THE KNOWLEDGE-BASED ECONOMY:
MODELED, MEASURED, SIMULATED

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Preface

How can an economy be based on something as volatile as knowledge? The urgency of improving our understanding of a *knowledge-based economy* provides the context and necessity of this study. In a previous study entitled *A Sociological Theory of Communications: The Self-Organization of the Knowledge-based Society,* I specified knowledge-based systems from a sociological perspective. In this book, I take this theory one step further and demonstrate how the knowledge base of an economic system can be operationalized, both in terms of measurement and by providing simulation models.

How does a knowledge-based economy differ from a market-based or political economy? Markets and political (e.g., national) systems can be considered as providing different kinds of subdynamics to the social system. Markets, for example, function mainly to clear imbalances in the system, while political systems, among other things, regulate markets. My thesis is that organized knowledge production and control adds yet a *third* subdynamic to the social system (Schumpeter, [1939] 1964; cf. Hanneman and Collins, 1986; Whitley, 1984). Innovations in the technologies upset the equilibrium-seeking dynamics of the market.

The interactions among three subdynamics can be expected to lead to a non-equilibrium dynamics (Li and Yorke, 1975). This complex dynamics evolves in terms of trajectories and regimes changing the system in which they emerge (Nelson and Winter, 1982; Dosi, 1982). In a complex dynamics, however, the independent (steering) variables at one moment in time may become dependent at a next moment. In other words, the complex dynamics can become self-organizing because the incentives for change are distributed. Consequently, the economic and political mechanisms do not control, but provide a feedback mechanism to enable and constrain the development of scientific and technological knowledge.

Technologies develop in terms of generations along the time axis, while selection environments (e.g., the market) operate at each moment of time. In general, the dynamics of the market at each moment are tangential to the recursive dynamics of a historically evolving system. When three subdynamics interact, the model requires a third axis. This model of three subdynamics will be introduced and micro-founded in Chapter One. It is elaborated empirically into the Triple Helix model in Chapter Seven. The events can have different meaning along the three axes of the system, and also when projected on the planes which can be spanned between each two of them. The knowledge base will be modeled in this study as a second-order interaction term among (first-order) interactions between each two of these three subdynamics.

Each two subdynamics may act upon each other selectively, and thus co-evolve under certain conditions along an emerging axis in a process of mutual shaping (McLuhan, 1964). Such a stabilization can be made meta-stable when a third subdynamic is added. A meta-stabilized system can also be globalized. Reflexively, the various stabilizations can be made the subject of positive theories, while globalization can be specified only as an expectation or an emerging order. In other words, globalization and a knowledge-based order can be considered as an *analytical* possibility, while the observables inform us about the phenotypical retention mechanism or the footprints of a complex dynamics that evolves in terms of fluxes. The crucial question is whether entertaining this hypothesis of a knowledge-based order is fruitful for the explanation of the phenomena. Are the knowledge-based transformations of national systems of innovation and international politics perhaps elusive? (Skolnikoff, 1993). Are the emergence of a knowledge-based economy and globalization merely political buzzwords (Godin, 2006), or can these concepts also be elaborated into relevant theories and indicators? (European Commission, 2000; OECD, 1996a and b). How can a knowledge-based system be made the subject of empirical studies and simulations, and how might one thus be able to generate a research agenda?

The function of scientific and technological developments in socio-economic processes of change has been central to my research interests since the time of my Ph.D. thesis concerning employees and processes of technological innovation (Leydesdorff, 1984). In this project, I worked with trade-union representatives in a high-tech (chemical) industry in the Amsterdam region (Leydesdorff and Zeldenrust, 1984; Leydesdorff and Van den Besselaar, 1987a).[1] The creation of the Amsterdam Science Shop in 1977/1978 provided me with access to work processes in and among R&D departments, pilot plants, and the industrial floor of knowledge-intensive manufacturing (Leydesdorff, 1980; Leydesdorff, Ulenbelt, and Teulings, 1984; Zaal and Leydesdorff, 1987; Leydesdorff and Ward, 2005). Technology assessments of new production processes in the chemical industry taught me that

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[1] In previous projects we had focused on the informal division of labour in solid state physics between the Philips Research Laboratories and the Dutch university system. In this context, I was astonished by the lack of socio-economic considerations in the decision-making processes about R&D despite the industrial contexts of these efforts (Leydesdorff *et al.*, 1980; Leydesdorff and Van Erkelens, 1981).

the relations between knowledge-intensive processes of technological innovation and the social impacts of the consequent reconfigurations are mediated by management to a varying extent. A careful reconstruction of how corporations structure these processes in terms of strategic and operational planning was required in order to appreciate the various moments at which decisions might be open to external influence (Lewy, 1976; Newman and Logan, 1981).

