The Knowledge-Based Economy and the Triple Helix Model

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Few concepts introduced by evolutionary economists have been more successful than that of a 'knowledge-based economy' (Foray & Lundvall, 1996; Abramowitz & David, 1996; OECD, 1996). This assumption of a qualitative transition in economic conditions has become commonplace among policy-makers and mainstream economists. For example, the European Summit of March 2000 in Lisbon was specifically held "to agree a new strategic goal for the Union in order to strengthen employment, economic reform and social cohesion as part of a knowledge-based economy" (European Commission, 2000). The findings of this meeting concluded that, among other things, "the shift to a digital, knowledge-based economy, prompted by new goods and services, will be a powerful engine for growth, competitiveness and jobs. In addition, it will be capable of improving citizens' quality of life and the environment."[1]

The metaphor of a 'knowledge-based economy' has raised a number of hitherto unanswered questions. For example, can such a large impact on the real economy be expected from something as elusive and poorly defined as the knowledge base of an economy (Skolnikoff, 1993)? Should one consider this concept merely as a rhetorical reflection of the optimism regarding the potential impact of ICT and the Internet during the latter half of the 1990s (Godin, 2005)? How would a knowledge-based economy be expected to differ from a market economy or a political economy?

[1] See the Conclusions of the EU Presidency at http://www.europarl.eu.int/summits/lis1_en.htm#b .

In this study, I argue that one can expect a knowledge-based economy to exhibit dynamics different from those of a market-based or political economy. The systematic organization of knowledge production and control (Merton, 1973; Whitley, 1984) provides a third coordination mechanism to the social system in addition to the traditional mechanisms of economic exchange and political decision-making. From the perspective of complex systems and evolution theory, the interactions among these three coordination mechanisms can be expected to generate a knowledge base within the system.

1. What is the knowledge base of an economy?

How can a process such as the economy be based on something as ephemeral as 'knowledge'? In an introduction to a special issue on this topic, David & Foray (2002) voiced a caveat against using the metaphor of a knowledge-based economy. These authors cautioned that the terminology was coined recently and noted that "as such, it marks a break in the continuity with earlier periods, more a 'sea-change' than a sharp discontinuity" (*ibid*., p. 9). The authors suggest that the transformation can be analyzed at a number of different levels. Furthermore, 'knowledge' and 'information' should be more carefully distinguished by analyzing the development of a knowledge-based economy in terms of codification processes (Cowan & Foray, 1997; Cowan *et al*., 2000).

The focus of most economic contributions to the topic has hitherto remained on the *consequences* of knowledge-based developments, such as the impact of globalization on the relationships among competitors and among labor markets. The emergence of a knowledge-based economy is then invoked as a factor to explain historical developments and changes. However, the evolutionary dynamics of the knowledge base itself remain unexplained by these historical analyses. I do not wish to deny the social relevance of historical transitions and their impacts on the economy; on the contrary, my argument implies that knowledge-based dynamics can be expected to provide a coordination mechanism qualitatively different from the hitherto prevailing dynamics of politics and market-driven economics. The dynamic of knowledge production and control adds a degree of freedom to the complex system of social relations and coordination that needs to be explained. In other words, I focus on the knowledge base as an *explanandum* rather than as an *explanans* for its economic implications.

Under what conditions can a knowledge-based dynamics be expected to emerge in socio-economic systems? In order to operationalize, model, and eventually also measure the knowledge base of a system one must first flesh out the meaning of the concept. After the specification of the organization and codification of knowledge as an evolutionary mechanism, one is able to specify, among other things, why the emergence of a knowledge-based economy can be expected to induce 'globalization.' Why and how can a knowledge-based economy be considered a driving force of this social transformation. Furthermore, what can function as an indicator of the knowledge base operating within a system?

First, I will consider the theoretical side with a focus on the specification of knowledge-based innovation systems. Thereafter, I turn to the question of how the knowledge base can be operationalized and to whether this knowledge base can be measured and/or simulated. It will be argued that the concept of the knowledge base of an economy can be elaborated, and that this analysis results in an apparatus which provides a heuristics for empirical research and simulation studies.

2. The emergence of a knowledge base

Knowledge enables us to codify the *meaning* of information. Knowledge can be considered as a meaning which makes a difference. Some information can be more meaningful than other given a perspective. However, meaning is provided from the perspective of hindsight. Providing meaning to an uncertainty (that is, Shannon-type information) can be considered as a first codification. Knowledge enables us to discard some meanings and retain others in a second layer of codifications. Knowledge itself can also be codified and codified knowledge can, for example, be commercialized. Thus, a knowledge-based system operates in recursive loops that one expects to be increasingly selective.

The knowledge base of a social system can thus be further developed over time (Cowan & Foray, 2000). Knowledge operates in the present in terms of informed expectations. Increasingly, codified anticipations drive a knowledge-based economy rather than its historical conditions (Lundvall & Borras, 1997). In other words, science-based representations of possible futures (e.g., 'competitive advantages') feed back on the historical processes (Nonaka & Takeuchi, 1995). This orientation towards the future inverts the time axis locally. However, an inversion of the arrow of time may meta-stabilize a historically stabilized system. While stabilization and destabilization are historical processes, meta-stabilization potentially changes the dynamics of the system. A meta-stabilized system can under certain conditions be globalized (Coveney & Highfield, 1990; Mackenzie, 2001; Urry, 2003).

Before the emergence of a knowledge-based economy, the economic exchange of knowledge was first developed and stabilized as distinct from the exchange of commodities within the context of the market economy. For example, the patent system can be considered as a typical product of industrial competition in the late 19th century (Van den Belt & Rip, 1987). Patent legislation became crucial for regulating intellectual property when knowledge markets emerged increasingly in chemistry and later in electrical engineering (Noble, 1977). Patents package scientific knowledge so that new knowledge can function at the interface of science with the economy and be incorporated into knowledge-based innovations (Granstrand, 1999; Jaffe & Traitenberg, 2002). Patents thus provide a format for codifying knowledge contents for purposes other than the internal requirements of quality control in scientific communication.

The production and control of organized knowledge has existed as a subdynamic of the socio-economic system in advanced capitalist societies since approximately 1870 (Braverman, 1974; Noble, 1977). Schumpeter (1939) is well-known for his argument that the dynamics of innovation upset the market mechanism (Nelson & Winter, 1982). While market forces seek equilibrium at each moment of time, novelty production generates an orthogonal subdynamic along the time axis. This has been modeled as the difference between factor substitution (the change of input factors along the production function) versus technological development (a shift of the production function towards the origin) (Sahal, 1981). Technological innovations enable enterprises to reduce factor costs in both labor and capital (Salter, 1960).

Innovative change *over time* (novelty production) and economic substitution at each *moment of time* can thus be considered as two analytically independent subdynamics, but these subdynamics may interact in the case of innovation. Improving a system innovatively presumes that one is able to handle the system purposefully. When this reflection is further refined by organizing knowledge, the innovative dynamic can be reinforced. This reinforcement will occur at some *places* more than at others. Thus, a third dimension pertinent to our subject can be specified: the geographical—and potentially national—distribution of whatever is invented, produced, traded, and retained. Nation states, for example, can be expected to differ in terms of the relationship between the economy and their respective knowledge bases (Lundvall, 1992; Nelson, 1993). Different fields of science are organized nationally and/or internationally to varying degrees (Wagner & Leydesdorff, 2003; Walsh & Bayma, 1996).

