Triple Helix of innovation: Introduction

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The Triple Helix of Innovation

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A triple helix of overlapping, yet relatively independent institutional spheres is required to capture contemporary innovation processes. The triple helix model attempts to account for a synthesis between opposing principles in which new resolutions are found that allow several tasks to be accomplished, even as each influences the other. Thus the opposition between basic research and applied research is superseded by the development of "strategic basic research" combining steering and autonomy, as relative rather than absolute dimensions. We also increasingly see organizations in different institutional spheres taking each the role of the other. For example, universities in regions that lack governmental structures can serve as a "regional innovation organizer" (RIO), encouraging the creation of connections between academic research and local industry (Gebhardt and Etzkowitz, 1996; De Rosa Pires and De Castro, 1997).

The Triple Helix model is formulated not at the level of the phenomena to be explained, but as a model for helping with the explanation. In this sense, it is a methodological tool: the focus on the recursive overlay of communications among universities, industries, and governments allows for the organization of research questions in relation to the various models and metaphors. Which subdynamics are addressed in which studies? To what extent are the case studies informative beyond the specificities of their local contexts? What does it mean when the dynamics of innovation upset the tendencies towards equilibrium in the market (Nelson and Winter 1982)? Or, what does it mean that the overlay of a network system feeds back on "natural trajectories" of technological innovation? How is the proposed "Mode 2" model of research (Gibbons *et al.* 1994) different from the traditional "Mode 1" (Weingart 1997; Godin 1998)? These questions require empirical research and the results of such research demand a framework for theoretical appreciation.

Methodologically, this framework has to encompass both multivariate and dynamic explanations. The Triple Helix is sufficiently complex as a model to account for the various underlying dynamics in double and single helices, as well as for the possibility of a trilateral overlay. Double helices are expected to lead to co-evolutions in processes of mutual shaping as in processes of (co-)evolution. For example, the lock-in between a technology and its institutions may drive a technology life-cycle (Nelson 1994; cf. Freeman and Perez 1988).

Evolution, Reconstruction, and Revolution

The process of cultural evolution adds a reflexive layer to the "natural" phenomena. Both the systems under study and their "natural" environments can be reconstructed. For example, the institutional environments of biotechnology have been developed as this technology emerged (McKelvey 1997). As reflexivity is further pursued and institutionalized in terms of systematic R&D, a knowledge-based economy is increasingly generated. Science-based innovations continuously reshape systems at more than a single level (cf. Schumpeter 1943). Turpin and Garret-Jones (1997) have used in this context the concept of a "systematic disorganization" of existing innovation networks during the 1980s.

The social system of communications is more dynamic than systems which are artificially engineered or biologically given (Luhmann 1984; cf. Weber [3]1968). The process of cultural evolution based on reflexive discourse can be traced back to the scientific revolution of the 17th century and the foundations of modernity (Giddens 1990), but it has been thoroughly modified by the process of enlightened rationalization and industrialization, by the formation of nation states and the institutionalization of science, by the scientific-technical revolution and the emergence of modern corporations, and by post World War II developments. Nowadays, lateral networks and "strategic alliances" supplement and even supersede large corporations as the primary sites of innovative activities.

The exemplar of innovation has shifted from the "technostructure" to the "startup firm." Drawing upon individuals and groups from different institutional spheres for its complement of human capital, the startup process exemplifies the trend away from the vertical and toward the lateral as the fundamental principle of social organization. The individual inventor has re-emerged from the corporate habitus, even as high-tech design shops morph into large manufacturing companies while retaining much of the collegial culture of the academic research groups from which many of them emerged (McElheny, 1998: 142).

Institution-formation is a necessary complement and corrective to theories of random, stochastic processes of social change. The reverse side of the coin of "creative destruction" (Schumpeter, 1943: 81-86) is "institution-formation" (Etzkowitz, 1970): the design and construction of new organizational formats as well as the reformation of old ones. For example, the origins of academic technology transfer modalities have been specified as a synthesis of initiatives and the resistance to these initiatives, eventually codified by government (Etzkowitz, 1999). As traditional structures are renovated or displaced by new ones, institution-building capacities and capabilities become a renewed focus of attention.