For example, what appears at the work floor to be a management decision may sometimes be mainly a constraint driven by changes in technologies and markets. In other cases there may be more room for negotiations with the unions and local authorities. In planning cycles economic considerations are matched with new technological perspectives (R&D management) and with geographic considerations. Interactions and frictions among the various perspectives give rise to new problems and puzzles. In the implementation stage, however, one deals with the consequences of managerial decisions about how these puzzles can best be solved. At the lower ends, trade unions—and even national governments—cannot distinguish clearly between the techno-economic environment at the global level and the firm's decisions about these variables (Leydesdorff and Van den Besselaar, 1987b). The resulting practices reflect several rounds of negotiations in which a wealth of analytical considerations had to be optimized from the perspective of management and control.

The reconstruction of decision cycles enabled us to improve our advice to the unions to such an extent that in some cases jobs could be saved. For example, relevant questions could be raised in the enterprise council at the right moments, that is, before decisions had already been made definitive. In the longer run, however, these interventions alienated us from the union's base at the work floor. (Our reports were sometimes appreciated by management.) Increasingly, an asymmetry became manifest between our interests in studying the social influences on knowledge production processes and the union's interests in the social consequences of the new technologies. When the *Science and Society* groups managed to organize an interfaculty department of *Science and Technology Dynamics* at the University of Amsterdam in the early 1980s, I decided to make the methodological question of how to measure scientific knowledge and its communication the focus of my research.

If the subdynamics of 'organized knowledge production and control' (Whitley, 1984) are *analytically* independent from the two other sources of variance (markets and institutions), one needs instruments for measuring these 'elusive' dynamics. At that time, Studer and Chubin (1980) had raised the question of a baseline for measurement in science and technology studies in an appendix to their evaluative study of the cancer mission as a government priority program in the U.S.A. during the 1970s. They formulated the methodological problem as follows:

> Relationships among journals, individuals, references, and citations can be analyzed in terms of their structural properties. But can one be used as a baseline to calibrate our understanding of another? Does it make sense to attempt to "control" for one relationship while studying others? What would be meant by "controlling for ideas" or "controlling for cocitations?" If disparate dimensions of science are not carefully analyzed in their own terms, the possibility of relating their respective contributions is nil. (*ibid.*, at p. 269)

Another crucial step had been to consider the development of the sciences not only in terms of its social contexts (as Studer and Chubin had done in the aforementioned study) but as discourses (Gilbert and Mulkay, 1984). Mulkay *et al.* (1983) had claimed priority for the communication-theoretical approach of discourse analysis in science and technology studies: the sciences develop as systems of *discursive* knowledge. However, these authors did not raise the follow-up question of whether the study of communications would require a statistics different from the parametric statistics prevailing in the social sciences.

Can the dynamics of science and technology be measured in terms of scientific communications? In Leydesdorff (1995a), I argued that the mathematical theory of communication provides a basis for developing a non-parametric (entropy) statistics for knowledge-based systems. These systems are *specific* in terms of their selections from the variations. Specific selections produce and reproduce skewed distributions (Brookes, 1979). Furthermore, systems which develop reflexively, that is, with reference to both their previous states and the incoming (e.g., experimental) information, add a selection mechanism over time to the structural selections at each moment. The expected information content of the resulting distributions and the meaning of the uncertainty can then be evaluated within the system as signals with reference to the two (or more) co-evolving systems and at different levels. For example, one can improve on the quality of the communication by controlling for error in the measurement. Thanks to this process of codification within the (sub)systems, a knowledge base is increasingly developed. I return to these process of codifications below, but let me here first trace the historical line of my intellectual development.

