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The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university–industry–government relations

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Abstract

The Triple Helix of university–industry–government relations is compared with alternative models for explaining the current research system in its social contexts. Communications and negotiations between institutional partners generate an overlay that increasingly reorganizes the underlying arrangements. The institutional layer can be considered as the retention mechanism of a developing system. For example, the national organization of the system of innovation has historically been important in determining competition. Reorganizations across industrial sectors and nation states, however, are induced by new technologies (biotechnology, ICT). The consequent transformations can be analyzed in terms of (neo-)evolutionary mechanisms. University research may function increasingly as a locus in the "laboratory" of such knowledge-intensive network transitions.

Keywords: Mode 2; Triple helix; University–industry–government relations; Innovation

1. Introduction: From the endless frontier to an endless transition

The Triple Helix thesis states that the university can play an enhanced role in innovation in increasingly knowledge-based societies. The underlying model is analytically different from the national systems of innovation (NSI) approach (Lundvall, 1988, 1992; Nelson, 1993), which considers the firm as having the leading role in innovation, and from the "Triangle" model of Sábato (1975), in which the state is privileged (cf. Sábato and Mackenzi, 1982). We focus on the network overlay of communications and expectations that reshape the institutional arrangements among universities, industries, and governmental agencies.

As the role of the military has decreased and academia has risen in the institutional structures of contemporary societies, the network of relationships among academia, industry, and government have also been transformed, displacing the Cold War "Power Elite" trilateral mode of Mills (1958) with an overlay of reflexive communications that increasingly reshape the infrastructure (Etzkowitz and Leydesdorff, 1997). Not surprisingly, the effects of these transformations are the subject of an international debate over the appropriate role of the university in technology and knowledge transfer. For example, the Swedish *Research 2000 Report* recommended the withdrawal of the universities from the envisaged

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''third mission'' of direct contributions to industry (see Benner and Sandström, this issue). Instead, the university should return to research and teaching tasks, as traditionally conceptualized. However, it can be expected that proponents of the third mission from the new universities and regional colleges, which have based their research programmes on its premises, will continue to make their case. Science and technology have become important to regional developments (e.g., Braczyk et al., 1998). Both R&D and higher education can be analyzed also in terms of markets (Dasgupta and David, 1994).

The issues in the Swedish debate are echoed in the critique of academic technology transfer in the USA by several economists (e.g., Rosenberg and Nelson, 1994). The argument is that academic technology-transfer mechanisms may create unnecessary transaction costs by encapsulating knowledge in patents that might otherwise flow freely to industry. But would the knowledge be efficiently transferred to industry without the series of mechanisms for identifying and enhancing the applicability of research findings? How are development processes to be carried further, through special grants for this purpose or in new firms formed on campus and in university incubator facilities?

The institutional innovations aim to promote closer relations between faculties and firms. The ''endless frontier'' of basic research funded as an end in itself, with only long-term practical results expected, is being replaced by an ''endless transition'' model in which basic research is linked to utilization through a series of intermediate processes (Callon, 1998), often stimulated by government.

The linear model either expressed in terms of ''market pull'' or ''technology push'' was insufficient to induce transfer of knowledge and technology. Publication and patenting assume different systems of reference both from each other and with reference to the transformation of knowledge and technology into marketable products. The rules and regulations had to be reshaped and an interface strategy invented in order to integrate market pull and technology push through new organizational mechanisms (e.g., OECD, 1980; Rothwell and Zegveld, 1981).

In the USA, these programs include the Small Business Innovation Research program (SBIR) and the Small Business Technology Transfer Program (STTR), the Advanced Technology Program (ATP), the Industry/University Cooperative Research Centers (IUCRC) and Engineering Research Centers (ERC) of the National Science Foundation, etc. (Etzkowitz et al., 2000). In Sweden, the Knowledge Competency Foundation and the Technology Bridge Foundation were established as public venture capital source, utilizing the Wage Earners Fund, originally intended to buy stock in established firms on behalf of the public. The beginnings of a Swedish movement to involve academia more closely in this direction has occasioned a debate similar to the one that took place in the US in the early 1980s. At that time, Harvard University sought to establish a firm jointly with one of its professors, based on his research results.

Can academia encompass a third mission of economic development in addition to research and teaching? How can each of these various tasks contribute to the mission of the university? The late 19th century witnessed an academic revolution in which research was introduced into the university mission and made more or less compatible with teaching, at least at the graduate level. Many universities in the USA and worldwide are still undergoing this transformation of purpose. The increased salience of knowledge and research to economic development has opened up a third mission: the role of the university in economic development. A ''second academic revolution'' seems under way since World War II, but more visibly since the end of the Cold War (Etzkowitz, forthcoming).

In the USA in the 1970s, in various Western European countries during the 1980s, and in Sweden at present, this transition has led to a reevaluation of the mission and role of the university in society. Similar controversies have taken place in Latin America, Asia, and elsewhere in Europe. The Triple Helix series of conferences (Amsterdam, 1996; Purchase, New York, 1998; and Rio de Janeiro, 2000) have provided a venue for the discussion of theoretical and empirical issues by academics and policy analysts (Leydesdorff and Etzkowitz, 1996, 1998). Different possible resolutions of the relations among the institutional spheres of university, industry, and government can help to generate alternative strategies for economic growth and social transformation.

2. Triple Helix configurations

The evolution of innovation systems, and the current conflict over which path should be taken in university–industry relations, are reflected in the varying institutional arrangements of university–industry–government relations. First, one can distinguish a specific historical situation which one may wish to label Triple Helix I. In this configuration the nation state encompasses academia and industry and directs the relations between them (Fig. 1). The strong version of this model could be found in the former Soviet Union and in Eastern European countries under ''existing socialism''. Weaker versions were formulated in the policies of many Latin American countries and to some extent in European countries such as Norway.

A second policy model (Fig. 2) consists of separate institutional spheres with strong borders dividing them and highly circumscribed relations among the spheres, exemplified in Sweden by the noted *Research 2000 Report* and in the US in opposition to the various reports of the Government–University–Industry Research Roundtable (GUIRR) of the National Research Council (MacLane, 1996; cf. GUIRR, 1998). Finally, Triple Helix III is generating a knowledge infrastructure in terms of overlapping institutional spheres, with each taking the role of the other and with hybrid organizations emerging at the interfaces (Fig. 3).