The Contextualization of S&T policies

The concepts of R&D management and S&T policies were a result of the events around World War II. R&D projects for developing radar, the proximity fuse, and the atomic bomb can be considered as precursors of Mode 2 and Triple Helix research. On the basis of a strong corporate industry (e.g., in aviation), large-scale research facilities, and orchestration by the U.S. national government, a new type of mission-oriented R&D and innovation was generated.

Scientists from the MIT "Rad Lab," for example, went into the battlefields as observers on airplanes equipped with radar sets to see how the crews were using them, and they fed their experience back into the designs before the radar sets went into mass production (Buderi 1997). Similarly, engineers from manufacturing companies came to the research site at MIT to start designing production lines before the designs were finalized. A "seamless web" of technology transfer and feedback loops from R&D to production could be maintained under the condition of the war effort.

After the war this innovation system could not serve as a political metaphor for the stimulation of civilian innovation. Vannevar Bush's famous report *The Endless Frontier* (1945) defined science as functionally different from market forces. The institutional phase of a science policy then legitimated the creation of large R&D budgets within national agencies that pursued scientific and technological development for both civil and military purposes (e.g., England 1982).

The neat division of tasks along functional lines, weakly coordinated at the national level, obscured the crucial role of R&D in the economy. The 1957 Soviet launch of Sputnik I came as a surprise and was perceived not only as a challenge to the U.S., but to capitalism and democracy as economic and social systems. In response, an element of planning from above was instituted in the guise of science and technology policy. The President's Science Advisory Council and other mechanisms such as the Advanced Research Projects Agency (ARPA) in the Department of Defense were established to insure U.S. technological competitiveness in the military and space arenas (Eisenhower 1965; York 1971).

The economic role of R&D and higher education was revealed in studies of post-war growth (e.g., Solow 1957, OECD 1964). During the 1960s, the OECD took the lead in developing and coordinating S&T policies among the advanced industrialized democracies. The assumption at the time was, however, that S&T policies had to remain national, although loosely coordinated at the level of intergovernmental organizations like the OECD and NATO.

Even in the face of the emerging environmental crises of the late 1960s, the emphasis on functional differentiation within national systems remained dominant. For example, in the so-called Harvey Brooks report entitled *Science, Growth, and Society* (1971), "science for policy" and "policy for science" were emphatically distinguished as different domains.

The oil crises of the 1970s shifted the terms of reference. The role of government in industrialization and innovation policies became redefined (Rothwell and Zegveld 1981). Innovation policies challenged interface management and systems integration. The new models were further legitimated by the newly emerging science technologies, as became increasingly clear when several top-down initiatives in energy research were regarded with hindsight as relative failures (e.g., Van den Daele *et al.* 1977; Jagtenberg 1983; Dits 1988).

Biotechnology, information and communication technologies, computer sciences, and new materials research cut across existing (e.g., disciplinary) delineations within the scientific community. These new techno-sciences require an entrepreneurial bottom-up model *and* a network mode. A bottom-up planning model was typically instituted in programs like the Small Business Innovation Research grant program (SBIR) and the Advanced Technology Program (ATP). Meetings were called at regular intervals from the mid-1980s bringing together university, company, and government representatives to identify "reverse salients" (Hughes 1983). These were competitive grants programs to which individual firms and consortia of university, government, and industrial research groups could usefully address their projects (Gulbrandsen and Etzkowitz, in press).