Geographical units of analysis, economic exchange relations, and novelty production cannot be reduced to one another. However, they can be expected to interact to varying extents (Storper, 1997). Given these specifications one can create a model of the three dimensions and their interaction terms as follows:

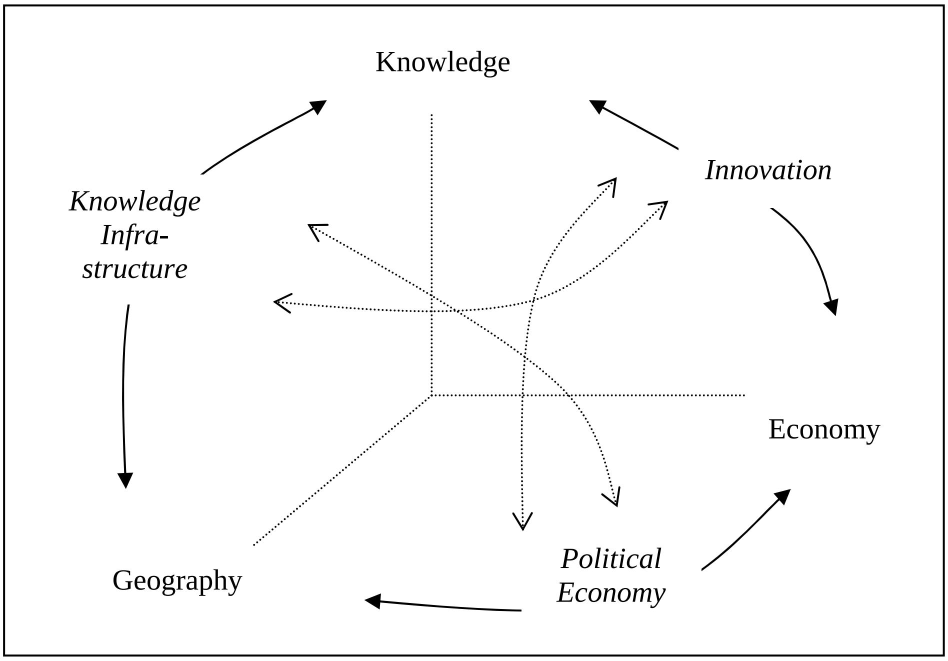

Figure 1: Three dimensions with their three first-order interaction terms.

The three dimensions will provide us below with different micro-operations of the social system because agents are (1) differently positioned, (2) can maintain exchange relations, and (3) learn from these relations with reference to their positions. Figure 1 elaborates the conceptualization by displaying the interaction terms between each two of the three dimensions. In a modern society, these interactions are no longer synchronized *ex ante*. A knowledge-based economy is continuously disturbed by interactions at various interfaces and fails to be at rest. Interactions among the subdynamics generate an evolutionary dynamics of transition *within* the system (Schumpeter, 1949).

In general, two interacting subdynamics can be expected to co-evolve along trajectories when the third dynamic is kept relatively constant. Over time, two subdynamics can lock-in into each other in a process of mutual shaping (Arthur, 1994; Callon *et al*., 2002; McLuhan, 1964). For example, during the formation of political economies in national systems during the 19th century knowledge production was first considered as a given (List, 1841; Marx, 1848, 1867).[2] Under the condition of constitutional stability in the various nation states after 1870, *national systems of innovation* could gradually be developed among the axes of economic exchange and organized knowledge production and control (Noble, 1977; Rosenberg, 1976 and 1982).

A hitherto stable context may begin to change historically. The erosion of relative stability in the nation states after World War II has thus changed the conditions of innovation systems. When three subdynamics can interact, behaviour of the resulting systems can become complex. For example, a previously relatively stabilized coevolution between production and diffusion capacities within a national system can then increasingly be the subject of conflicting conditions of the local production and the world market. The multinational corporation thus emerged during the 1950s. Alternatively, the other feedback term may globalize a historically stabilized trajectory of the technology into a technological regime (Dosi, 1982; Leydesdorff & Van den Besselaar, 1998).

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[2] Marx (1857) extensively discussed the technological condition of industrial capitalism. For example, he formulated as follows: "Nature does not build machines, locomotives, railways, electric telegraphs, selfacting mules, etc. These are the products of human industry; natural resources which are transformed into organs of the human control over nature or one's practices in nature. (…) The development of the fixed assets shows to what extent knowledge available at the level of society is transformed into immediate productive force, and therefore, to what extent the conditions of social life itself have been brought under the control of the general intellect and have been transformed accordingly. Crucial is the degree to which the socially productive forces are produced not only as knowledge, but as immediate organs of social practice, that is, of the real process of living" (Marx, 1857: 594; my translation). Thus, Marx's focus remained on the historical state of the development of science and technology, and the integration of this condition into the political economy.

When Lundvall (1988) proposed that the nation be considered as a first candidate for the *integration* of innovation systems, he formulated this claim carefully in terms of heuristics:

> The interdependency between production and innovation goes both ways. […] This interdependency between production and innovation makes it legitimate to take the national system of production as a starting point when defining a system of innovation. (Lundvall, 1988: 362)

The assumption of integrating innovation into production at the *national* level has the analytical advantage of providing us with an obvious system of reference. If the market is continuously upset by innovation, can the nation then perhaps be considered as another, albeit institutionally organized equilibrium (Aoki, 2001)? This specification of a stable system of reference enables the analyst to study, for example, the so-called 'differential productivity growth puzzle' which is generated by the different speeds of development among the industrial sectors (Nelson & Winter, 1975). This problem of the relative rates of innovation cannot be defined properly without the specification of a system of reference that integrates different sectors of an economy (Nelson, 1982, 1993). The solutions to this puzzle can accordingly be expected to differ among nation states.

The historical progression varies among countries, and integration at the national level still plays a major role in systems of innovation (Skolnikoff, 1993). However, the emergence of transnational levels of government like the European Union, as well as the increased awareness of regional differences within and across nations, have changed the functions of national governments (Braczyk *et al.*, 1998). 'Government' has evolved from a hierarchically fixed point of reference into a variable 'governance' that spans a variety of sub- and supranational levels. Larédo (2003) recently argued that this polycentric environment of stimulation has become even a condition for innovation policies in the European Union.

3. Interactive knowledge production and control

While a political economy can be indicated in terms of only two subdynamics (for example, as a 'dialectics' between production forces and production relations), a complex dynamics can be expected when three subdynamics are set free to operate upon one another (Li &

Yorke, 1975; Leydesdorff, 1994). It will be argued here that the new configuration of three possible degrees of freedom—markets, governance, and knowledge production—can be modeled in terms of a triple helix of university-industry-government relations (Etzkowitz & Leydesdorff, 1997; Leydesdorff & Etzkowitz, 1998). Governance can be considered as the variable that instantiates and organizes systems in the geographical dimension of the model, while industry is the main carrier of economic production and exchange. Thirdly, academe can play a leading role in the organization of the knowledge production function (Godin & Gingras, 2000).

In this (neo-)evolutionary model of interacting subdynamics, the institutional dimensions cannot be expected to correspond one-to-one with the functions in the network carried by and among the agencies. Each university and industry, for example, has also a geographical location and is therefore the subject of regulation and legislation. In a knowledge-based system, functions no longer develop exclusively at the local level, that is, contained within the institutional settings. Instead, the interactions generate evolutionary dynamics of change in the relations at the network level. In other words, university-industry-government relations develop in terms of institutional arrangements that recombine three functions of the socio-economic system: (1) wealth generation and retention, (2) novelty production, and (3) control at the interfaces of these subdynamics. The functions provide a layer of development analytically different, but historically coupled to the institutional arrangements.

The first two functions (economy and science) can be considered as relatively open and ‘universal’ (Parsons, 1951; Luhmann, 1984). However, the third function of normative control bends the space of possible interactions reflexively back to the position of the operating units (e.g., the firms and the nations) in the market place and at the research front, respectively. In this dimension, the question of what can be retained locally during the reproduction of the innovation processes becomes crucial. The advantages of entertaining a knowledge base can be incorporated only if the knowledge produced by the interacting fluxes can also be retained. In other words, the development of a knowledge base is dependent on the condition that knowledge production be socially organized.