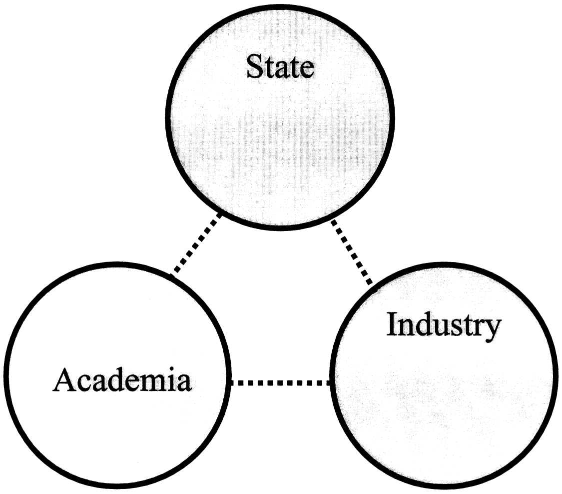

Fig. 2. A ''laissez-faire'' model of university–industry–government relations.

The differences between the latter two versions of the Triple Helix arrangements currently generate normative interest. Triple Helix I is largely viewed

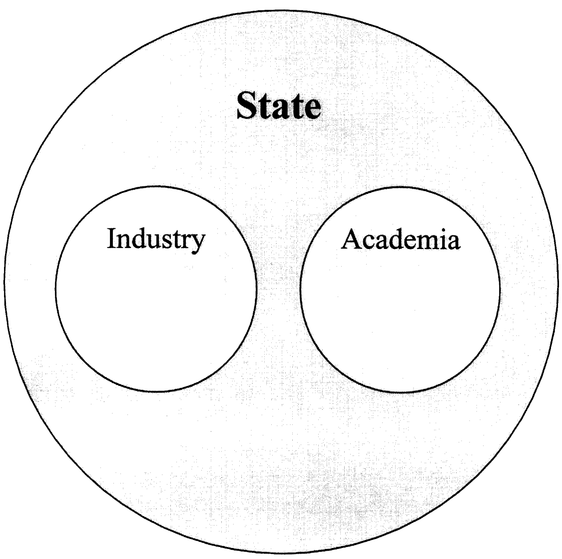

Fig. 1. An etatistic model of university–industry–government relations.

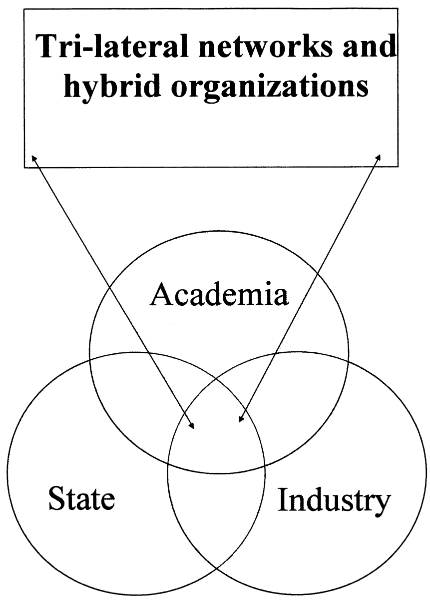

Fig. 3. The Triple Helix Model of University–Industry–Government Relations.

as a failed developmental model. With too little room for ''bottom up'' initiatives, innovation was discouraged rather than encouraged. Triple Helix II entails a laissez-faire policy, nowadays also advocated as shock therapy to reduce the role of the state in Triple Helix I.

In one form or another, most countries and regions are presently trying to attain some form of Triple Helix III. The common objective is to realize an innovative environment consisting of university spin-off firms, tri-lateral initiatives for knowledge-based economic development, and strategic alliances among firms (large and small, operating in different areas, and with different levels of technology), government laboratories, and academic research groups. These arrangements are often encouraged, but not controlled, by government, whether through new ''rules of the game,'' direct or indirect financial assistance, or through the Bayh–Dole Act in the USA or new actors such as the abovementioned foundations to promote innovation in Sweden.

3. The Triple Helix of innovation

The Triple Helix as an analytical model adds to the description of the variety of institutional arrangements and policy models an explanation of their dynamics. What are the units of operation that interact when a system of innovation is formed? How can such a system be specified?

In our opinion, typifications in terms of ''national systems of innovation'' (Lundvall, 1988; Nelson, 1993); ''research systems in transition'' (Cozzens et al., 1990; Ziman, 1994), Mode 2 (Gibbons et al., 1994) or ''the post modern research system'' (Rip and Van der Meulen, 1996) are indicative of flux, reorganization, and the enhanced role of knowledge in the economy and society. In order to explain these observable reorganizations in university–industry–government relations, one needs to transform the sociological theories of institutional retention, recombinatorial innovation, and reflexive controls. Each theory can be expected to appreciate a different subdynamic (Leydesdorff, 1997).

In contrast to a double helix (or a coevolution between two dynamics), a Triple Helix is not expected to be stable. The biological metaphor cannot work because of the difference between cultural and biological evolutions. Biological evolution theory assumes variation as a driver and selection to be naturally given. Cultural evolution, however, is driven by individuals and groups who make conscious decisions as well as the appearance of unintended consequences. A Triple Helix in which each strand may relate to the other two can be expected to develop an emerging overlay of communications, networks, and organizations among the helices (Fig. 4).

The sources of innovation in a Triple Helix configuration are no longer synchronized a priori. They do not fit together in a pregiven order, but they generate puzzles for participants, analysts, and policymakers to solve. This network of relations generates a reflexive subdynamics of intentions, strategies, and projects that adds surplus value by reorganizing and harmonizing continuously the underlying infras-

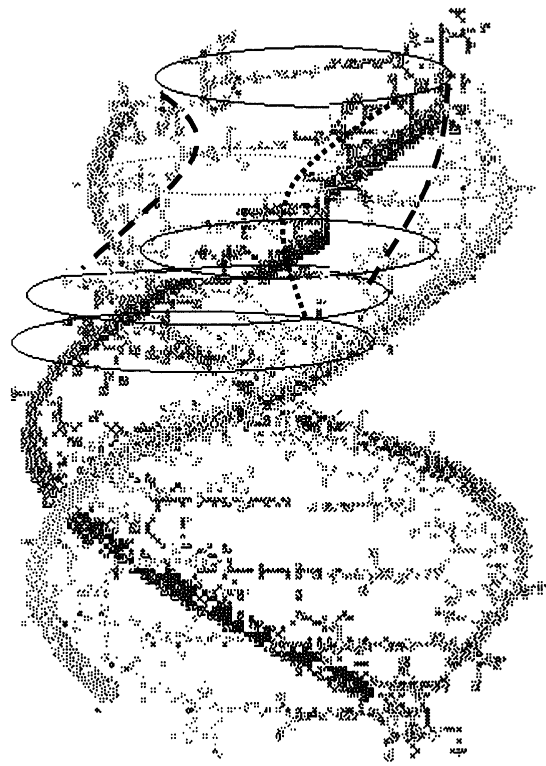

Fig. 4. The overlay of communications and expectations at the network level guides the reconstruction of institutional arrangements.

tructure in order to achieve at least an approximation of the goals. The issue of how much we are in control or non-control of these dynamics specifies a research program on innovation.