In summary, S&T policies had to step back from the model of a strong state and government. Policies had to be developed that were both liberal and neo-corporatist (Rothwell and Zegveld 1981; OECD 1988). The dynamics became complex, enabling partners to draw up a research agenda in an interactive and reflexive mode. At the level of the intellectual research agenda, the focus on interfaces was reflected by introducing the network model as a dominant metphor for technology studies during the 1980s (e.g., Callon *et al.* 1986). Evolutionary economists, however, stressed the rigidities created by trajectories within the economy (Nelson and Winter 1977; Dosi 1982), whereas some policy analysts had emphasized the interactive and feedback terms in so-called chain-linked models of innovation (Kline and Rosenberg 1986).

These various models all belong analytically to the domain of non-linear dynamics, but different terms are emphasized in the theoretical apparatus (Leydesdorff and Van den Besselaar 1998). For example, the trajectory approach is based on recursive (e.g., Markov chain) models, while the network models emphasize the fluidity of technological developments in relation to historical contexts. A focus on the operation of innovation systems in terms of their internal interactions leads to the Triple Helix model, which enables us to explain both the recursive axes and the resulting fluidities.

The Triple Helix of university-industry-government relations

The evolutionary perspective has to be enriched with sociological and methodological reflections before one can achieve analytical clarity about the relative value of the different models for innovation studies. In addition to the interaction terms between the different phases of the innovation process and the different agencies involved, each of these interactants has its own history. The specific histories can be accounted for in terms of a recursive model. Any two dynamics may drift into a co-evolution; lock-ins are then expected because of "network externalities" (David 1985; Arthur 1988). Furthermore, historical accounts tend to "follow the actors" (Latour 1987), while the evolutionary perspective focuses on the system in the present and assesses its rigidities ("stabilizations") by backtracking (Blauwhof 1994). How, why, and when do the historically generated constraints of the systems under study condition their further developments?

The network of university-industry-government relations continuously restructures the opportunity matrix of a complex system which itself is the result of the reconstruction from different angles by each of the participating instances. All agencies are embedded in discourses at different levels, that is, within their respective institutions, at the specific interfaces between the helices, and at generalized levels where third actors may come into play. The reflections are only partially synchronized by the network of relations, thus enabling the participants to find niches in the knowledge-based economy (cf. Bruckner *et al.* 1994).

At the analytical level, the specification of the systems of reference and the reflexive angles taken by the analysts are significant in defining the relevance of their respective contributions. Is the analysis pursued from a policy perspective (e.g., at the national level; cf. Potì, *this issue*), or should it be considered as mainly a single (in-depth) case history (e.g., Leventman 1998)? From another perspective, the analyst may focus on the complexities of the system at a certain moment in time by comparing among cases (e.g., Jones-Evans and Klofsten, *this issue*). The various reflections are expected to take different angles, follow different time horizons, and use different bodies of literature and knowledge for their reflexive assessments.

The super-systemic question (from the "Triple Helix overlay" perspective) evaluates how and why the various reflections are able to contribute to the sustainability of technological developments in relevant communities. These relevant communities can no longer be defined substantively or prescriptively, for example, at the national level (cf. Lundvall 1992; Nelson 1993). Policy objectives are expected to vary, for example, between metropolitan areas and less developed regions. Sustainability increasingly means that the emerging system of expectations can be recognized reflexively as non-alienating, community-constructing, and in need of influx and throughflux of human capital as the main resource of a knowledge-based economy (Leydesdorff and Etzkowitz 1998). These criteria are formal, and the assessment has therefore to be substantiated with case studies, empirical research, and theoretical analysis.

The Endless Transition

The poly-contextuality of technological innovation in this model means, among other things, that as a methodology the Triple Helix provides a meeting place between high-quality (that is, reflexively elaborated) contributions to the theme of University-Industry-Government Relations. Thus, the model can be used as a discursive tool for integrating the contributions by trying to organize them in terms of the expected subdynamics of the complex system. The different contributions, however, are founded at the same time in their own scholarly traditions. The Triple Helix as a scholarly enterprise itself builds reflexively on these disciplines in terms of what they contribute to the theme issue.