The knowledge-base of an economy can be considered as a second-order interaction effect in the historical trade-offs between functions and institutions. In other words, the interfaces between institutions and functions can be expected to resonate into coevolutions in some configurations more than in others. However, these resonances remain incomplete because the coevolving subdynamics are continuously disturbed by the third one. Therefore, the knowledge base cannot be stabilized and should not be reified reflexively. It remains merely an order of expectations pending as selection pressure upon the local configurations. The expectations, however, can be further codified through the use of knowledge. Knowledge can increasingly be codified in textual practices, for example, as 'scientific knowledge.'

Thus, one can distinguish between the stabilization of innovations along *technological trajectories* and the knowledge base as a next-order *regime* that remains emergent (Dosi, 1982; Sahal, 1985). As innovations are further developed along trajectories, a knowledge base becomes reflexively available as the evolutionary mechanism for restructuring of the historical trajectories. The next-order perspective of a regime rests as an additional selection environment on the trajectories. In terms of the previous figure, this second-order system can be added as follows:

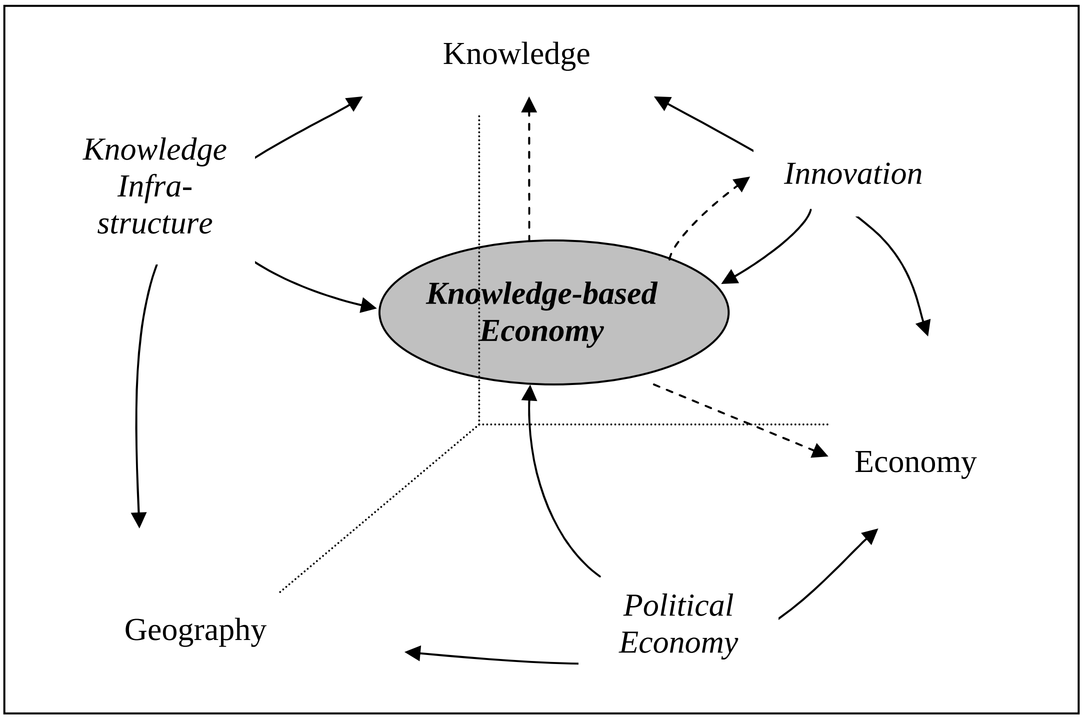

Figure 2: The first-order interactions generate a knowledge-based economy as a next-order system.

In summary, the carriers of a knowledge-based system entertain a dually layered network: one layer of institutional relations in which they constrain each other's behaviour historically and one layer of functional relations in which they shape each other's expectations with reference to the future. The second-order interaction term (the knowledge base) remains a historical result of the first-order interactions in the knowledge infrastructure. An evolving knowledge base can be developed under the condition that the various interactions be left free to seek their own resonances, that is, in a self-organizing mode. This self-organization among the functions exhibits a dynamics potentially different from the organization of relations among the institutions.

4. The globalization of knowledge production and control

The availability and growth of a knowledge base reinforces the capacity of the system to develop solutions that improve on combinations developed hitherto. However, the knowledge base remains a reflexive construct that emerges endogenously within the system and is expected to remain under reconstruction. It self-organizes under the conditions of the organizations upon which it is created as a second-order layer. However, these second-order interaction terms can be expected to reflect changes as the first-order interaction terms change. Thus, a knowledge base may be replaced when the organizations change dramatically during periods of historical transition such as in Eastern Europe (and China!) after the demise of the Soviet Union. The horizon of expectations then changes.

Interacting expectations can provide a basis for changes in the behavior of the carrying agents. These behavioral changes differ from the institutional imperatives and market incentives that have driven the system previously. While institutions and markets develop historically along the time axis, the knowledge-based structure of expectations drives the system in an anticipatory mode. Future-oriented planning cycles can be expected to become more important than current trends in the market. Thus, informed anticipations increasingly change the dynamics of the system from an agent-based perspective towards a more abstract knowledge-based one.

The social organization of knowledge production and control in R&D programs has reinforced this knowledge-based subdynamic in the last century. Knowledge refines the communication by adding codification as a selection mechanism over time (while markets select at each moment of time). In other words, institutional dynamics develop along historical trajectories, but the knowledge base can be expected to function evolutionarily as the technological regime of the same system. The emerging regime remains pending as anticipated selection pressure generated and reproduced by the interactions among the lower-level subdynamics. The three subdynamics—which continue to develop recursively along their respective axes—are expected to interact in the complex dynamics of a knowledge-based economy.

Using ICT as its main medium, the knowledge-based economy can be expected to continue to expand and grow. Each knowledge-based subdynamic operates by reconstructing the past in the present on the basis of representations that contain informed expectations (e.g., curves and functions on sheets of paper and computer screens). As the intensity and speed of communication among the carrying agencies increases, the codification of knowledge becomes a functional means to reduce the complexity in the communication. This emerging order of expectations remains accessible by reflexive agents. The expectations can be improved upon as they become more theoretically informed.

When the operation of a knowledge base is assumed, both participants and analysts are able to improve this understanding of the restructuring of the expectations at interfaces within the systems under study, which allows the codifications in the expectations to be further developed. For example, in a knowledge-based economy the price-mechanism of a market-based economy can increasingly be reconstructed in terms of price/performance ratios based on expectations about the life-cycles of technologies (Galbraith, 1967). Thus, more abstract and knowledge-intensive criteria are increasingly guiding economic and political decision-making.

5. The operation of the knowledge base

The dynamics of a complex system of innovations based on the effects of second-order interactions are by definition non-linear (Allen, 1994). This non-linearity is a consequence of interaction terms among the subsystems and the recursive processes operating within each of them simultaneously. In the long run, the non-linear (interaction) terms can be expected to outweigh the linear (action) terms. For example, the *interaction* effects between 'demand pull' and 'technology push' can over time become more important for the systemic development of innovations than the sum of the linear action terms (Kline & Rosenberg, 1986; Mowery & Rosenberg, 1979).

As noted, trajectories can be stabilized when two of the three subdynamics co-evolve in a process of mutual shaping. For example, when a sector is innovated technologically, a 'lock-in' into a market segment may first shape a specific trajectory of innovations (Arthur, 1994). Learning curves can be steep, following a breakthrough in the marketplace (Arrow, 1962; Rosenberg, 1982). The third subdynamic, however, potentially meta-stabilizes a knowledge-based innovation system into its global regime. From this latter perspective, it is possible to compare different trajectories, but only by using a theoretical model (Scharnhorst, 1998). The model provides a basis for discussing alternatives beyond what has historically been available.