Innovation systems, and the relationships among them, are apparent at the organizational, local, regional, national, and multinational levels. The interacting subdynamics, that is, specific operations like markets and technological innovations, are continuously reconstructed like commerce on the Internet, yet differently at different levels. The subdynamics and the levels are also reflexively reconstructed through discussions and negotiation in the Triple Helix. What is considered as ''industry'', what as ''market'' cannot be taken for granted and should not be reified. Each ''system'' is defined and can be redefined as the research project is designed.

For example, national systems of innovation can be more or less systemic. The extent of systemness remains an empirical question (Leydesdorff and Oomes, 1999). The dynamic ''system(s) of innovation'' may consist of increasingly complex collaborations across national borders and among researchers and users of research from various institutional spheres (Godin and Gingras, this issue). There may be different dynamics among regions. The systems of reference have to be specified analytically, that is, as hypotheses. The Triple Helix hypothesis is that systems can be expected to remain in transition. The observations provide an opportunity to update the analytical expectations.

4. An endless transition

The infrastructure of knowledge-intensive economies implies an endless transition. Marx's great vision that ''all that is solid, melts into air'' (Berman, 1982) underestimated the importance of seemingly volatile communications and interactions in recoding the (complex) network system. Particularly, when knowledge is increasingly utilized as a resource for the production and distribution system, reconstruction may come to prevail as a mode of ''creative destruction'' (Schumpeter, 1939, 1966; Luhmann, 1984).

Can the reconstructing forces be specified? One mode of specification is provided by evolutionary economics in which the three functional mechanisms are: technological innovation provides the variation, markets are the prevailing selectors, and the institutional structures provide the system with retention and reflexive control (Nelson, 1994). In advanced and pluriform societies, the mechanisms of institutional control are again differentiated into public and private domains. Thus, a complex system is developed that is continuously integrated and differentiated, both locally and globally.

Innovation can be defined at different levels and from different perspectives within this complex dynamics. For example, evolutionary economists have argued that one should consider firms as the units of analysis, since they carry the innovations and they have to compete in markets (Nelson and Winter, 1982; cf. Andersen, 1994). From a policy perspective, one may wish to define national systems of innovation as a relevant frame of reference for government interventions. Others have argued in favour of networks as more abstract units of analysis: the semi-autonomous dynamics of the networks may exhibit lock-ins, segmentation, etc. (e.g., David and Foray, 1994). Furthermore, the evolving networks may change in terms of relevant boundaries while developing (Maturana, 1978).

In our opinion, these various perspectives open windows of appreciation on the dynamic and complex processes of innovation, but from specific angles. The complex dynamics is composed of subdynamics like market forces, political power, institutional control, social movements, technological trajectories and regimes. The operations can be expected to be nested and interacting. Integration, for example, within a corporation or within a nation state, cannot be taken for granted. Technological innovation may also require the reshaping of an organization or a community (Freeman and Perez, 1988). But the system is not deterministic: in some phases intentional actions may be more successful in shaping the direction of technological change than in others (Hughes, 1983).

The dynamics are nonlinear while both the interaction terms and the recursive terms have to be declared. First, there are ongoing transformations within each of the helices. These reconstructions can be considered as a level of continuous innovations under pressure of changing environments. When two helices are increasingly shaping each other mutually, coevolution may lead to a stabilization along a trajectory. If more than a single interface is stabilized, the formation of a globalized regime can be expected. At each level, cycles are generated which guide the phasing of the developments. The higher-order transformations (longer-term) are induced by the lower-order ones, but the latter can seriously be disturbed by events at a next-order system's level (Schumpeter, 1939; Kampmann et al., 1994).

Although this model is abstract, it enables us to specify the various windows of theoretical appreciation in terms of their constitutive subdynamics (e.g., Leydesdorff and Van den Besselaar, 1997). The different subdynamics can be expected to select upon each other asymmetrically, as in processes of negotiation, by using their specific codes. For example, the markets and networks select upon technological feasibilities, whereas the options for technological developments can also be specified in terms of market forces. Governments can intervene by helping create a new market or otherwise changing the rules of the game.

When the selections ''lock-in'' upon each other, next-order systems may become relevant. For example, airplane development at the level of firms generates trajectories at the level of the industry in coevolutions between selected technologies and markets (e.g., Nelson, 1994; cf. McKelvey, 1996). Nowadays, the development of a new technological trajectory invokes the support of national governments and even international levels (like the EU), using increasingly a Triple Helix regime (Frenken and Leydesdorff, forthcoming).

We have organized this theme issue about the Triple Helix of university–industry–government relations in terms of three such interlocking dynamics: institutional transformations, evolutionary mechanisms, and the new position of the university. This approach allows us to pursue the analysis at the network level and then to compare among units of analysis. For example, both industries and governments are entrained in institutional transformations, while the institutional transformations themselves change under the pressure of information and communication technologies (ICT) or government policies. Before explaining the organization of the theme issue in detail, however, we wish to turn briefly to the analytical position of the Triple Helix model in relation to other nonlinear models of innovation, like Mode 2 and national systems of innovation.

5. Nonlinear models of innovation

As noted, nonlinear models of innovation extend upon linear models by taking interactive and recursive terms into account. These nonlinear terms can be expected to change the causal relations between input and output. The production rules in the systems under study, for example, can be expected to change with the further development of the input/output relations (e.g., because of economies of scale). Thus, the unit of operation may be transformed, as is typical when a pilot plant in the chemical industry is scaled up to a production facility.

By changing the unit of analysis or the unit of operation at the reflexive level, one obtains a different perspective on the system under study. But the system itself is also evolving. In terms of methodologies, this challenges our conceptual apparatus, since one has to be able to distinguish whether the variable has changed or merely the value of the variable. The analysis contains a snapshot, while the reality provides a moving picture. One needs metaphors to reduce the complexity for the discursive understanding. Geometrical metaphors can be stabilized by higher-order codifications as in the case of paradigms. The understanding in terms of fluxes (that is, how the variables as well as the value may change over time), however, calls for the use of algorithmic simulations. The observables can then be considered as special cases which inform the expectations (Leydesdorff, 1995).

Innovation, in particular, can be defined only in terms of an operation. Both the innovator(s) and the innovated system(s) are expected to be changed by the innovation. Furthermore, one is able to be both a participant and an observer, and one is also able to change perspectives. In the analysis, however, the various roles are distinguished although they can sometimes be fused in ''real life'' events. Langton (1989) proposed to distinguish between the ''phenotypical'' level of the observables and the ''genotypical'' level of analytical theorizing. The ''phenotypes'' remain to be explained and the various explanations compete in terms of their clarity and usefulness for updating the expectations. Confusion, however, is difficult to avoid given the pressure to jump to normative conclusions, while different perspectives are continuously competing, both normatively and analytically.

