept) is ideal for defining, measuring and evaluating static notions (organization, competence, processes, production growth, R&D expenditures, etc.). It is less applicable for evaluating a technology construction process or a whole diffusion process. It is not ideal for selecting from competing technologies or R&D methodologies. The network concept is ideal for modelling and evaluating novelties in the system, i.e. for identifying better learning or R&D competences. Some important elements to evaluate knowledge and learning are thus missing: 1, to measure the heterogeneity of knowledge elements; 2, to define a market value and production cost of knowledge elements; 3, to provide a scale of selection among knowledge elements. They understand knowledge as comprising cumulative (loosely determined) and tacit (protectable, marketable) features and technology as being composed of both artefact and information (knowledge).

Combining these two models, they arrive at the following basic assumptions: 1, technology constitution should be included in all types of technology analysis; 2, the diffusion of technology ensures a real interpretation and final form of technology (its starting characteristics also change); 3, the flow and the composition of technology and information are not separate phenomena; 4, as technologies are specific and partly tacit, their adoption is greatly dependent upon the organization's competence to manage these features.

Working with these assumptions, they progress to the following evaluation framework: 1. Organizational learning and an organization's competence to adopt new technologies (above all, R&D) are basic preconditions for the success of state innovation policy, they can thus serve as the distinctive characteristics of organizations. Technologies can also be evaluated based on how they change organizations. 2. The relationship among organizations can be interpreted as a stable chain for innovation. It has feedback and interaction processes and it replaces the old innovation model. "L'innovation dépend de l'existence d'interactions étroites entre le monde de la science, de la technique et le marché." "Innovation depends on the existence of narrow interactions between science, technology and market" (Callon/Laredo/Rabeharisoa, p.302). Consequently, external relations of organizations are also to be investigated and evaluated (i.e. durability, interactivity, complexity, etc.) 3. Further processes enhancing development are: learning by doing and network externalities. An organization's adoption capability (R&D) becomes crucial in the case of network externalities.

As a result of these conceptual changes, the role of the state in promoting and supporting innovations is also modified. This new type of rationality focuses on the creation of a critical mass for establishing an innovative network. The efficiency of a technological program or policy can be evaluated based on the catalyst role of the state, of establishing durable, innovation diffusing relationships among organizations, on encouraging organizations to learn and to develop new technologies, and finally, to identify future strategic competences (among organizational R&D methodologies).

The new model, the so-called actor-network model is a techno-economic network composed of actors with strategic autonomy and intermediary tools that circulate among them. Actors are organisations, groups of scientists, engineers, companies, etc. Intermediary tools are written documents, competences, money, technological objects, etc. They are emitted, produced, consumed, used and transformed by the actors. There are three actors and two main poles within this network based on the similar characteristics of the actors and the intermediary tools they circulate: 1, scientific (creating authentic, proven knowledge); 2, technological (producing material products that can provide certain services); 3, market (world of users or consumers – they only define demand); 4, transfer pole between science and technology; 5, development pole between technology and market. Internal development comes from trial and error processes (analogous to engineering knowledge). The state is necessary to create and stimulate these networks as it is the only actor big enough to bear the financial burden to realise the investments that serve as a configuration for a network.

The reason for establishing this network model is to provide a new analytical framework for "meta-coordination" of the state. And to better understand organizations, together with all their relationships to R&D partners, suppliers, consumers, etc., to understand that alliances can be mobile, contracts can be flexible, configurations can be changeable, and coordination methods can be multiple. It is to contradict the simple model of innovation as "en même temps que l'innovation prend progressivement corps le réseau se déforme puis se stabilise peu à peu: la dynamique du réseau technico-économique colle à celle du processus de l'innovation". "At the same time as innovation is incorporated progressively in the network, it stabilises step by step, the dynamics of the techno-economic network takes the speed of the innovation process" (Callon/Laredo/Rabeharisoa, p.310). These networks can be characterized by their development level, by their integration level, and by their length.

The main importance of the actor-network concept is that it considers economy and science and technology as a loose system, where innovation creates stable relations and where the learning competence of actors is crucial.

5. The new model of innovation

The new complex model of innovation is based on feedback and interaction. Its central process remains the same as in the old model, but feedback gains momentum. Two main areas are related in a way that generates efficiency increase. Knowledge accumulates and research is conducted more actively if there is an active exchange process between science and innovation. The relationship between science and invention can lead to radical innovations.

6. Technology policy implications

Technology programs can be evaluated on the basis of how they contribute to the establishment of stable relations in the process of innovation, or the enhancement of actor cooperation. The direction taken by innovation can and should be influenced by technology policies. Thus, if there are multiple innovation systems, then there are also multiple coordination and motivation measures to promote innovation. Effective evaluation work can only be done when the elements of these innovation systems have been identified.