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, however, these 'lock-ins' can be expected to erode because of the ongoing processes of 'creative destruction' (Schumpeter, 1943). Such creative destruction is based on recombinations of market forces with new insights (Kingston, 2003). Interaction effects among negative feedbacks, however, may lead to global crises that require the restructuring of the carrying layer of institutions (Freeman & Perez, 1988).

Historically, interactions among the subdynamics were first enhanced by geographical proximity (for example, within a national context or the context of a single corporation), but as the economic and technological dimensions of the systems globalized, dynamic scale effects became more important than 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 (global) oil crises of the 1970s (OECD, 1980). Improving the knowledge base in the economies of these nations became a priority as science-based innovations were increasingly recognized as providing the main advantages to these economies (Rothwell & Zegveld, 1981; Freeman, 1982; Porter, 1990).

In other words, the relatively stabilized arrangements of a political economy endogenously generate the meta-stability of a knowledge-based system when the geographical units begin to interact and exchange more intensively in the economic and technological dimensions. Under the condition that the institutional make-up of the national systems must be restructured, the national and the international perspectives can induce ‘an oscillation’ of a system between its stabilized and globalized states. The oscillating system uses its resources (e.g., innovation) for the continuation of this ‘endless transition’ (Etzkowitz & Leydesdorff, 1998). From this perspective, the stimulation programs of the European Union may have functioned as catalysts because these programs have reinforced interactions among universities, industries, and governance at a trans-national level (Frenken & Leydesdorff, 2004).

A previously stabilized system globalizes with reference to its next-order or regime level as an order of expectations. The knowledge base emerges by recursively codifying the expected information content of the underlying arrangements (Maturana & Varela, 1980; Fujigaki, 1998; Leydesdorff, 2001). Innovations can be considered as the historical carriers of this emerging system because they reconstruct and thus restabilize the relevant interfaces. Innovations instantiate the innovated systems in the present and potentially restructure existing interfaces in a competitive mode. In an innovative environment, the existing arrangements have to be continuously reassessed. For example, if one introduces high-speed trains, the standards and materials for constructing railways and rails may have to be reconsidered.

Once in place, a knowledge-based system thus feeds back on the terms of its construction by offering comparative improvements and advantages to the solutions found hitherto, that is, on the basis of previous crafts and skills. Knowledge-intensity drives differentiation at the global level by providing us with alternative possibilities. However, the emerging system continues to operate locally in terms of institutions and solutions that organize and produce observable integration across interfaces. The production facilities provide the historical basis for further developing the knowledge-based operations. The complex knowledge-based system tends to resonate into a regime as a basin of attraction, but along a historical trajectory. This trajectory is evolutionarily shaped as a series of solutions to puzzles.

The expectations are heavily structured and invested with interests in finding solutions to puzzles. Some authors (e.g., Gibbons *et al*., 1994; Nowotny *et al*., 2001) have claimed that the contemporary system exhibits de-differentiation among policy-making, economic transactions, and scientific insights due to the mutual 'contextualization' of these processes. These authors posit that a new mode of operation ('Mode 2') would have emerged at the level of the social system because of the dynamics of incorporating scientific knowledge. Indeed, the perpetual restructuring of the system which is guided by the knowledge base, can be expected to induce new institutional arrangements. Such rearrangements may include the temporary reversal of traditional roles between industry and the university, e.g., in interdisciplinary research centers (Etzkowitz *et al.*, 2000). Among codified expectations, however, exchanges are expected to remain highly structured and continue to reproduce also the differentiation for evolutionary reasons (Shinn, 2002).

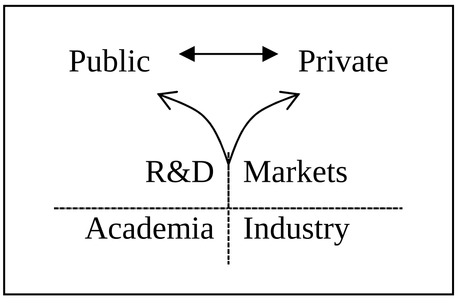

Figure 3: Vertical and horizontal interfaces allow for functional and institutional reorganization

Complex systems need both the *integration* of the various subdynamics into organizational formats (stabilization) and *differentiation* (globalization) in order to enhance further developments. This tension allows for meta-stabilization as a transitory state that can sustain both innovation and retention. In such systems, functions develop in interactions with one another and along their own axes, and thirdly in interaction with the exchanges among the institutions. At the interfaces between the economics of the market and the heuristics in R&D processes translation mechanisms can be further developed that structure and codify these interactions over time. I gave above the example of developing the price mechanism into the price/performance criterion, but in innovative environments one can expect all criteria to become multivariate. For example, knowledge-based corporations organize a sophisticated interface between strategic (long-term) and operational (medium-term) planning cycles in order to appreciate and to update the different perspectives (Galbraith & Nathanson, 1978).

Since social coordination, communication, and control in a knowledge-based system no longer provide a single frame of reference, integration and differentiation can be expected to operate concurrently at the various interfaces, but without *a priori* synchronization at the systems level. In terms of the dynamics of the system, differentiation and integration can thus be considered as two sides of the same coin: integration may take different forms and differentiations can be relatively integrated (as subsystems). From an evolutionary perspective, the question becomes, where in the network can the relevant puzzles be solved and hence competitive edges be maintained? Thus, one can expect both geographically confined innovation systems and technological systems of innovation (Carlson, 2002, 2004; Carlson & Stankiewicz, 1991; Edqvist, 1997). The horizontal and vertical overlapping of systems and subsystems of innovation can be considered a hallmark of the knowledge-based economy.

In other words, the definition of a system of innovations becomes itself increasingly knowledge-based in a knowledge-based economy since the subsystems are differently codified, yet interacting (at different speeds) in the reproduction of the system. Governance of a knowledge-based economy can only be based on a set of assumptions about the relevant systems. These assumptions are predictably in need of more informed revisions because one expects new formats to be invented at the hitherto stabilized interfaces.

6. Niches

While the market can be considered in a first approximation as an open network seeking equilibrium, innovation requires closure of the network in terms of the relevant stakeholders (Callon, 1998). Innovations are generated and incubated by locally producing units such as scientific laboratories, artisan workshops, and communities of instrument makers, but in interaction with market forces. This provides innovation with both a market dimension and a technological dimension. The two dimensions are traded off at interfaces: what can be produced in terms of technical characteristics versus what can be diffused into relevant markets in terms of service characteristics (Lancaster, 1979; Saviotti, 1996; Frenken, 2005). Thus, a competitive edge can be shaped locally. Such a locally shielded network density can also be considered as a *niche* (Kemp *et al*., 1998).

Systems of innovation can be considered as complex systems because they are based on maintaining interfaces in a variety of dimensions. Problems at interfaces may lead to costs, but they can be solved more easily within niches than in their surroundings. Unlike organizations, niches have no fixed delineations. They can be considered as densities of interfaces in an environment that is otherwise more loosely connected. Within a niche, competitive advantages are achieved by reducing transaction costs (Biggiero, 1998; Williamson, 1985). Niches can thus be shaped, for example, within the context of a multinational and diversified corporation or, more generally, within the economy. In another context, Porter (1990) proposed analyzing national economies in terms of *clusters* of innovation. Clusters may span vertical and horizontal integrations along business columns or across different types of markets. They can be expected to act as systems of innovation that proceed more rapidly than their relevant environments and thus are able to maintain a competitive edge.