As a metaphor for public policy, the Triple Helix model makes us aware of the reflexive, and thereby limited character of policy discourse among other discourses. The policy inputs are expected to gain in quality and therefore in effectiveness as the reflection of the systems under study can be improved. Note that effectiveness means here something different from efficiency: a direct relation between input and intended output is no longer assumed, since the systems are expected to contain also their own dynamics. The policy metaphors induce unintended consequences given the dynamics and the complexities of the systems of innovation. The carriers of the metaphors have to fight the blindness of the metonyms, which is part of the expectation (Kaghan and Barnett 1997).

With monitoring and reflexive awareness, the quality of policy inputs can benefit from discursive improvement. The policy incentives can be improved by taking the expectations into account. The evaluations can then be made more systematic. New questions can be added to the research agenda. This process cannot come to a halt in a knowledge-based economy because of the inherent uncertainties in the discourses. The model challenges the systems to take a proactive role, although their information is by definition incomplete and based on past experiences.

The historical development of university-industry-government relations develops an overlay of mutual expectations. The various discourses continously evaluate historical contingencies in terms of their relevance for future development. The communication at this level is both institutionally defined and functionally differentiated, that is, in terms of economic utility, R&D, and control functions. For example, one is able to differentiate which integrations need further interface management and which can perhaps be left to market forces--and in which stages. The various partners are able to assume each other's roles reflexively, and thus they may recombine perspectives into synergies.

For example, industry and academic respresentatives on the boards of the National Science Foundation sponsored Industry/University Cooperative Research Centers (IUCRC) take each others goals and objectives into account in formulating joint projects and work programmes for their respective Centers (Leventman, 1998). Of course, each side also maintains its own stream of independent research projects. Transcending "epistemic drift" (Elzinga, 1992) is the consensus that over time there is a fructifying mutual influence, both intellectual and practical, among the participating academic research groups and firms. Recognizing the utility of a Triple Helix, industry has requested that NSF maintain its evaluatory and legitimating role in the IUCRC centers beyond the originally conceived five year time limit for government seed funding.

The institutional and the functional levels operate upon each other selectively during processes of mutual adjustment. For example, one is able to reorganize an institutional arrangement with reference to its functionality for further development, whereas one selects among possible combinations of expectations on the basis of institutional strengths and weaknesses. The two levels provide the necessary variation for making mutual selection processes possible. Such a dual-layered system may propel its own dynamics in a process of self-organization or "autopoiesis" (Maturana and Varela 1980; Luhmann 1994).

The two layers are complex in themselves: the functional differentiation among economic, political, and scientific considerations, and the institutional interfaces among industries, academic disciplines, and government offices constitute sufficient variation for the mutual selections, and these dynamics can further be reinforced by interaction terms. While it is volatile as a system of communications, society is also continuously in need of institutional reproduction. The continuation is based on the internal differentiation, while the different (sub-)dynamics integrate by using their (selective) operations, that is, by invoking their specific codes.

Unification at the European level, for example, generates an inter-institutional network among the various national innovation systems that interacts with the functional networks of research activities, small business enterprises, and fluidity at the global level, in the case of emerging techno-sciences like biotechnology (McKelvey 1997). Fingerprints of these interactions between networks can be retrieved in the case of documents with European addresses as opposed to document sets with American and Japanese addresses (Leydesdorff and Heimeriks 1998).

The ongoing adjustments bring all relevant systems of reference into flux, and transition is expected as the mode of operation of the resulting dynamics. Changes at the institutional level open up new expectations in terms of possible recombinations. The communication of expectations allows for codification, which may lead to new institutionalizations or changes in existing ones. Human agency in different roles is entrained in this complex dynamics since it is the source of the reflexivity needed to maintain the evolutionary momentum. The consequent social system operates in a distributed (network) mode which is ultimately beyond the control of any of the participating agents.

Control remains, however, a relevant category at each moment. It is a consequence of the need for reproduction of the dynamics. However, one has to invest in the quality of the contribution if one wishes to stay on top of the developments. All participants are able to communicate recursively so long as they are able to improve on their contributions, that is, in competition with other participants. Thus, the metaphor invites reflection on one's own position and for improving standards on the basis of reflexive assessments.