Let us first focus on the problem of the unit of analysis and the unit of operation. In addition to extending the linear (input/output) models of neoclassical and business economics, evolutionary economists also changed the unit of analysis. Whereas neoclassical economics focused on markets as networks in terms of input/output relations among individual (rational) agents, evolutionary economists have tended to focus on firms as the specific (and bounded) carriers of an innovation process. Both the unit of analysis and the unit of operation were changed (Andersen, 1994; cf. Alchian, 1950).

Lundvall (1988, at p. 357) noted that the interactive terms between demand and supply in user–producer relations assume a system of reference in addition to the market. The classical dispute in innovation theory had, in his opinion, referred to the role of demand and supply, that is, market forces, in determining the rate and direction of the process of innovation (cf. Mowery and Rosenberg, 1979; Freeman, 1982, p. 211). If, however, the dynamics of innovation (e.g., product competition) are expected to be different from the dynamics of the market (e.g., price competition), an alternative system of reference for the selection should also be specified. For this purpose, Lundvall proposed ''to take the national system of production as a starting point when defining a system of innovation'' (p. 362).

Lundvall added that the national system of production should not be considered as a closed system: ''the specific degree and form of openness determines the dynamics of each national system of production''. In our opinion, as a first step, innovation systems should be considered as the dynamics of *change* in systems of both production and distribution. From this perspective, national systems compete in terms of the adaptability of their knowledge infrastructure. How are competencies distributed for solving ''the production puzzle'' which is generated by uneven technological developments across sectors (Nelson, 1982; Nelson and Winter, 1975)? The infrastructure conditions the processes of innovation which are possible within and among the sectors. In particular, the distribution of relevant actors contains an heuristic potential which can be made reflexive by a strategic analysis of specific strengths and weaknesses (Pavitt, 1984).

The solution of the production puzzle typically brings government into the picture shifting the dynamics from a double to a triple helix. The consequent processes of negotiation are both complex and dynamic: one expects that the (institutional) actors will be reproduced and changed by the interactions. Trilateral networks and hybrid organizations are created for resolving social and economic crises. The actors from the different spheres negotiate and define new projects, such as the invention of the venture capital firm in New England in the early postwar era (Etzkowitz, forthcoming). Thus, a Triple Helix dynamics of university–industry–government relations is generated endogeneously.

Gibbons et al. (1994) argued that this ''new mode of the production of scientific knowledge'' has become manifest. But: how are these dynamics in the network arrangements between industries, governments, and academia a consequence of the user–producer interactions foregrounded by Lundvall (1988)? Are national systems still a relevant unit of analysis? Since the new mode of knowledge production (Mode 2) is characterized as an outcome, it should, in our opinion, be considered as an emerging system. The emerging system rests like a hyper-network on the networks on which it builds (such as the disciplines, the industries, and the national governments), but the knowledge-economy transforms ''the ship while a storm is raging on the open sea'' (Neurath et al., 1929).

Science has always been organized through networks, and to pursue practical as well as theoretical interests. Centuries before ''Mersenne'' was transmogrified into an Internet site, he was an individual, who by visits and letters, knitted the European scientific community together. The Academies of Science played a similar role in local and national contexts from the 16th century.

The practical impetus to scientific discovery is long-standing. The dissertation of Merton (1938) reported that between 40% and 60% of discoveries in the 17th century could be classified as having their origins in trying to solve problems in navigation, mining, etc. Conversely, solution of practical problems through scientific means has been an important factor in scientific development, whether in German pharmaceutical science in the 17th century (Gustin, 1975) or in the British-sponsored competition to provide a secure basis for navigation (Sobel, 1995).

The so-called Mode 2 is not new; it is the original format of science before its academic institutionalization in the 19th century. Another question to be answered is why Mode 1 has arisen after Mode 2: the original organizational and institutional basis of science, consisting of networks and invisible colleges (cf. Weingart, 1997; Godin, 1998). Where have these ideas, of the scientist as the isolated individual and of science separated from the interests of society, come from? Mode 2 represents the material base of science, how it actually operates. Mode 1 is a construct, built upon that base in order to justify autonomy for science, especially in an earlier era when it was still a fragile institution and needed all the help it could get.

In the USA, during the late 19th century, large fortunes were given to found new universities, and expand old ones. There were grave concerns among many academics that the industrialists making these gifts would try to directly influence the universities, by claiming rights to hire and fire professors as well as well as to decide what topics were acceptable for research and instruction (Storr, 1953). To carve out an independent space for science, beyond the control of economic interests, a physicist, Henry Rowland, propounded the doctrine that if anyone with external interests tried to intervene, it would harm the conduct of science. As president of the American Association for the Advancement of Science, he promoted the ideology of pure research in the late 19th century. Of course, at the same time as liberal arts universities oriented toward pure research were being founded, land grant universities, including MIT, pursued more practical research strategies. These two contrasting academic modes existed in parallel for many years.

Decades hence, Merton posited the normative structure of science in 1942 and strengthened the ideology of "pure science." His emphasis on universalism and skepticism was a response to a particular historical situation, the need to defend science from corruption by the Nazi doctrine of a racial basis for science and from Lysenko's attack on genetics in the Soviet Union. Merton's formulation of a set of norms to protect the free space of science was accepted as the basis for an empirical sociology of science for many years.

The third element in establishing the ideology of pure science was, of course, the Bush Report of 1945. The huge success of science in supplying practical results during World War II in one sense supplied its own legitimation for science. But with the end of the war at hand and wanting to insure that science was funded in peacetime, a rationale was needed in 1944 when Bush persuaded President Roosevelt to write a letter commissioning the report (Bush, 1980).

In the first draft of his report, Bush proposed to follow the then current British method of funding science at universities. It would be distributed on a per capita basis according to the number of students at each school. In the contemporary British system of a small number of universities, the funds automatically went to an elite. However, if that model had been followed in the US, even in the early postwar era, the flow of funds would have taken a different course. The funding would not only have flowed primarily to a bicoastal academic elite but would have been much more broadly distributed across the academic spectrum, especially to the large state universities in the Midwest.

In the time between the draft and the final report, the mechanism for distribution of government funds to academic research was revised and "peer review" was introduced. Adapted from foundation practices in the 1920s and 1930s, it could be expected that "the peers", the leading scientists who would most surely be on those committees, would distribute the funds primarily to a scientific elite. The status system of U.S. universities that had been in place from the 1920s was reinforced.