Sometimes, the geographical delineation of systems of innovation in niches is straightforward, as in the case of the Italian industrial districts. These comprise often only a few valleys (Beccatini *et al.,* 2003; Biggiero, 1998). For political reasons one may wish to define a system of innovation *a priori* as national or regional (Cooke, 2002). However, an innovation system evolves, and its shape is therefore not fixed (Bathelt, 2003). While one may entertain the *hypothesis* of an innovation system, the operationalization and the measurement remain crucial for the validation (Cooke & Leydesdorff, 2005). For example, Riba & Leydesdorff (2001) were *not* able to identify a Catalonian system of innovations in terms of knowledge-intensive indicators such as patents and publications despite references to this regional system of innovation prevalent in the literature on the basis of occupational indicators (Braczyk *et al*., 1998).

'National systems of innovation' have been posited for a variety of reasons, for example, because of the need to collect statistics on a national basis and in relation to national production systems (Lundvall, 1988; Nelson, 1993). In the case of Japan (Freeman, 1988), or in comparisons among Latin-American countries (Cimoli, 2000), such a delineation may provide better heuristics than those of the nations participating in the common frameworks of the European Union (Leydesdorff, 2000). Systems of innovation can be expected to vary in terms of their strengths and weaknesses in different dimensions. While one would expect a system of innovations in the Cambridge region to be science-based (Etzkowitz *et al.*, 2000), the system of innovations of the Basque country is industrially based and reliant on technology centers that focus on applied research more than on universities for their knowledge base (Moso & Olazaran, 2002). The evaluation of a 'system of innovation' can also vary according to the different perspectives of policy making. While the OECD, for example, has focused on comparing national statistics, the EU has had a tendency to focus on changes in the interactions among the member states, for example, in trans-border regions.[3]

Belgium provides an interesting example of regional differentiation. The country has been regionalized to such an extent that one no longer expects the innovation dynamics of Flanders to be highly integrated with the francophone parts of the country. In general, the question of which dimensions are relevant to the specificities of which innovation system requires empirical specification and research (Carlson, 2004). However, in order to draw conclusions from such research efforts a theoretical framework is required. This framework should enable us to compare across innovation systems and in terms of relevant dimensions, but without an *a priori* identification of specific innovation systems. The systems under study provide the evidence, while the frameworks should carry the explanation of the differences.

Three such frameworks have been elaborated in innovation studies during the 1990s:

1. the approach of comparing (national) systems of innovation (Lundvall, 1988 and 1992; Nelson, 1993; Edqvist, 1997);
2. the thesis of a new 'Mode 2' in the production of scientific knowledge (Gibbons *et al.*, 1994; Nowotny *et al.*, 2001); and
3. the Triple Helix of University-Industry-Government relations (Etzkowitz & Leydesdorff, 1997, 2000; Leydesdorff & Etzkowitz, 1998).

[3] The Maastricht Treaty (1991) assigned an advisory role to the European Committee of Regions with regard to economic and social cohesion, trans-European infrastructure networks, health, education, and culture (Council of the European Communities, 1992). This role was further strengthened by the Treaty of Amsterdam in 1997, which envisaged direct consultations between this Committee of Regions and the European Parliament and extended the advisory role to employment policy, social policy, the environment, vocational training, and transport.

I submit that the Triple Helix can further be elaborated into an *evolutionary* model that accounts for interactions among three dimensions (cf. Lewontin, 2000; Ulanowicz, 1996). This generalized model will enable me to integrate three approaches: the 'Mode 2' thesis of the new production of scientific knowledge, the study of systems of innovation in evolutionary economics, *and* the neo-classical perspective on the dynamics of the market. In the Triple Helix model, the three micro-operations are first distinguished and then recombined.

7. Different micro-foundations

In their seminal study entitled 'In search of useful theory of innovation,' Nelson and Winter (1977) formulated their research program as follows:

> Our objective is to develop a class of models based on the following premises. First, in contrast with the production function oriented studies discussed earlier, we posit that almost any nontrivial change in product or process, if there has been no prior experience, is an innovation. That is, we abandon the sharp distinction between moving along a production function and shift to a new one that characterizes the studies surveyed earlier. Second, we treat any innovation as involving considerable uncertainty both before it is ready for introduction to the economy, and even after it is introduced, and thus we view the innovation process as involving a continuing disequilibrium. […] We are attempting to build conformable sub-theories of the processes that lead to a new technology ready for trial use, and of what we call the selection environment that takes the flow of innovations as given. (Of course, there are important feedbacks.) (Nelson & Winter, 1977: 48f.)

These two premises led these authors to a programmatic shift in the analysis from a focus on the specification of expectations to observable firm *behaviour* and the development of industries along historical trajectories (Andersen, 1994). Thus, a 'heterodox paradigm' was increasingly generated (Storper, 1997). However, this shift in perspective has had epistemological consequences.

Both the neo-classical hypothesis of profit maximization by the operation of the market and Schumpeter's hypothesis of the upsetting dynamics of innovations were formulated as analytical perspectives. These theories specify expectations. However, the theory of the firm focuses on observable variation. The status of the model thus changed: analytical idealizations like factor substitution and technological development cannot be expected to develop historically in their ideal-typical forms. Nelson & Winter's first premise proposed focusing on the observables not as an *explanandum*, but as *variation* to be selected in selection environments (second premise). Innovation is then no longer to be explained, but trajectory formation among innovations functions as the *explanandum* of the first of the two 'conformable theories.' Trajectories enable enterprises to retain competences in terms of routines. Under evolutionary conditions of competition, one can expect the variation to be organized by firms along trajectories. Thus, the knowledge base is completely embedded in the institutional context of the firm. The relations between the evolutionary and the institutional perspective were thus firmly engraved in the research program (Casson, 1997; Nelson, 1994).

The supra-institutional aspects of organized knowledge production and control are considered by Nelson & Winter (1977, 1982) as part of the selection environment. However, science and technology develop and interact at a global level with a dynamics different from institutional contexts (Leydesdorff, 2001). In the Nelson & Winter models, the economic uncertainty and the technological uncertainty cannot be distinguished other than in institutional terms (e.g., market versus non-market environments). The undifferentiated selection environments generate 'uncertainty' both in the phase of market introduction and in the R&D phase. Thus, the two sources of uncertainty are not considered as a consequence of qualitatively different selection mechanisms which use different codes for the selections. The potentially different selection environments—geography, markets, knowledge—are not specified as selective subdynamics that may interact in a non-linear dynamics (including coevolutions in organizational frameworks).

In other words, the models elaborated by Nelson & Winter were based on a biological model of selection operating blindly. Dosi (1982) added the distinction between 'technological trajectories' and 'technological regimes,' but his theory remained within the paradigm of Nelson & Winter's theory due to its focus on innovative firm behaviour, that is, variation. Others have extended on these models by using aggregates of firms, for example, in terms of sectors (e.g., Pavitt, 1984). However, the units of analysis remained institutionally defined.

In a thorough reflection on this 'post-Schumpterian' model, Andersen (1994) noted that firms (and their aggregates in industries) cannot be considered as the evolving units of an economy. He formulated his critique as follows:

> The limitations of Nelson & Winter's (and similar) models of evolutionary-economic processes are most clearly seen when they are confronted with the major alternative in evolutionary modeling which may be called 'evolutionary games.' […] This difference is based on different answers to the question of "What evolves?" Nelson and Winter's answer is apparently 'organisational routines in general' but a closer look reveals that only a certain kind of routines is taken into account. Their firms only interact in anonymous markets which do not suggest the playing of strategic games—even if the supply side may be quite concentrated. (Andersen, 1994: 144).

In summary, Nelson & Winter's models are formulated strictly in terms of the biological metaphor of variation and selection (Nelson, 1995). Variation is organized along trajectories using a set of principles which is—for analytical reasons—kept completely separate from selection. The selection environments are not considered as differentiated (and thus at variance). The various selection mechanisms do not interact. Technological innovation is considered as endogenous to firm behaviour. The technological component in the selection environments is consequently not appreciated as a global effect of the interactions among firms.

