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Guest Editorial

The Triple Helix of university–industry–government relations

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The Triple Helix of university–industry–government relations provides a neo-evolutionary model of the process of innovation that is amenable to measurement. Economic exchange, intellectual organization, and geographical constraints can be considered as different dynamics that interact in a knowledge-based economy as a complex system. Differentiation spans the systems of innovation, while performative integration enables organizations to retain wealth from knowledge. Because of the systematic organization of interfaces among the subsystems under study, different perspectives can be expected in the reflection. Consequences for the heuristics, the research design, and normative implications are specified and the organization of the issue is further explained.

Introduction

The knowledge-based economy poses a number of challenges to the modeling and the measurement of its "knowledge base". The aim of this special issue is to address some of these challenges by using the Triple Helix model of university–industry–government relations (ETZKOWITZ & LEYDESDORFF, 2000). These relations span networks that enable and constrain fluxes of communication. The communications provide the dynamics to the system (LUHMANN, 1984; GIBBONS et al., 1994). Three functionally different sub-dynamics can be expected to span a knowledge-based innovation system: economic exchanges on the market, geographical variations, and the organization of knowledge (Figure 1). Along these axes differentiations continuously expand the system, while various forms of integration are historically organized at the interfaces.

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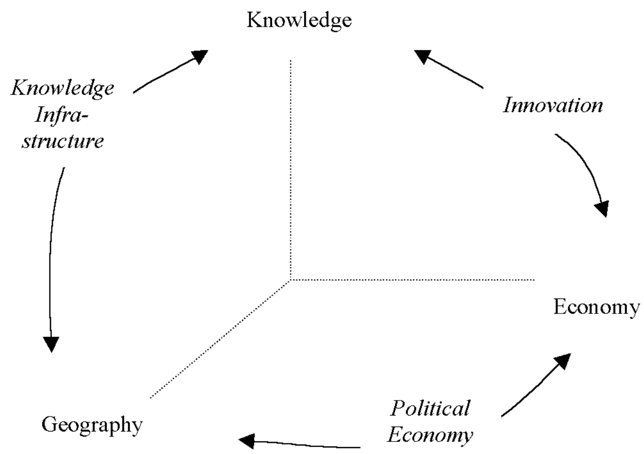

Figure 1. Three dynamics of a knowledge-based economy

For example, a political economy interfaces the economy within the geographical domain of a nation state (NELSON, 1993). Organized knowledge production, however, continuously upsets these historical arrangements (SCHUMPETER, [1939], 1964). In principle, dissemination in (semi–)markets can generate wealth from knowledge, but this global process has to be localized geographically (KRUGMAN, 1996).

The innovations first generate a "differential production growth puzzle" in the political economy. The various sectors of the economy grow at different speeds (NELSON & WINTER, 1975, 1977). These puzzles have continuously to be solved by equilibrium-seeking mechanisms. During the 20th century the knowledge production system became increasingly organized and controlled (NOBLE, 1977; WHITLEY, 1984). Furthermore, this subsystem has become increasingly interfaced with the economy, to the extent that the upsetting forces of innovation could no longer be contained within the institutional arrangements of a political economy.

The three subdynamics – which continue to develop recursively along their respective axes – are then expected to interact in the complex dynamics of a knowledge-based economy. This next-order system can also be considered as a technological regime. While a political economy provides an institutional infrastructure, the knowledge-based economy develops in terms of fluxes of communication through the networks. A technological regime, however, is expected to contain technological trajectories (DOSI, 1982). Trajectories can be stabilized wherever two of the three dynamics co-evolve in a process of mutual shaping. The third dynamic potentially meta-stabilizes a knowledge-based innovation system into its global regime.

For example, when a sector is innovated technologically, a "lock-in" into a market segment may shape a specific trajectory (ARTHUR, 1994). Learning curves are often steep (ARROW, 1962). In other words, the trajectory follows an "up-hill" search in the phase space of possible technological solutions (ALLEN, 1994; KAUFFMAN, 1993). Analogously, when a science-based technology locks into a national state (e.g., in the energy or health sector), a monopoly can be immunized against market forces for considerable periods of time. Over longer periods of time "lock-ins" can be expected to erode because of the ongoing processes of "creative destruction" (SCHUMPETER, 1943). This may also lead to crises (FREEMAN & PEREZ, 1988).