Organization of the theme issue

In their paper entitled "When path dependencies collide," Henry Etzkowitz, Jose Mello, and Branca Terra discuss the political history of technological development in the Brazilian region of Rio de Janeiro. The authors follow the actors in constructing the emerging knowledge infrastructure at the regional level. The study is based on extensive interview materials. The results indicate that new transitions and lock-outs from existing trajectories became possible when the various actors were challenged to communicate outside their traditional arenas. The policy system had to nourish the emerging niche and to take initiatives whenever the process seemed to stagnate.

We present this paper together with a contribution by Dylan Jones-Evans and Magnus Klofsten entitled "The Role of the University in the Technology Transfer Process -- A European View." These authors address a similar question, but from a perspective of hindsight and in relation to already established (European) innovation systems. Which transformations have to be implemented into regional systems of innovation so that they will be able to compete in the changing environments of the European market? How does this situation affect different national environments (in this case, Sweden and Ireland), and why?

Reinder van Duinen, the President of the Netherlands Research Organization (NWO) in The Hague, contributes a discussion of the results of a survey among European Research Councils about the changing conditions of funding decisions. As noted, the European context is affected both by changes at the global level, like the development of information and communication technologies, biotechnology, etc., and by the ongoing reorganizations among the nation states in relation to the emerging S&T policies of the European Commission. How do Research Councils take the more complex configurations into account? Van Duinen's conclusion is that the tendency is to be reactive. Suggestions for a more proactive role are formulated.

Yuko Fujigaki and Akiya Nagata (NISTEP, Tokyo) use co-word analysis to map the Japanese reflection of developments in science and technology policies over the longer time span since World War II. Theis paper is entitled "Concept Evolution in Science and Technology Policy: The process of change in relationships among university, industry, and government." The authors show two things: first, new word combinations indicate new policies, and the diffusion of words and co-words in different domains can be followed. Together the two analyses inform us about the dynamics of the systems under study.

For the purpose of this study, Fujigaki and Nagata have created an electronic database using full texts of policy documents. The specificities of the various character sets in Japanese allowed them to circumvent the problem of creating a baseline for the changing meaning of words as they are known from studies in English (Leydesdorff 1997). The recurrence of themes elegantly illustrates our discussion of the role of various metaphors in the science and technology policy debate.

Frances Anderson (Statistics Canada, Ottawa), in her contribution entitled "Where is Research Located in Canada? A Statistical Approach," discusses how existing indicators can be recombined in order to inform us about newly emerging questions relevant to the issue of university-industry-government relations. Indicators research has to be developed beyond comparing time series in terms of different, yet essentially uni-variate dimensions (e.g., percentage of GDP) and towards a multivariate model of funding that accounts for interaction terms.

Taking the context of the Italian national system of innovation, Bianca Potì (CNR, Rome) in her contribution analyzes the role of public sector research in industry, thus highlighting the dynamics at the interface. This study, entitled "The Role of the Public Research System in the Creation of National Wealth," is based on an extensive survey of Italian industries executed by the Centro Nazionale di Ricerca (CNR), yet within an OECD context. As opposed to the Brazilian context, the relevant subsystems like the Italian public research institutes are heavily entrained in existing trajectories. Optimization of their roles at the changing interfaces requires a dynamics different from that governing the optimization of institutions under construction for the purpose of transfer (Biggiero 1997; cf. Foray and Gibbons 1996).

In summary, by focusing both on national contexts and on a variety of relevant systems of reference for assessing R&D and innovation, we hope to inform policy makers and policy analysts about the potential of the Triple Helix model as a means of understanding processes of innovation. General recipes cannot be provided. Innovation is both poly-contextual and interactive. The various contexts are differently codified, but a reflexive perspective on these discourses can enrich our conceptualization of the processes under study.

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