It is argued here that the knowledge base can be considered as an attribute of the economy as a system. Although selection environments cannot be observed directly, they can be hypothesized as structural (sub)dynamics. This hypothesis is theoretically informed, but the model then becomes more abstract than an institutional one which begins with the observables. As Andersen (1994) noted, studies about evolutionary games begin with highly stylized starting points. These abstract assumptions can be compared with and traded-off (e.g., in simulations) against other hypotheses, such as the hypothesis of profit maximization prevailing in neo-classical economics. For example, one can ask to what extent an innovation trajectory can be explained in terms of the operation of market forces, in terms of its own internal dynamics of innovation, and/or in terms of interactions among the various subdynamics.

If selection mechanisms other than market choices can be specified—for example, in organized knowledge production and control—the interactions between these selection mechanisms can be made the subject of simulation studies. From this perspective, the observables and the trajectories are considered as the historically stabilized results of selective structures operating upon one another. In other words, the selection mechanisms span a phase space of possible events. The evolutionary progression is a result of continually solving puzzles at the interfaces between the subdynamics. Thus, the routines and the trajectories can be explained from a systems-theoretical perspective.

7.1 User-producer relations in systems of innovation

In an evolutionary model one can expect mechanisms to operate along the time axis other than the one prompted by the neo-classical assumption of profit maximization at each moment of time. While profit maximization remains pervasive at the systems level, this principle cannot explain the development of rigidities in the market like trajectories along the time axis (Rosenberg, 1976). In an evolutionary model, however, this (potentially stabilizing) subdynamic has to be specified in addition to market clearing. Thus, a second selection environment over time is defined in an evolutionary model.[4]

In general, the number of selection mechanisms determines the dimensionality of the model. Innovations take place at interfaces and the study of innovation requires therefore at least the specification of two systems of reference (e.g., knowledge production and economic exchanges). It has been argued above that the emergence of a knowledge base requires the specification of three systems of reference. Before the three dynamics can interact, however, each selection mechanism has to be 'micro-founded' as an analytically independent operation of the complex system.

In his study about 'national systems of innovation' Lundvall (1988) argued that the learning process in interactions between users and producers provides a *micro-foundation* for the economy different from the neo-classical basis of profit maximization by individual agents. He formulated this as follows:

[4] The comparison among different states (e.g., using different years) can be used for the comparative static analysis, but the dynamics along the time axis are then not yet specified.

> The kind of 'microeconomics' to be presented here is quite different. While traditional microeconomics tends to focus upon decisions, made on the basis of a given amount of information, we shall focus upon a *process of learning*, permanently changing the amount and kind of information at the disposal of the actors. While standard economics tends to regard optimality in the allocation of a given set of use values as the economic problem, *par préférence*, we shall focus on the capability of an economy to produce and diffuse *use values with new characteristics*. And while standard economics takes an atomistic view of the economy, we shall focus upon the *systemic interdependence* between formally independent economic subjects. (Lundvall, 1988: 349f.)

After arguing that the interaction between users and producers belonging to the same national systems may work more efficiently for reasons of language and culture, Lundvall (1988: 360 ff.) proceeded by proposing the nation as the main system of reference for innovations. Optimal interactions in user-producer relations enable developers to reduce uncertainties in the market more rapidly and over longer stretches of time than in the case of less coordinated economies (Hall & Soskice, 2001; cf. Teubal, 1979). I have discussed this above when defining the function of niches.

Lundvall's theory about user-producer interactions as a micro-foundation of economic wealth production at the network level can be considered as a contribution beyond his original focus on national systems. The relational system of reference for the micro-foundation is different from individual agents with preferences. The concept of 'systems of innovation' was generalized to cross-sectoral innovation patterns and their institutional connections (Carlson & Stankiewicz, 1991; Edqvist, 1997; Whitley, 2001). User-producer relations contribute to the creation and maintenance of a system as one of its subdynamics. In an early stage of the development of a technology, for example, a close relation between technical specifications and market characteristics can provide a specific design with a competitive advantage (Rabehirosa & Callon, 2002).

In other words, proximity can be expected to serve the incubation of new technologies. However, the regions of origin do not necessarily coincide with the contexts that profit from these technologies at a later stage of development. Various Italian industrial districts provide examples of this flux. As local companies develop a competitive edge, they have tended to move out of the region, generating a threat of deindustrialization which has continuously to be countered at the regional level (Beccatini *et al*., 2003). This mechanism is further demonstrated by the four regions designated by the EU as ‘motors of innovation’ in the early 1990s. These regions—Catalonia, Lombardia, Baden-Württemberg, and Rhône-Alpes—were no longer the main loci of innovation in the late 1990s (Krauss & Wolff, 2002; Viale & Campodall’Orto, 2002). Such observations indicate the occurrence of a bifurcation resulting when the rate of diffusion becomes more important than the local production. Diffusion may reach the level of the global market, and thereafter the globalized dimension can feed back on local production processes, for example, in terms of deindustrialization. Given the globalization of a dominant design, firms may even compete in their capacity to destroy knowledge bases from a previous period (Frenken, 2005).

In summary, a system of innovation defined as a localized nation or a region can be analyzed in terms of the stocks and flows contained in this system. Control and the consequent possibility of appropriation of the competitive edge emerge from a recombination of institutional opportunities and functional requirements. In some cases and at certain stages of the innovation process, local stabilization in a geographic area may prove beneficial, for example, because of the increased puzzle-solving capacity in a niche. However, at a subsequent stage this advantage may turn into a disadvantage because the innovations may become increasingly locked into these local conditions. As various subdynamics compete and interact, the expectation is a more complex dynamics. Therefore, the institutional perspective on a system of innovation has to be complemented with a functional analysis.

7.2 ‘Mode 2’ in the production of scientific knowledge

The ‘Mode 2’ thesis of the new production of scientific knowledge (Gibbons *et al*., 1994) implies that the contemporary system has more recently gained a degree of freedom under the pressure of globalization and the new communication technologies. What seemed to be institutionally rigid under a previous regime (e.g., nation states) can be made flexible under this new regime of communication. In a follow-up study, Nowotny *et al*. (2001) specified that the new flexibility is not to be considered as only ‘weak contextualization.’ The authors argue that a system of innovation is a construct that is continuously undergoing reconstruction and can be reconstructed even *in the core of its operations*. This ‘strong contextualization’ not only affects the selections themselves, but also the structure in the selections over time. The possibilities for novelty and change are limited more in terms of our capacity to reconstruct expectations than in terms of historical constraints.

How does one allocate the capacities for puzzle-solving and innovation across the system when the system boundaries become so fluid? The authors of the Mode-2 thesis answered as follows:

> There is no longer only one scientifically 'correct' way, if there ever was only one, especially when—as is the case, for instance, with mapping the human genome—constraints of cost-efficiency and of time limits must be taken into account. There certainly is not only one scientifically 'correct' way to discover an effective vaccine against AIDS or only one 'correct' design configuration to solve problems in a particular industry. Instead, choices emerge in the course of a project because of many different factors, scientific, economic, political and even cultural. These choices then suggest further choices in a dynamic and interactive process, opening the way for strategies of variation upon whose further development ultimately the selection through success will decide. (Nowotny *et al*., 2001: 115f.)

The perspective, consequently, is changed from interdisciplinary to *transdisciplinary*. The global perspective provides us with more choices than were realized hitherto. Reflections (which the authors consider as a property of the communication) enable us to make this difference in the discourse. Such reflexive communications add another dimension to the reflection by individual agents.