The dynamics of a complex system of innovations are non-linear. This non-linearity is a consequence of the interaction terms among the subsystems and the recursivity in each of them. The non-linear terms can be expected to outweigh the linear (action) terms in the longer run. For example, the *interaction* between "demand pull" and "technology push" may become more important for the systemic development of innovations than the linear action terms (KLINE & ROSENBERG, 1986; MOWERY & ROSENBERG, 1979, 1989). Historically, interactions among the subdynamics were first enhanced by geographical proximity (for example, within a national context), but as the system globalizes, the dynamic scale effects become more important than the static ones for the retention of wealth. Such dynamic scale effects through innovation were first realized by multinational corporations (GALBRAITH, 1967; GRANSTRAND et al., 1997; BRUSONI et al., 2000). They became a concern of governments in advanced industrialized countries after the oil crises of the 1970s (OECD, 1980).

The relatively stabilized system of a political economy endogenously generates the meta-stability of a knowledge-based system. Under certain conditions this system can be expected to oscillate into its globalization. The globalization of a knowledge-based economy reaches out to a next-order or regime level as an order of expectations (BERGER & LUCKMAN, 1966; LUHMANN, 1984). Innovation can be considered as the operator of this system (FUJIGAKI, 1998). The subsequent shift of focus from Science and Technology Indicators towards Innovation Indicators (OECD/EUROSTAT, 1997) has been reflected in the study of scientometrics, econometrics, and economic geography. In addition to relations among these intellectual traditions at the level of relevant methodologies (e.g., FRENKEN & LEYDESDORFF, 2000), patent indicators have been developed to specify the relations between the development of technologies and economic sectors (PAVITT, 1984) or the relations with geographical distributions (JAFFE

& TRAJTENBERG, 2002). However, an information-theoretical perspective on the knowledge content of innovations (NARIN & NOMA, 1985) has hitherto not been developed sufficiently (LEYDESDORFF, 2001A; MEYER, 2000).

The methodological problem of different perspectives at interfaces

While the economic and geographical analyses can consider knowledge-based innovations as variables in market systems, the information-theoretical approach of science and technology studies has to open the black box (ROSENBERG, 1982; GILBERT & MULKAY, 1984). From a knowledge-based perspective the performative events (e.g., knowledge-based innovation) can be deconstructed and compared with other possible events. This perspective focuses on the interactions among the codified discourses of other disciplines (COWAN & FORAY, 1997; WOUTERS, 1999) and therefore has to become reflexive about its own epistemological status as yet another perspective (ROSENBERG, 1976, MULKAY et al., 1984; LEYDESDORFF, 2001b).

Each of the subdynamics can be studied by using a discursive metaphor that reduces the phenotypical complexity into a geometry. For example, evolutionary economists are interested in studying how technological change and stabilization are brought about over time, while neo-classical economists are mainly interested in the market equilibrating mechanisms at each moment in time. Analogously, in science studies we have witnessed debates between sociologists mainly interested in the practices of knowledge production at the laboratory bench (EDGE, 1979) and others who noted the asymmetries between local communication and the transformation of knowledge claims when competing for validation (GILBERT & MULKAY, 1984). The various metaphors span universes which are potentially incommensurate.

The epistemological reflection becomes increasingly urgent when we move from science to studying science-based innovation or science policy issues at interfaces. In general, innovations take place at interfaces, and interfaces can be approached from two sides by definition (LEYDESDORFF, 1994; WOUTERS, 1999). The systems of reference can thus be different, and in this case the same indicators can be expected to have different meanings. Within scientometrics, for example, one is aware of the tension between indicators (e.g., citations) which are useful for science-policy making and the use of these same indicators in information retrieval.

A complex system develops in terms of fluxes through the networks. These can be modeled in simulations, for example, by using difference or differential equations. However, the structural constraints have first to be specified theoretically and empirically. In order to specify the equations empirical data have to be appreciated.

There remains a tension between parameter estimation and scientometric data analysis because the problem is approached from the opposing sides of an epistemological interface. The epistemological interfaces reflect on the interfaces in the systems under study, but using different angles (LEYDESDORFF & SCHARNHORST, 2003).