After elaborating the methodological apparatus during the 1980s, I returned in the early 1990s to the more complex issues of innovation at interfaces. How do knowledge-based innovations over the longer term restructure social systems with a dynamics different from economic rationality and political or managerial decision-making (Leydesdorff, 1992; Leydesdorff and Van den Besselaar, 1994)? Discussions with evolutionary economists rapidly taught me that the controversy between evolutionary economists and neo-classical economics had blocked the understanding of the economy as a complex system composed of different and interacting subdynamics (Anderson *et al.*, 1988). While evolutionary economists are fascinated with the non-equilibrium dynamics of (co-)evolutions over time, the neo-classical approach emphasizes the continuous operation of the equilibrium-seeking market mechanism as a problem-solver at each moment of time.

A complex-systems approach legitimizes the specification of knowledge production and control as a *third* subdynamic analytically different from and potentially orthogonal to economic and political systems of communication and control. In the sociological tradition, Niklas Luhmann argued for the advantages of analyzing society as a complex and composed ('functionally differentiated') dynamics. His work is perhaps best known for the proposal to consider human agents as the environment of the self-organization of social systems of communication (Luhmann, 1984/1995). These two systems (society and agency) would then operate independently—that is, along their respective axes—but they remain structurally coupled through the exchange of meaning. I use this theory as a heuristics: my focus is on the systemic character of the exchange of meaning as distinct from the exchange of information (Maturana, 1978). Knowledge can then be considered as a meaning that is further codified (see Chapter Two).

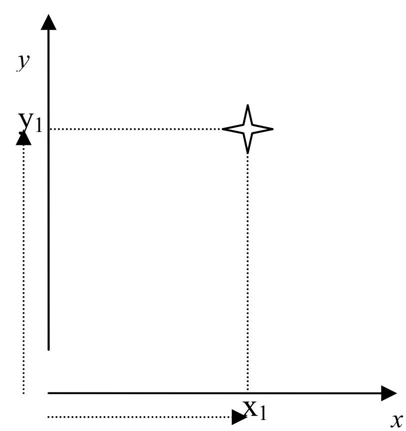

Figure 1. The interaction informs the interacting systems asymmetrically.

The analytical independence of two subdynamics (*x* and *y*) presumes that these axes are considered orthogonal (Figure 1). The interaction terms between them—indicated in Figure 1 as a star—are provided with a value using the operations (x_1 and y_1) along the respective axes. I consider providing an event with a value as a reflection. Note that this changes the common notion of reflection, which assumes the metaphor of a mirror reflecting with 180 degrees. Reflections at ninety degrees do not use a next level, but generate only another perspective.

The systems perform their own *autopoiesis*—that is, self-organization—along their respective axes, but they disturb each other's self-referential operations at interfaces.[2] The resulting system is complex because it contains both interactions (at specific moments of time) and recursion (over time). This complex dynamics can be expected to change endogenously, that is, through the operations of the interacting subdynamics upon one another. In the *Wissenschaft der Gesellschaft*—that is, *The Science of Society*—Luhmann (1990a) formulated the research program implied as follows:

> The differentiation of science in society changes also the social system in which it occurs, and this can again be made the subject of scientific theorizing. […] Developing this perspective, however, is only possible if an accordingly complex systems theoretical arrangement is specified. [3] (Luhmann, 1990a, at p. 340)

In a special issue of *Social Science Information* devoted to this theory, I quoted this statement as a concise formulation of my program of research (Leydesdorff, 1996a, at p. 299). How can a knowledge base emerge in a system as a result of a recursive interaction, and how does the emerging subdynamic feedback and potentially reorganize the system from which it is emerging?

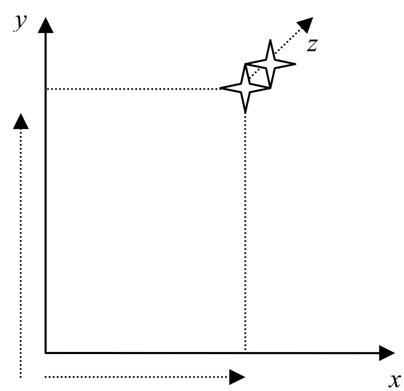

Figure 2. The development of a co-evolution on the basis of a recursive co-variation.