This model of "best science" is no longer acceptable to many as the sole basis for distribution of public research funds. Congresspersons who represent regions with universities that are not significant recipients of research funds have disregarded peer review and distributed research funds by direct appropriation, much as roads and bridges are often sited through "log rolling" and "pork barrel" processes. Nevertheless, these politically directed funds support also serious scientific research and instrumentation projects. Even when received by schools with little or no previous research experience, these ''one-time funds'' are typically used to rapidly build up competencies in order to compete within the peer-review system.

Indeed, when a leading school, Columbia University, needed to renew the infrastructure of its chemistry department, it contracted with the same lobbying firm in Washington, DC as less well-known schools. Through public relations advice, Columbia relabeled its chemistry department ''The National Center for Excellence in Chemistry''. A special federal appropriation was made and the research facilities were renovated and expanded. To hold its faculty, the university could not afford to wait for the slower route of peer review, and likely smaller amounts of funding.

Increasing competition for research funds among new and old actors has caused an incipient breakdown of ''peer review'', a system that could best adjudicate within a moderate level of competition. As competition for research funds continues to expand, how should the strain be adjusted? Some propose shrinking the research system; others suggest linking science to new sources of legitimation such as regional development.

6. The future legitimation of science

It is nowadays apparent that the development of science provides much of the basis for future industrial development. These connections, however, have been present from the creation of science as an organized activity in the 17th century. Marx pointed them out again in the mid-19th century in connection with the development of chemical industry in Germany. At the time, he developed a thesis of the growth of science-based industry on the basis of a single empirical example: Perkins researches on dyestuffs in the UK leading to the development of an industry in Germany.

The potential of science to contribute to economic development has become a source of regional and international competition at the turn of the millennium. Until recently, the location of research was of little concern. The relationship between the site where knowledge is produced and its eventual utilization was not seen to be tightly linked, even as a first mover advantage. This view has changed dramatically in recent years, as has the notion that high-tech conurbations, like Route 128 and Silicon Valley, are unique instances that cannot be replicated. The more recent emergence of Austin, TX, for example, is based in part on the expansion of research at the University of Texas, aided by state as well as industry and federal funds.

Less research-intensive regions are by now well aware that science, applied to local resources, is the basis of much of their future potential for economic and social development. In the USA, it is no longer acceptable for research funds to primarily go to the east and west coasts with a few places in between in the Midwest. The reason why funding is awarded on bases other than the peer review system, is that all regions want a share of research funding.

The classic legitimation for scientific research as a contribution to culture still holds and military and health objectives also remain a strong stimulus to research funding. Nevertheless, the future legitimation for scientific research, which will keep funding at a high level, is that it is increasingly the source of new lines of economic development.

Newly created disciplines are often the basis for these heightened expectations. Such disciplines do not arise only from the subdivision of new disciplines from old ones, as in the 19th century (Ben David and Collins, 1966). New disciplines have arisen, more recently, through syntheses of practical and theoretical interests. For example, computer science grew out of elements of older disciplines such as electrical engineering, psychology, philosophy, and a machine. Materials science and other fields such as nanotechnology that are on every nation's critical technology list were similarly created.

The university can be expected to remain the core institution of the knowledge sector as long as it retains its original educational mission (Etzkowitz, Webster, Gebhardt, and Terra, this issue). Teaching is the university's comparative advantage, especially when linked to research and economic development. Students are also potential inventors. They represent a dynamic flow-through of ''human capital'' in academic research groups, as opposed to more static industrial laboratories and research institutes. Although they are sometimes considered a necessary distraction, the turnover of students insures the primacy of the university as a source of innovation.

The university may be compared to other recently proposed contenders for knowledge leadership, such as the consulting firm. A consulting company draws together widely dispersed personnel for individual projects and then disperses them again after a project, solving a client's particular problem, is completed. Such firms lack the organizational ability to pursue a cumulative research program as a matter of course. The university's unique comparative advantages is that it combines continuity with change, organizational and research memory with new persons and new ideas, through the passage of student generations. When there is a break in the generations, typically caused by a loss of research funding, one academic research group disappears and can be replaced by another.

Of course, as firms organize increasingly higher level training programs (e.g., Applied Global University at the Applied Materials Devices, a semiconductor equipment manufacturer in Silicon Valley) they might in the future also, individually or jointly, attempt to give out degrees. Companies often draw upon personnel in their research units, as well as external consultants, to do some of the teaching in their corporate universities. Nevertheless, with a few notable exceptions, such as the RAND, they have not yet systematically drawn together research and training into a single framework. However, as the need for life-long learning increases, a university tied to the workplace becomes more salient.

7. Implications of the Triple Helix model

The Triple Helix denotes not only the relationship of university, industry and government, but also internal transformation within each of these spheres. The university has been transformed from a teaching institution into one which combines teaching with research, a revolution that is still ongoing, not only in the USA, but in many other countries. There is a tension between the two activities but nevertheless they coexist in a more or less compatible relationship with each other because it has been found to be both more productive and cost effective to combine the two functions.

The Triple Helix overlay provides a model at the level of social structure for the explanation of Mode 2 as an historically emerging structure for the production of scientific knowledge, and its relation to Mode 1. First, the arrangements between industry and government no longer need to be conceptualized as exclusively between national governments and specific industrial sectors. Strategic alliances cut across traditional sector divides; governments can act at national, regional, or increasingly also at international levels. Corporations adopt ''global'' postures either within a formal corporate structure or by alliance. Trade blocks like the EU, NAFTA, and Mercosul provide new options for breaking ''lock-ins'', without the sacrifice of competitive advantages from previous constellations. For example, the Airbus can be considered as an interactive opportunity for recombination at the supra-national level (Frenken, this issue).

Second, the driving force of the interactions can be specified as the expectation of profits. ''Profit'' may mean different things to the various actors involved. A leading edge consumer, for example, provides firms and engineers with opportunities to perceive ''reverse salients'' in current product lines and software. Thus, opportunities for improvements and puzzle-solving trajectories can be defined. Note that analytically the drivers are no longer conceptualized as ex ante causes, but in terms of expectations that can be evaluated only ex post. From the evolutionary perspective, selection (ex post) is structure determined, while variation may be random (Arthur, 1988; Leydesdorff and Van den Besselaar, 1998).

Third, the foundation of the model in terms of expectations leaves room for uncertainties and chance processes. The institutional carriers are expected to be reproduced as far as they have been functional hitherto, but the negotiations can be expected to lead to experiments which may thereafter also be institutionalized. Thus, a stage model of innovation can be specified.