While Lundvall (1988) focused already on interaction and argued that communications can stabilize the local innovation environment for agents, these authors argue that communications enable us to entertain a global perspective on the relevant environments. In other words, communications can be expected to develop an internal dynamics between local interactions and global perspectives. The global perspective adds a dynamic that is different from the historical one which follows the time axis. While the latter focuses on the opportunities and constraints of a given unit (e.g., a region) in its historical context, the discourse enables us to redefine the system of reference by contextualizing and analyzing the subjects under study from the perspective of hindsight. Thus, the focus shifts from the historical reconstruction of a system by ‘following the actors’ (Latour, 1987) to the functional analysis of an innovation system operating in the present. The robustness of this construct depends not on its historical generation, but on the present level of support that can be mobilized from other subsystems of society (e.g., the economy or the political systems involved).

What does this model add to the model of ‘national innovation systems’ in terms of providing a different micro-foundation? Lundvall’s micro-economics were grounded in terms of communication and interaction between users and producers rather than in terms of the individual preferences of agents. The authors of ‘Mode 2’ define another communication dynamic relevant to the systems of innovation. This other perspective is possible because a network contains a dynamic both at the level of the nodes and at the level of the links. While agency can be considered as a source of communication—and can be expected to be reflexive, for example, in terms of learning and entertaining preferences—an agent necessarily has a position at a node in the network (Burt, 1982). The links of a communication system operate differently from the nodes in the network. The systems of reference, however, are different. Nodes represent agents and the links represent the relations among them.

Categories like reflexivity and knowledge can be expected to have different meanings from one layer of the network to another. For example, agents entertain preferences, but the structure of communication provides some agents with more access than others. In addition to actions which generate the variations, the dynamics of communications, that is, at the level of the links, are able to generate changes at the systems level, that is, in terms of changes in the structural selection mechanisms. These changes are endogenous to the system because they can be the result of non-linear interactions among previously stabilized aggregates of actions. Recursion and interaction add non-linear terms to the aggregations of micro-actions.

Luhmann (1984) was the first to propose that communication be considered as a system of reference distinct from agency. He emphasized the analytical advantages of this hypothesis (e.g., Luhmann, 1996). The two systems of agency and communication are ‘structurally coupled’ in the events like the columns and rows of a matrix. An interaction can be attributed as an action to the actor, while it can be expected to function as a communication within the respective communication system (Maturana & Varela, 1980; Leydesdorff, 2001). In addition to communicating in terms of first-order exchange relations, social systems communicate reflexively by providing meaning to communications from the perspective of hindsight.

Global perspectives can be focused when the communications are increasingly codified. For example, scientific communications may enable us to deconstruct and reconstruct phenomena in ever more detail. As noted above, the price mechanism could be further refined in terms of price/performance ratios. The differentiation of the communication into various functions enables the social system to process more complexity than in a hierarchically controlled mode. However, under this condition one can expect to lose a central point of coordination as the interacting (sub)systems of communication become increasingly differentiated in terms of their potential functions for the (uncoordinated) self-organization of the system. This communication regime reshapes the existing communication structures as in a cultural evolution. In other words, selection mechanisms other than ‘natural’ ones reconstruct the system from various perspectives.

For example, in scientific communications ‘energy’ has a meaning different from its meaning in political discourse. While economists and politicians are able to worry about ‘shortages of energy,’ ‘energy’ is defined as a conserved quantity in physics. Words may have different meanings in other contexts. Thus, the evolutionary dynamics of social communication adds another layer of complexity to the first-order dynamics of the exchange. Institutionalization and organization stabilize the communication structures historically, but by providing meaning to the communication one is able to generate a global perspective (Husserl, 1929; Urry, 2003).

In summary, the communicative layer provides society with a selection environment for historical institutions. Unlike variation, selection remains deterministic albeit that in the case of communication systems selections operate probabilistically. Thus, the selection mechanisms cannot be observed directly. However, the specification of the expectation guides the observation. Furthermore, the communication structures of the social system are complex because the codes of the communication have been differentiated historically. Communications develop along the various axes, but they can additionally be translated into each other by using the different codes at the interfaces reflexively. Thus, systems of translation are generated. A translation adds an interface to the translated system.

For example, interaction terms among codes of communication emerged as a matter of concern within knowledge-based corporations when interfaces between R&D and marketing had increasingly to be managed (Galbraith, 1967). In university-industry-government relations three types of communications are interfaced. Frictions at the interfaces between the institutional layers and the dynamics of mutual expectations produce noise that can sometimes be locked-in and thus provide a competitive advantage. The systems thus generated can regain a degree of freedom which was previously locked-in into a co-evolution, in a later stage using the third dimension. The utilization of the degrees of freedom between institutions and functions among the three subsystems interacting in a Triple Helix increasingly provides the knowledge-based advantages in the economy.

7.3 A Triple Helix of university-industry-government relations

The systems-of-innovation approach defined innovation systems in terms of (aggregates of) institutional units of analysis. 'Mode 2' analysis defined innovations exclusively in terms of reconstructions on the basis of emerging perspectives in communication. The Triple Helix approach combines these two perspectives as different subdynamics of the systems under study. However, this model enables us to include the dynamics of the market as a third perspective with the micro-foundation of neo-classical economics in natural preferences. Thus, one can assume that innovation systems are driven by various subdynamics and to varying extents. Consequently, the discussion shifts from an ontological one about what an innovation system 'is,' or the epistemological question of how it should be defined, to the methodological question of how one can study innovation systems in terms of their different dimensions and subdynamics.

In the Triple Helix model, the main institutions of the knowledge-based economy have first been defined as university, industry, and government (Etzkowitz & Leydesdorff, 1995). These institutional carriers of an innovation system can be expected to entertain a dually layered network: one layer of institutional relations in which they constrain each other's behaviour, and another layer of functional relations in which they shape each other's expectations. Three functions have to be recombined and reproduced at the systems level: (a) wealth generation in the economy, (b) novelty generation by organized science and technology, and (c) control of these two functions locally for the retention and reproduction of the system. The layers can be expected to feedback onto each other, thus changing the institutional roles, the selection environments, and potentially the evolutionary functions of the various stakeholders in each subsequent round.

Within this complex dynamic, the two mechanisms specified above—user-producer interactions and reflexive communications—can be considered as complementary to the micro-foundation of neo-classical economics. First, each agent or aggregate of agencies is positioned differently in terms of preferences and other attributes. Secondly, the agents interact, for example in economic exchange relations. This generates the network perspective. Thirdly, the arrangements of positions (nodes) and relations (links) can be expected to contain information because not all network positions are held equally and links are selectively generated and maintained. The expected information content of the distributions can be *recognized* by relevant agents at local nodes. This recognition generates knowledge within these agents and their organizations. Knowledge, however, can also be processed as discursive knowledge in the network of exchange relations. Knowledge that is communicated can be further codified, for example, as discursive knowledge in the sciences. Figure 4 summarizes this configuration.