The Triple Helix model of innovation

Three models have been proposed for the study of knowledge-based innovation systems: (i) the distinction of 'Mode 2' type of knowledge production as opposed to disciplinary knowledge production in 'Mode 1' (GIBBONS et al., 1994; NOWOTNY et al., 2001); (ii) the model of 'national systems of innovation' in evolutionary economics (FREEMAN, 1988; LUNDVALL, 1988, 1992; NELSON, 1993); and (iii) the Triple Helix model of university–industry–government relations (ETZKOWITZ & LEYDESDORFF, 2000). The three models differ analytically in terms of how the integration into a system and the differentiation among its components are conceptualized.

The authors of the 'Mode 2' thesis (GIBBONS et al., 1994) have argued that the postmodern constellation has led to a de-differentiation of the relations between science, technology, and society. Internal codification mechanisms (like 'truth-finding') are discarded by these authors as an 'objectivity trap' (NOWOTNY et al., 2001, pp. 115 ff.). From this perspective, all scientific and technical communication can be translated and then compared with other communication from the perspective of science, technology, and innovation policies (CALLON et al., 1986; LATOUR, 1987).

In our opinion, the 'Mode 2' model focuses on the integration of representations, while the respresented systems can be expected to remain different and even differentiating in the long run (LUHMANN, 1984). The systems under study are asymmetrically integrated at the interfaces, for example, in the case of innovations. "Demand pull" and "technology push," for example, remain relevant, but as sub-dynamics. The subsystems are continuously interfaced because they have different substances in stock. However, they can be expected to restore their own order recursively by differentiating again in terms of their code of communication. The asymmetry of the differentiation is reproduced because the differences – potentially institutionalized in differentiations – provide the networked systems with complexity for a next round of competition for innovative integration.

In other words, differentiation and integration do not exclude each other, but rather depend on each other as different dimensions of the communication. The communication enables us to construct and sometimes stabilize an innovative integration, but the underlying structures compete both in terms of their definitions of social realities and in terms of the representations that can be constructed at the localizable interfaces. Systems of innovations solve the puzzles of how to interface different functions in the communication. These solutions and failures are manifest at the level of historical organization. However, the historical manifestations can be reshaped evolutionarily.

Evolutionary economists, secondly, have argued in favor of studying 'national systems of innovation' as another model. Indeed, they have provided strong arguments for this level as most relevant for the integration (LUNDVALL, 1992; NELSON, 1993; SKOLNIKOFF, 1993). However, these systems are continuously being restructured under the pressure of the global differentiation of expectations. For example, the transnational framework of the European Union has provided subnational regions with access to new resources (LEYDESDORFF et al., 2002). Others have argued that new technologies drive the shaping of new systems of innovation (CARLSSON & STANKIEWICZ, 1991).

Economies are interwoven at the level of markets and in terms of multinational corporations, sciences are organized internationally, and governance is no longer limited within national boundaries. The most interesting innovations can be expected to involve boundary-spanning mechanisms (e.g., the EU, the entrepreneurial university, new technologies, etc.). In sum, we concur with the 'Mode 2'-model in assuming a focus on communication as the driver of systems of organized knowledge production and control. However, the problem of structural differences among the communications and the organization of interfaces remains crucial to the understanding of innovation in a knowledge-based economy. The accumulated knowledge and options for further developments have to be retained by reorganizing institutional arrangements with reference to global markets.

The Triple Helix: an empirical program

The Triple Helix model of university–industry–government relations tries to capture the dynamics of both communication and organization by introducing the notion of an overlay of exchange relations that feeds back on the institutional arrangements. The institutions and their relations provide a knowledge infrastructure that (paradoxically) carries the knowledge base. Each of the helices develops internally, but they also interact in terms of exchanges of both goods and services, and in terms of their functions. Functional and institutional roles can be traded off on the basis of knowledge-based expectations as in the case of the "entrepreneurial university" (ETZKOWITZ et al., 2000).

The various dynamics have first to be distinguished and operationalized, and then they can also be measured. Economic transactions, for example, are different from scientific communications, but if both can be measured, one may also be able to model their relationships. The strength of this research program is that one can no longer generalize on the basis of unspecific denominators such as "the nation states" or "the influence of the Internet" since the evolving systems under study are complex and the terminologies can be deconstructed as hypotheses. Unintended consequences can also be expected. Empirical studies inform us about specific dimensions and interactions. But the Triple Helix model makes us reflexively aware that the provisionally contextualized dimensions remain relevant. The three subdynamics are expected to operate concurrently when producing modern science, technology, and innovation.