The stages of this model do not need to correspond with product life cycle theory. Barras (1990), for example, noted that in ICT ''a reverse product life'' cycle seems to be dominant. Bruckner et al. (1994) proposed niche-creation as the mechanism of potential lock-out in the case of competing technologies. A successful innovation changes the landscape, that is, the opportunity structure for the institutional actors involved. Structural changes in turn are expected to change the dynamics.

Fourth, the expansion of the higher-education and academic-research sector has provided society with a realm in which different representations can be entertained and recombined in a systematic manner. Kaghan and Barnett (1997) have used in this context the term ''desktop innovation'' as different from the laboratory model (cf. Etzkowitz, 1999). Knowledge-intensive economies can no longer be based on simple measures of profit maximization: utility functions have to be matched with opportunity structures. Over time, opportunity structures are recursively driven by the contingencies of prevailing and possible technologies. A laboratory of knowledge-intensive developments is socially available and can be improved upon (Etzkowitz and Leydesdorff, 1995). As this helix operates, the human capital factor is further developed along the learning curves and as an antidote to the risk of technological unemployment (Pasinetti, 1981).

Fifth, the model also explains why the tensions need not to be resolved. A resolution would hinder the dynamics of a system which lives from the perturbations and interactions among its subsystems. Thus, the subsystems are expected to be reproduced. When one opens the black-box one finds Mode 1 within Mode 2, and Mode 2 within Mode 1. The system is neither integrated nor completely differentiated, but it performs on the edges of fractional differentiations and local integrations. Using this model, one can begin to understand why the global regime exhibits itself in progressive instances, while the local instances inform us about global developments in terms of the exceptions which are replicated and built upon.

Case materials enable us to specify the negative selection mechanisms reflexively. Selection mechanisms, however, remain constructs. Over time, the inference can be corroborated. At this end, the function of reflexive inferencing based on available and new theories moves the system forward by drawing attention to possibilities for change.

Sixth, the crucial question of the exchange media — economic expectations (in terms of profit and growth), theoretical expectations, assessment of what can be realized given institutional and geographic constraints — have to be related and converted into one another. The helices communicate recursively over time in terms of each one's own code. Reflexively, they can also take the role of each other, to a certain extent. While the discourses are able to interact at the interfaces, the frequency of the external interaction is (at least initially) lower than the frequency within each helix. Over time and with the availability of ICT, this relation is changing.

The balance between spatial and virtual relations is contingent upon the availability of the exchange media and their codifications. Codified media provide the system with opportunities to change the meaning of a communication (given another context) while maintaining its substance (Cowan and Foray, 1997). Despite the ''virtuality'' of the overlay, this system is not ''on the fly'': it is grounded in a culture which it has to reproduce (Giddens, 1984). The retention mechanism is no longer given, but ''on the move'': it is reconstructed as the system is reconstructed, that is, as one of its subdynamics.

As the technological culture provides options for recombination, the boundaries of communities can be reconstituted. The price may be felt as a loss of traditional identities or alienation, or as a concern with the sustainability of the reconstruction, but the reverse of ''creative destruction'' is the option of increasing development. The new mode of knowledge production generates an endless transition that continuously redefines the borders of the endless frontier.

8. The organization of the theme issue

As noted above, this issue is organized in three main parts, addressing (1) institutional transformation, (2) evolutionary mechanisms, and (3) the second academic revolution. Each part contains five contributions.

In Part One (Institutional Transformations), Michael Nowak and Charles Grantham open the discussion with a paper about the impact of the Internet on incubation as an institutional mechanism for technological innovation. The increased complexity of the process induces reflexivity about the choices to be made, and human capital becomes increasingly crucial for carrying the transformations.

The failure of the ''opening to the market'' as an answer to the state-dominated economies in the former Soviet Union, because of the neglect of the knowledge-intensive dimension, is discussed by testing three models against each other in Judith Sedaitis' paper entitled ''Technology Transfer in Transitional Economies: Comparing Market, State, and Organizational Frameworks''. The author concludes that processes of transfer in these cases can be understood at the intermediate network level.

Norma Morris, in ''Vial Bodies: Conflicting Interests in the Move to New Institutional Relationships in Biological Medicines Research and Regulation'', discusses normative issues that arise when the borders are no longer defined institutionally and governmentally. The case of the EU places the role of safety regulation at national and transnational levels on the agenda. In a paper entitled ''The Evolution of Rules for Access to Megascience Research Environments Viewed from Canadian Experience'', Cooper Langford and Martha Whitney Langford document what it means for the organization of Canadian science that government and industry relations are deeply involved in this enterprise. Are the Kudos-norms of Merton (1942) increasingly being replaced by a new set of norms (Ziman, 1994)? If so, what are the expected effects on reward systems and funding? In a contribution to the latter question, Shin-Ichi Kobayashi argues that a third form of funding can be distinguished nowadays (in addition to peer recognition and institutional allocation). The author develops the new format using the metaphor of the audition system for the performing arts.

Thus, not only the institutions themselves are transformed, but also their mechanisms of transformation. These evolutionary mechanisms are central to the second part of the theme issue. The contribution from the Aveiro team (Eduardo Anselmo de Castro, Carlos José Rodrigues, Carlos Esteves, and Artur da Rosa Pires) returns to the impact of ICT on changing the stage. How can institutional arrangements be shaped to match the options which telematics provide? How can a retention mechanism be organized as a niche or a habitat for knowledge-intensive developments?

While the Portuguese team focuses on the regional level, Susanne Giesecke takes the analysis to the level of comparing national governments in her contribution entitled ''The Contrasting Roles of Government in the Development of the Biotechnology Industries in the US and Germany''. She notes the counter-effective policies of German governments which have operated on the basis of assumptions about previous developments. Policies have to be updated in terms of bottom-up processes and thus come to be understood in terms of reflexive feedbacks (instead of control).

Rosalba Casas, Rebeca de Gortari, and Ma. Josefa Santos from Mexico combine the issues of regional developments and differences between the technologies involved by cross-tabling them for the case of Mexico. These authors focus on what they call ''the building of knowledge spaces''. How is the interrelationship between knowledge-intensity, industrial activity, and institutional control shaped in terms of interhuman and interinstitutional relations? What is the function of shared culture, values, and trust? Is the region a habitat for the technology, or the technology a precondition for restructuring the region?

In a contribution entitled ''The Triple Helix: An Evolutionary Model of Innovations'', Loet Leydesdorff uses simulations to show how a lock-in can be enhanced using a coevolution like the one between regions and technologies. A third source of random variation, however, may intervene, reversing the order in a later stage and leading to more complex arrangements of market segmentation (that is, different suboptima). A mechanism for lock-out can also be specified.