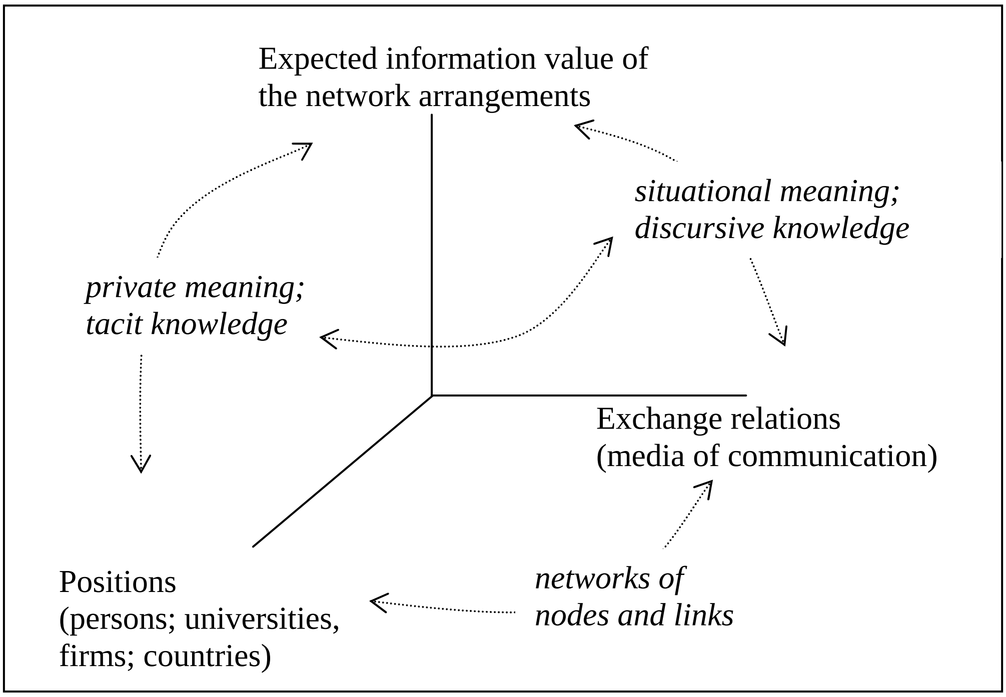

Figure 4: Micro-foundation of the Triple Helix Model of Innovation

With this visualization I intend to make my argument epistemologically consistent by relating the various reflections (Cowan *et al*., 2000; Lundvall & Borras, 1997) to the underlying dimensions of the Triple Helix model. The three analytically independent dimensions of an innovation system were first distinguished in Figure 3 (above) as (1) the geography which organizes the positions of agents and their aggregates; (2) the economy which organizes the exchange relations; and (3) the knowledge content which emerges first with reference to either of these dimensions. Given these specifications, we were able to add the relevant interaction terms. The second-order interaction among these interactions then provided us with the possibility of the development of a knowledge base endogenous to the system under study. Figure 4 specifies this as an interaction between discursive and tacit knowledge. This second-order interaction may generate configurational knowledge as an order of expectations. The three different micro-foundations (preferences of agents, learning in interaction, anticipation in the learning through codification) can thus be distinguished reflexively with reference to the analytically distinguished dimensions.

8. The Triple Helix: A program of empirical studies and simulations

I have argued that the Triple Helix can be elaborated into a neo-evolutionary model which enables us to recombine sociological notions of meaning processing, economic theorizing about exchange relations, and insights from science and technology studies regarding the organization and control of knowledge production. The further codification of meaning in scientific knowledge production can add value to the exchange (Foray, 2004; Frenken, 2005). This model can serve as heuristics, but should not be reified. Its abstract and analytical character enables us to explain current transitions towards a knowledge-based economy as a new regime of operations.

Unlike biological models that focus on observable realities as variation with reference to 'natural' selection mechanisms, the Triple Helix model focuses primarily on the specification of the selection mechanisms. Three helices are sufficiently complex to understand the social reproduction of the dynamics of innovation (Leydesdorff, 1994; Leydesdorff & Etzkowitz, 1998; Lewontin, 2000). What is observable can be specified as relative equilibria at interfaces between different selection mechanisms operating upon each other. When repeated over time, a *co*variation can be developed into a *co*evolution, and a next-order, that is, more complex, system can be generated in a process of 'mutual shaping' (McLuhan, 1964).

The differentiation in terms of selection mechanisms can be both horizontal and vertical. Vertically the fluxes of communications are constrained by the institutional arrangements that are shaped in terms of stabilizations of previous communications. Horizontally, these communications are of a different nature because they can use different codes. For example, market transactions are different from scientific communications. Market transactions can also be cross-tabled with organizational hierarchies (Williamson, 1985), but from the perspective of a Triple Helix model, this would require the specification of two different dynamics: (1) markets can be organized at different levels (e.g., at local, national, and global levels), and (2) control mechanisms can be made the subject of political or managerial governance by taking a different angle. While the control mechanisms at interfaces can be considered as functional for the differentiation among communications, the hierarchy in the organization provides us with a multi-level problem within the institutional dimension.

In summary, the functional perspective is different from the institutional one. Functional communications evolve; institutional relations function as retention mechanisms which respond to functional incentives. The specification of functions in the socio-economic analysis requires reflexivity. All reflections can again be made the subject of communication. Thus, one can study a Triple Helix at different levels and from different perspectives. For example, one can study university-industry-government relations from a (neo-)institutional perspective (e.g., Etzkowitz *et al*., 2000; Gunasekara, 2005) or one can focus on the relations between university science and the economy in terms of communications (e.g., Langford *et al*., 1997; Leydesdorff, 2003b). Different interpretations of the Triple Helix model can be at odds with each other and nevertheless inform the model. Each metaphor stabilizes a geometrical representation of an otherwise more complex dynamics.

Innovation can be considered as the reflexive recombination at an interface, such as between a technological option and a market perspective. Specification of the two different contexts requires theorizing. For the purpose of innovation, the perspectives have to be translated into each other, for example, in terms of a plan. Such translations potentially reinforce the research process by raising new questions, for example, by comparing across different contexts, yet with reference to emerging phenomena. Competing hypotheses derived from different versions of the Triple Helix can be explored through formal modeling and appreciated through institutional analysis. The case studies inform the modeling efforts about contingencies and boundary conditions, while the simulation model enables us to relate the various perspectives. In summary, the Triple Helix model is sufficiently complex to encompass the different perspectives of participant observers (e.g., case histories) and, from an analytical perspective, to guide us heuristically in searching for options newly emerging from the interactions.

What is the contribution of this model in terms of providing heuristics to empirical research? First, the neo-institutional model of arrangements among different stakeholders can be used in case study analysis. Given the new mode of knowledge production, case studies can be enriched by raising the relevance of the three major dimensions of the model. This does not mean to disclaim the legitimacy of studying, for example, academic-industry relations or government-university policies, but one can expect more interesting results by observing the interactions of the three subdynamics. Secondly, the model can be informed by the increasing understanding of complex dynamics and simulation studies from evolutionary economics (e.g., Malerba *et al.*, 1999; Windrum, 1999). Thirdly, the second-order perspective adds to the meta-biological models of evolutionary economics the sociological notion of meaning being exchanged among the institutional agents (Luhmann, 1984; Leydesdorff, 2001).

Finally, on the normative side of developing options for innovation policies, the Triple Helix model provides us with an incentive to search for mismatches between the institutional dimensions in the arrangements and the social functions carried by these arrangements. The frictions between the two layers (knowledge-based expectations and institutional interests), and among the three domains (economy, science, and policy) provide a wealth of opportunities for puzzle solving and innovation. The evolutionary regimes are expected to remain in transition because they are shaped along historical trajectories (Etzkowitz & Leydesdorff, 1998). The knowledge-based regime continuously upsets the political economy and the market equilibria as different subdynamics. Conflicts of interest can be deconstructed and reconstructed, first analytically and then perhaps also in practice in the search for solutions to problems of economic productivity, wealth retainment, and knowledge growth.

The rich semantics of partially conflicting models reinforces a focus on solving puzzles among differently codified communications reflexively. While the lock-ins and the bifurcations are systemic, i.e., largely beyond control, further developments require variety and self-organization of the interactions among the subsystems. New resonances among selections can shape trajectories in coevolutions and the latter may recursively drive the system into new regimes. This neo-evolutionary framework assumes that the processes of both integration and differentiation remain under reconstruction. While Neurath's (1933, at p. 206) metaphor that 'the ship is repaired on the open sea' focused at that time exclusively on science, a knowledge-based society has internalized the new dynamic of knowledge production and control into the economy at both the micro- and the macro-level.

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