If the various subdynamics can be specified, one may also be able to develop simulation models on the basis of reconstructions in different dimensions. As noted, there is an intimate connection between the algorithmic evaluation of indicators and simulation studies. When analyzing knowledge-based systems, indicators study knowledge production and communication in terms of the traces that communications leave behind, while simulations try to capture the operations and their possible interactions. The common assumption is that knowledge production, communication, and control are considered as operations that change the materials on which they operate.

The historically observable units of analysis (e.g., patents) are supplemented reflexively with units of operation that can be specified on the basis of theoretical knowledge of the respective subdynamics. On the normative side, the Triple Helix model thus provides us with an incentive to search for possible tensions between the communication level ("the knowledge base") and the organizational level ("the knowledge infrastructure"). These frictions provide opportunities for innovation because the solutions that were stabilized hitherto can be considered as suboptimal from an evolutionary perspective.

The organization of the issue

The geographical perspective on systems of innovation

We begin this theme issue with an analysis of the best documented national system of innovation, that is, Sweden. In their paper entitled "Regional R&D Activities and Interactions in the Swedish Triple Helix," Rickard Danell and Olle Persson decompose this national system in terms of its 21 regions. A set of indicators is used to study the fluxes of patents, publications, and persons across regions and sectors. The conclusion states that knowledge tends to accumulate in regions with higher concentrations notwithstanding counteracting policies.

In her paper entitled "The Triple Helix as a Model to Analyze the Israeli Magnet Program and Lessons for Late-Developing Countries like Turkey," Devrim Goktepe compares Turkey and Israel as national systems of innovation. She raises the question of what the Turkish system can learn from the Israeli one. The differences in geography between the two economies leads her to question whether the model should be imitated at the national or the regional level of the Turkish innovation system.

In a third contribution to this section we turn to the global dimension. Arnold Verbeek, Koenraad Debackere, and Marc Luwel's study is entitled "Science cited in patents: A geographic 'flow' analysis of bibliographic citation patterns in patents." The authors compare the citation flows among the three world regions of the U.S., Europe, and Japan, in the cases of biotechnology and information technology. Options for the innovation policies of the European Union are formulated.

University–industry relations in a knowledge-based economy

The global dimension tends to resonate with increased knowledge-intensity. New structures were shaped first at the business end and then also on the academic side (ETZKOWITZ et al., 2000). In their study of "Large Firms and the Science/Technology Interface: Patents, Patent Citations, and Scientific Output of Multinational Corporations in Thin Films," Sujit Bhattacharya and Martin Meyer compare these globally operating enterprises in terms of how they differ in organizing their knowledge bases. Whether firms outsource to universities or develop the relevant knowledge base in-house, and how this can be evaluated in terms of cost avoidance is the theme of a study by Denis O. Gray and Harm-Jan Steenhuis. These authors focus on the institutional dimension of university-industry collaboration in terms of what this collaboration implies for the industries involved.

Liana Marina Ranga, Koenraad Debackere, and Nick von Tunzelman raise the question of the effect of collaborations with industry on the quality of basic research ("Entrepreneurial Universities and the Dynamics of Academic Knowledge Production: a case study of basic versus applied research in Belgium"). While this study focuses on the effects on basic research, Martin Meyer, Tatiana Goloubeva, and Jan Timm Utecht have surveyed academic inventors and analyzed their university-related patents as indicators of new formats in social relations with industry.

The final paper of this section returns to the macro-question of the effects of knowledge-based development on other economic parameters in regions. Susan Cozzens and Kamau Bobb use the Theil index for "Measuring the Relationship between High Technology Development Strategies and Wage Inequality." The study confirms the findings of Danell & Persson that knowledge-intensity tends to stimulate concentration. The authors formulate suggestions for counter-acting strategies from a welfare perspective.