Koen Frenken takes the complexity approach one step further by confronting it with empirical data in the case of the aircraft industry. Using Kauffman's (1993) model of ''rugged fitness landscapes'' he shows the working of a Triple Helix in different phases of this industry (cf. Frenken and Leydesdorff, forthcoming). The model can be extended to account for the additional degree of freedom in international collaborations to develop new aircraft. The failure of Fokker Aircraft, for example, can be explained using these concepts: one cannot bet on two horses at the same time, since the markets are fiercely competitive, technological infrastructures are expensive, and learning curves are steep.

In the third part of the issue, we turn to the second academic revolution. In their contribution entitled ''The Place of Universities in the System of Knowledge Production'', Benoît Godin and Yves Gingras argue against the thesis that the university would have lost its salient position in the university–industry–government relations of Mode 2. Using scientometric data, they show that collaboration with academic teams is central to the operations of the networks which transform this knowledge infrastructure. Although based on Canadian data, the argument is made that this holds true also for other OECD countries.

From another world region, Judith Sutz reports about university–industry–government relations in Latin America. These young democracies, on one hand, wish to free themselves from the limitation of the so-called ''import substitution'' regime by opening up to the market. On the other hand, the connections are then established through the world system, and regional infrastructures tend to remain underdeveloped. The issue will be central to the Third Triple Helix Conference to be held in Rio de Janeiro, 26–29 April 2000. How can social, economic, and scientific developments be networked at the regional level? What does niche management mean in an open system's environment?

In a contribution entitled ''Institutionalizing the Triple Helix: Research Funding and Norms in the Academic System'', Mats Benner and Ulf Sandström take a neo-institutional approach to the transformation of the university system in Europe. How does the system react (resist and embody) institutional transformation and neo-evolutionary pressures? In a further article, Eric Campbell and his colleagues raise the question of how this affects research practices in terms of ''Data Withholding in Academic Medicine''. Can characteristics of faculty denied access to research results and biomaterials be distinguished?

In a final article, Henry Etzkowitz, Andrew Webster, Christiane Gebhardt, and Branca Terra substantiate their claim that the transformation of the university system is a worldwide phenomenon. In addition to research and higher eduction, the university nowadays has a third role in regional and economic development because of the changing nature of both knowledge production and economic production. While a ''hands off'' may have been functional to previous configurations, the exigencies of today demand a more intensive interrelationship. As noted, a Triple Helix arrangement that tends to reorganize the knowledge infrastructure in terms of possible overlays, can be expected to be generated endogenously.

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References

Alchian, A.A., 1950. Uncertainty, evolution, and economic theory. Journal of Political Economy 58, 211–222.

Andersen, E.S., 1994. Evolutionary Economics: Post-Schumpeterian Contributions. Pinter, London.

Arthur, W.B., 1988. Competing technologies. In: Dosi, G., Freeman, C., Nelson, R., Silverberg, G., Soete, L. (Eds.), Technical Change and Economic Theory. Pinter, London, pp. 590–607.

Barras, R., 1990. Interactive innovation in financial and business services: the vanguard of the service revolution. Research Policy 19, 215–237.

Ben David, J., Collins, R., 1966. Social factors in the origins of new science: the case of psychology. American Sociological Review 3, 45–85.

Benner, M., Sandström, U., this issue. Institutionalizing the Triple Helix: research funding and norms in the academic system, Research Policy.

Berman, M., 1982. All that is Solid Melts into Air: The Experience of Modernity. Simon and Schuster, New York.

Braczyk, H.-J., Cooke, P., Heidenreich, M. (Eds.), Regional Innovation Systems. University College London Press, London.

Bruckner, E., Ebeling, W., Jiménez Montaño, M.A., Scharnhorst, A., 1994. Hyperselection and innovation described by a stochastic model of technological evolution. In: Leydesdorff, L., Van den Besselaar, P. (Eds.), Evolutionary Economics and Chaos Theory: New Directions in Technology Studies. Pinter, London, pp. 79–90.

Bush, V., 1980. The Endless Frontier: A Report to the President, reprinted by Arno Press, New York (1945).

Callon, M., 1998. An essay on framing and overflowing: economic externalities revisited by sociology. In: Callon, M.

(Ed.), The Laws of the Market. Macmillan, London, pp. 244–269.

Cowan, R., Foray, D., 1997. The Economics of Codification and the Diffusion of Knowledge. MERIT, Maastricht.

Cozzens, S., Healey, P., Rip, A., Ziman, J. (Eds.), 1990. The Research System in Transition. Kluwer Academic Publishers, Boston.

Dasgupta, P., David, P., 1994. Towards a new economics of science. Research Policy 23, 487–522.

David, P.A., Foray, D., 1994. Dynamics of competitive technology diffusion through local network structures: the case of EDI document standards. In: Leydesdorff, L., Van den Besselaar P. (Eds.), Evolutionary Economics and Chaos Theory: New Directions in Technology Studies. Pinter, London, pp. 63–78.

Etzkowitz, H., 1999. Bridging the gap: the evolution of industry–university links in the United States. In: Branscomb, L., Kodama, F. (Eds.), Industrializing Knowledge: University–Industry Linkages in Japan and the United States. MIT Press, Cambridge, MA.

Etzkowitz, H., forthcoming. The Second Academic Revolution: MIT and the Rise of Entrepreneurial Science. Gordon & Breach, London.

Etzkowitz, H., Leydesdorff, L., 1995. The triple helix–university–industry–government relations: a laboratory for knowledge-based economic development. EASST Review 14 (1), 14–19.

Etzkowitz, H., Leydesdorff, L. (Eds.), 1997. Universities in the Global Economy: A Triple Helix of University–Industry–Government Relations. Cassell Academic, London.

Etzkowitz, H., Gulbrandsen, M., Levitt, J., 2000. Public Venture Capital: Government Funding Sources for Technology Entrepreneurs. Harcourt-Brace, New York.

Freeman, C., 1982. The Economics of Industrial Innovation. Pinter, London.

Freeman, C., Perez, C., 1988. Structural crises of adjustment, business cycles and investment behaviour. In: Dosi, G., Freeman, C., Nelson, R., Silverberg, G., Soete, L. (Eds.), Technical Change and Economic Theory. Pinter, London, pp. 38–66.

Frenken, K., this issue. A complexity approach to innovation networks. The case of the aircraft industry (1909–1997). Research Policy.

Frenken, K., Leydesdorff, L., forthcoming. Scaling trajectories in civil aircraft (1913–1997). Research Policy.

Gibbons, M., Limoges, C., Nowotny, H., Schwartzman, S., Scott, P., Trow, M., 1994. The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies. Sage, London.

Giddens, A., 1984. The Constitution of Society. Polity Press, Cambridge.

Godin, B., 1998. Writing performative history: is this a new Atlantis?. Social Studies of Science 38 (3), 465–483.