For example, technologies can be expected to develop at interfaces between the sciences and the economy; interface systems can be updated from both sides, that is, by selecting upon each other's variations. Innovation patterns may then result as a third subdynamic (*z*) from the interactions along the axis of an emerging co-evolution (Figure 2). Additionally, this mutual shaping of markets and techno-

[2] The subsystems of a self-organizing system can be expected to self-organize themselves to a variable degree, namely, to the extent that this self-organization is functional for the system's development (Leydesdorff, 1993b, 1994a).
[3] 'Die Ausdifferenzierung verändert auch das System der Gesellschaft, in dem sie stattfindet, und auch dies kann wiederum Thema der Wissenschaft werden. [...] Das allerdings ist nur möglich, wenn man ein entsprechend komplexes systemtheoretisches Arrangement zugrundelegt.'

sciences in a positive feedback loop can be 'locked-in' (David, 1985; Arthur, 1988 and 1989).

At the time (Leydesdorff, 1992 and 1993a), my concern was twofold: first, the lack of empirical operationalization and methodological rigour in Luhmann's sociology, and secondly, the failure in social systems theory more generally to bridge the gap with the modeling of complex systems in terms of simulations, as had become common in evolutionary economics (Leydesdorff, 1995b; 2001a; Leydesdorff and Van den Besselaar, 1994). From my perspective, 'an accordingly complex systems theoretical arrangement' should combine the perspective of non-linear dynamics with the study of systems which process meaning in addition to and in interaction with (Shannon-type) information exchange. Thus, the systems are composed both horizontally and vertically of different subdynamics.

It turned out that such elaboration was not a single task. The relationship between the simulation models and the empirical studies required also a further development of the theorizing. For example, the frictions among the subsystems were not appreciated by Luhmann (1984, 1997a) as Shannon-type information. (This will be elaborated in Chapter Two.) In scientific reasoning, however, 'empirical evidence' containing an external reference is crucial for the production of novelty (Fry, 2006). The uncertainty in the communication provides the basis for the production of novelty (Leydesdorff, 1996a).

Two branches of research have been further developed after the specification of these problems at interfaces. In collaboration with Henry Etzkowitz, I developed the Triple Helix of university-industry-government relations into a model of technological innovation (Leydesdorff and Etzkowitz, 1998). A series of workshops, conferences, and special issues of journals has provided me with a wealth of empirical materials that have significantly informed my theorizing about the different modes in which a composed dynamics can operate. This perspective is elaborated in the empirical chapters of this study. An instrument for measuring the Triple Helix-dynamics will be proposed and tested. The knowledge base is measured both at the level of the global system (Chapter Eight) and more specifically for the Dutch and German economies (Chapters Nine and Ten, respectively).

In collaboration with Peter van den Besselaar and Daniel Dubois I have elaborated simulation models for knowledge-based innovations (Leydesdorff and Van den Besselaar, 1998a and 1998b; Leydesdorff, 1995b, 2000a, 2000b, 2001a, 2002a, 2005a; Leydesdorff and Dubois, 2004). A European project entitled 'The Self-Organization of the European Information Society' (SOEIS) provided a context for collaboration with Japanese colleagues of similar interests (Fujigaki and Leydesdorff, 2000; Leydesdorff and Heimeriks, 2001). The series of conferences on 'Computing Anticipatory Systems' (CASYS) organized by Daniel Dubois in Liège (Belgium) and my continuous participation in his program committee have provided the stimulus to study knowledge-based systems as *anticipatory systems* (Leydesdorff, 2000a, 2005a, 2006e). I am grateful to him for providing the proofs of some of the algorithms discussed in Chapter Four (Leydesdorff and Dubois, 2004).

An anticipatory system can be defined as a system which accommodates a model of the system itself (Rosen, 1985). Anticipatory systems reduce uncertainty locally within the system by using the time axis as a degree of freedom (Coveney and Highfield, 1990; Leydesdorff, 1994c; Raju, 2003). In other words, the modeling subroutine of an anticipatory system runs ahead upon the system which is modeled and provides the latter with a prediction about the state of the system at a future moment in time—that is, by looking backward from the position at that future moment in time. Dubois (1998) has called this 'incursion' in order to distinguish it from 'recursion' which follows the arrow of time. At the level of the social system, however, a prediction remains also discursive.