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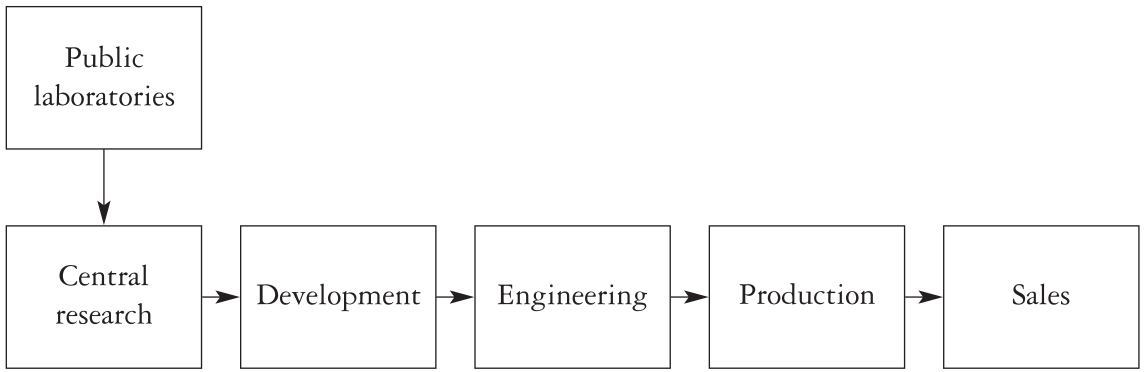
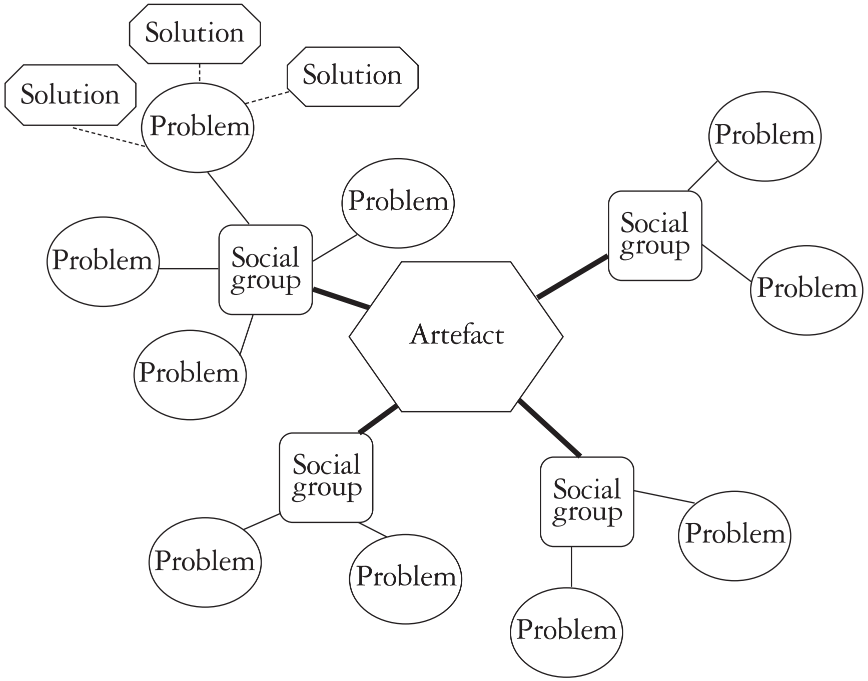
The linear model of innovation



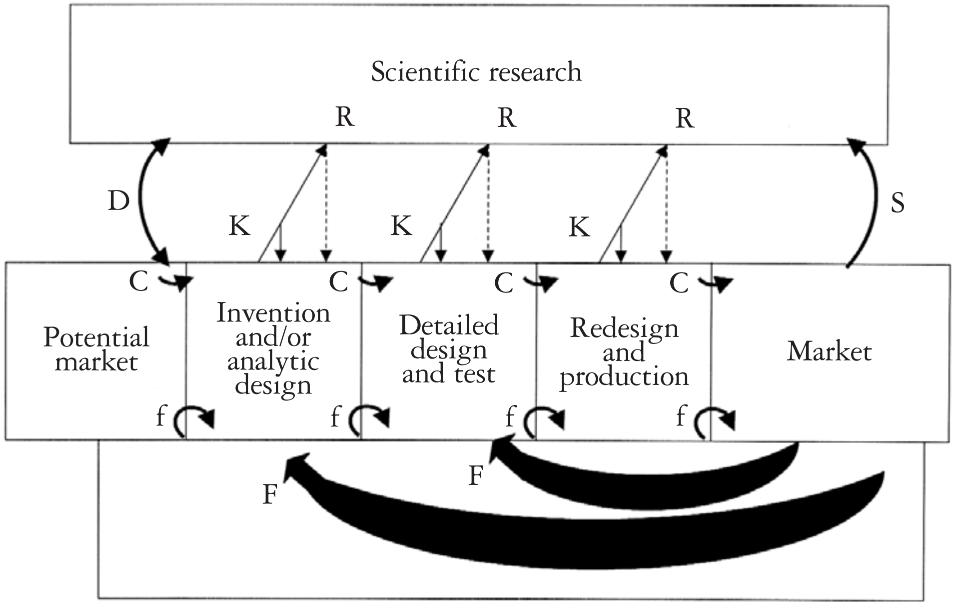
Source: Bandt/Foray: L'evaluation economique de la recherche et du changement technologique p. 400.

The social constructivist network model



Source: Bijker/Hughes/Pinch: The social construction of technological systems p. 35-36.

The new model of innovation



C = Central chain of innovation

f = short curves

F = long curves

D = direct link between research and innovation

S = management of scientific research

KR = links of knowledge and research: if the problem is resolved at the level of K, this link is not active

Source: Bandt-Foray: L'evaluation economique de la recherche et du changement technologique p. 402.