Godin, B., Gingras, Y., this issue. The Place of Universities in the System of Knowledge Production. Research Policy.

Government–University–Industry Research Roundtable GUIRR, 1998. National Science and Technology Strategies in a Global Context. Report of an International Symposium. National Academy Press, Washington, DC. <http://bob.nap.edu/readingroom/books/nst/>

Gustin, B., 1975. The emergence of the German chemical profession, 1790–1867. PhD dissertation, University of Chicago.

Hughes, T.P., 1983. Networks of Power: Electrification of Western Society 1880–1930. Johns Hopkins Univ. Press, Baltimore, MD.

Kaghan, W.N., Barnett, G.B., 1997. The desktop model of innovation. In: Etzkowitz, H., Leydesdorff, L. (Eds.), Universities in the Global Economy: A Triple Helix of University–Industry–Government Relations. Cassell Academic, London, pp. 71–81.

Kampmann, C., Haxholdt, C., Mosekilde, E., Sterman, J.D., 1994. Entrainment in a disaggregated long-wave model. In: Leydesdorff, L., Van den Besselaar, P. (Eds.), Evolutionary Economics and Chaos Theory: New Directions in Technology Studies. Pinter, London, pp. 109–124.

Langton, C.G. (Ed.), 1989. Artificial Life. Addison Wesley, Redwood City, CA.

Leydesdorff, L., 1995. The Challenge of Scientometrics: The Development, Measurement, and Self-organization of Scientific Communications. DSWO Press, Leiden University, Leiden.

Leydesdorff, L., 1997. The non-linear dynamics of sociological reflections. International Sociology 12, 25–45.

Leydesdorff, L., Etzkowitz, H., 1996. Emergence of a Triple Helix of university–industry–government relations. Science and Public Policy 23, 279–286.

Leydesdorff, L., Etzkowitz, H., 1998. The Triple Helix as a model for innovation studies. Science and Public Policy 25 (3), 195–203.

Leydesdorff, L., Oomes, N., 1999. Is the European monetary system converging to integration?. Social Science Information 38 (1), 57–86.

Leydesdorff, L., Van den Besselaar, P., 1997. Scientometrics and communication theory: towards theoretically informed indicators. Scientometrics 38, 155–174.

Leydesdorff, L., Van den Besselaar, P., 1998. Competing technologies: lock-ins and lock-outs. In: Dubois, D.M. (Ed.), Computing Anticipatory Systems, Proceedings of the American Institute of Physics 437. American Institute of Physics, Woodbury, NY, pp. 309–323.

Luhmann, N., 1984. Soziale Systeme. Grundriß einer allgemeinen Theorie (Suhrkamp, Frankfurt am Main). [Social Systems (Stanford University Press, Stanford) 1995].

Lundvall, B.-Å., 1988. Innovation as an interactive process: from user–producer interaction to the national system of innovation. In: Dosi, G. Freeman, C., Nelson, R., Silverberg, G., Soete, L. (Eds.), Technical Change and Economic Theory. Pinter, London, pp. 349–369.

Lundvall, B.-Å. (Ed.), 1992. National Systems of Innovation. Pinter, London.

MacLane, S., 1996. Should universities imitate industry?. American Scientist 84 (6), 520–521.

Maturana, H.R., 1978. Biology of language: the epistemology of reality. In: Miller, G.A., Lenneberg, E. (Eds.), Psychology and Biology of Language and Thought. Essays in Honor of Eric Lenneberg. Academic Press, New York, pp. 27–63.

McKelvey, M.D., 1996. Evolutionary Innovations: The Business of Biotechnology. Oxford Univ. Press, Oxford.
Merton, R.K., 1938. Science, Technology and Society in Seventeenth Century England. Sainte Catherine Press, Burges.
Merton, R.K., 1942. Science and technology in a democratic order. Journal of Legal and Political Sociology 1, 115–126.
Mills, C.W., 1958. The Power Elite. Oxford Univ. Press, New York.
Mowery, D.C., Rosenberg, N., 1979. The influence of market demand upon innovation: a critical review of some empirical studies. Research Policy 8, 102–153.
Nelson, R.R. (Ed.), 1982. Government and Technical Progress: A Cross-Industry Analysis. Pergamon, New York.
Nelson, R.R. (Ed.), 1993. National Innovation Systems: a Comparative Study. Oxford Univ. Press, New York.
Nelson, R.R., 1994. Economic growth via the coevolution of technology and institutions. In: Leydesdorff, L., Van den Besselaar, P. (Eds.), Evolutionary Economics and Chaos Theory: New Directions in Technology Studies. Pinter, London, pp. 21–32.
Nelson, R., Winter, S., 1975. Growth theory from an evolutionary perspective: the differential productivity growth puzzle. American Economic Review 65, 338.
Nelson, R.R., Winter, S.G., 1982. An Evolutionary Theory of Economic Change. Belknap Press, Cambridge, MA.
Neurath, O., Carnap, R., Hahn, H., 1929. Wissenschaftliche Weltauffassung-Der Wiener Kreis. Veröffentlichungen des Vereins Ernst Mach, Vienna.
OECD, 1980. Technical Change and Economic Policy. OECD, Paris.
Pasinetti, L., 1981. Structural Change and Economic Growth. Cambridge Univ. Press, Cambridge.
Pavitt, K., 1984. Sectoral patterns of technical change: towards a theory and a taxonomy. Research Policy 13, 343–373.
Rip, A., VanderMeulen, B., 1996. The post-modern research system. Science and Public Policy 23 (6), 343–352.
Rosenberg, N., Nelson, R.R., 1994. American universities and technical advance in industry. Research Policy 23, 323–348.
Rothwell, R., Zegveld, W., 1981. Industrial Innovation and Public Policy. Pinter, London.
Sábato, J., 1975. El pensamiento latinoamericano en la problemática ciencia–technología–desarrollo-dependencia. Paidós, Buenos Aires.
Sábato, Jorge, Mackenzi, M., 1982. La Producción de Technología. Autónoma o Transnacional. Nueva Imagen, Mexico.
Schumpeter, J., 1964. Business Cycles: A Theoretical, Historical and Statistical Analysis of Capitalist Process. McGraw-Hill, New York [1939].
Schumpeter, J., 1966. Invention and Economic Growth. Harvard University Press, Cambridge, MA.
Sobel, D., 1995. Longitude. Penguin, Harmondsworth.
Storr, R., 1953. The Beginnings of Graduate Education in America. University of Chicago Press, Chicago.
Weingart, P., 1997. From ''Finalization'' to ''Mode 2'': old wine in new bottles?. Social Science Information 36 (4), 591–613.
Ziman, J., 1994. Prometheus Bound: Science in a Dynamic Steady State. Cambridge Univ. Press, Cambridge.