The intellectual organization of knowledge-based innovations

A series of five papers discusses the development of indicators that focus on the exchange processes in the intellectual dimension and their measurement. Sujit Bhattacharya, Hildrun Kretschmer, and Martin Meyer's study entitled "Characterizing Intellectual Spaces between Science and Technology" analyzes patent references in terms of knowledge transfer. They use words and co-words to map these relations. Gaston Heimeriks, Marianne Hörlesberger, and Peter van den Besselaar develop a set of indicators for the "Mapping of Communications and Collaboration in Heterogeneous Research Networks". Advanced tools for the visualizations are also introduced. Wolfgang Glänzel and Martin Meyer analyze patents cited in the scientific literature as indicators of 'reverse' citation relations, that is, when science draws on technologies.

The two final contributions to the issue can be considered as more methodological than substantive. José Luis Ortega Priego contributes to the theme issue with a study that elaborates the Vector Space Model for the Triple Helix dimensionality. This methodology allows for a triangular representation. Loet Leydesdorff shows how the mutual information in three dimensions can be used as an indicator of the complex dynamics of university–industry–government relations.

Conclusion

The Triple Helix model provides us with an empirical program because contributions from the different theoretical perspectives can be appreciated as the specification of relevant subdynamics. The dimensionality of interfacing the dynamics of economic wealth generation, knowledge-based novelty production, and geographic variety enables us to position the contributions analytically without demanding an integration on the basis of an a priori assumption (like the nation state). From this perspective the role of theorizing becomes that of providing heuristics which can be applied to the study of historical puzzles and their solutions (SIMON, 1973).

The Triple Helix overlay perspective adds to the perspectives on which it builds. The solutions at interfaces found hitherto can be provided with relevance for formulating innovative options because the boundary-spanning mechanisms can be expected to change the systems from which they emerged given the conditions of a knowledge-based economy. The interactions between the organized interfaces (e.g., the political economy and the knowledge infrastructure) may generate knowledge at a next-order (global) level that feeds back on the local production processes of new knowledge (Figure 2). However, the knowledge production system is also changed because it is structurally interfaced with the economy after this path-dependent transition (DAVID & FORAY, 2002). The knowledge base feeds back on both the economic exchange and the organization of knowledge in innovation.

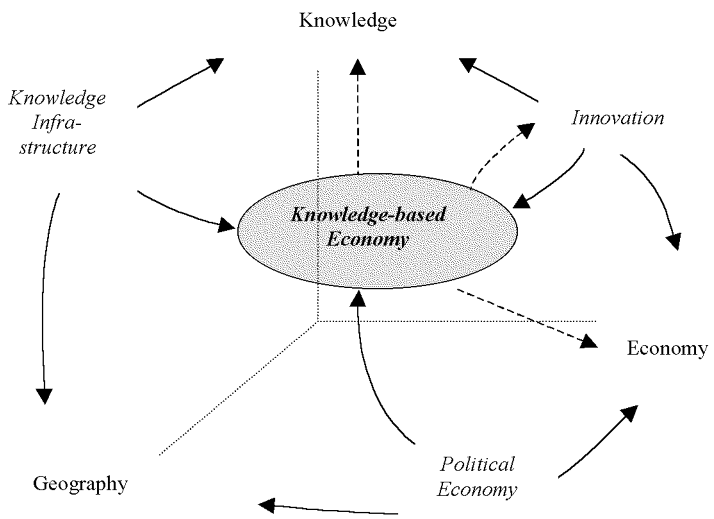

Figure 2. The interactions generate a knowledge-based economy as a next-order system

While hypotheses at the level of empirical case studies can often be specified with reference to a specific theory (e.g., about national or technological systems), the disciplinary frameworks function from this perspective as a mechanism of quality control (e.g., peer review). The exchange, however, adds to the disciplinary perspectives. For example, the study of patents as indicators in economic geography, business economics, or information retrieval inform one another, albeit from different disciplinary perspectives and with different criteria. The theme of innovation as evolutionary selections at interfaces thus brings together contributions from a variety of intellectual traditions.

As organizers of the scientometrics track of the Fourth Triple Helix Conference in Copenhagen (6-9 November 2002) we were extremely pleased to see scientometrics making such an important contribution to the development of theorizing about university–industry–government relations. We are grateful to the Editor of the journal *Scientometrics* for providing us with space to deviate from the usual focus of the journal, and hope that the contributions will stimulate further research about Triple Helix relations in the quantitative terms of scientometrics.

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