For example, in scientific discourse one can investigate future events in terms of 'what if' questions. Thus, the clocks of the modeled system and the modeling systems are differentiated in the time dimension by codifying the two discourses—the historical one following the participants along the axis of time, and the analytical one—differently. This generates a 'double hermeneutics' (Giddens, 1978). For example, a scientific discourse enables us to discuss future states of systems in the present on the basis of an analysis of examples from the past independently of the participants who experienced these situations historically. In my opinion, reflexivity about this difference in perspectives provides the *differentia specifica* of the sociological perspective (Giddens, 1984; Leydesdorff, 1997a, 2001b, 2006b).

Within the social system the differentiation which occurs along the time axis can interact with the differentiation in the codification at each moment of time (for example, between science and the economy) and thus a strongly anticipatory system can additionally be shaped (Chapter Four). Unlike a weakly anticipatory system, which only entertains a prediction of its future state(s), a strongly anticipatory one can also reconstruct its next state (Dubois, 2003). I shall explain in Chapter Five how this restructuring may lead to techno-economic co-evolutions which change the 'natural' environment by operating at the supra-individual level, that is, beyond the control of individuals or any aggregated group agency. The co-constructing agents are enrolled in the knowledge-based system, and this enrollment transforms them from economic agents with 'natural preferences' to informed places of decision-making. Decisions can be codified into decision-rules (e.g., in organizations).

I shall argue that contrary to biological evolution, cultural evolution restructures the past to the extent that the past can be overwritten by the interactions that occur among anticipatory subdynamics. In a Dutch polder landscape, for example, one can consider the polder vegetation as 'natural' or wish 'to return to nature' by flooding the country. This overwriting of the previous state by a techno-economic co-evolution at the supra-individual level is possible because the functional differentiation in the coding provides the social system with a second updating mechanism in addition to anticipation in the structural coupling between agency and social structures. The communication of information can be codified into meaning at one interface, and meaning can further be codified into knowledge at a next one. Knowledge can be considered as a meaning which makes a difference. However, the codification of the expected information content of a distribution remains always uncertain at the level of the social system because the social system operates in terms of exchanges; distributions are changed by the exchanges, but the distributions can be expected to contain an uncertainty. Consequently, the knowledge-based systems remain emergent and incomplete. Yet, they can be distinguished analytically from their historical realizations.

Because more complexity can be processed when a knowledge base is constructed within the system, the emerging dynamics of expectations may increasingly take control by operating in the present with reference to the future given the system's historical conditions. This idea of a 'rewrite' on the basis of an inversion along the historical axis was first expressed in Joseph Schumpeter's (1939) concept of 'creative destruction.' It can also be related to Edmund Husserl's (1929) notion of 'intersubjectivity' as a system (a 'monade') other than 'subjectivity.' Husserl wrestled with the question of how 'intersubjectivity' can contain 'intentionality' differently from subjective intentionality (Chapter Eleven). The intentionality of the social system is contained in the distribution and is therefore different from (and even orthogonal to) those of human beings. However, the two types of intentionality remain interwoven because of the structural coupling between communications and the carriers of communication.

In other words, the historical stabilization of a system (along the axis of time) can be meta-stabilized if the stabilization is reflected in the present as one among possible representations. Meta-stabilizations create the possibility for globalization.

Globalization occurs with reference to a next-order system. Thus, the social system can be brought into a new regime of knowledge-based development. However, this happens *within* history, and thus the transition towards a knowledge-based economy cannot be completed. A globalizing system is structurally coupled to its manifest (that is, stabilized) layer. The operations of the virtual system remain trade-offs between stabilizations and globalization, but control tends to shift towards the knowledge-based end of the emerging system.

The reflexive systems operate on top of the reflected ones (using ninety degrees for the reflection), but the layers remain dependent on each other in an autocatalytic loop because of the various couplings. The processing of information (uncertainty generation) can then be slowed down or accelerated by the processing of meaning and the processing of knowledge. Information theory enables us to study information-processing, meaning-processing, and next-order knowledge-processing as different subdynamics, but these processes have first to be distinguished analytically and then operationalized. When the differences are clearly specified and the operationalizations independent, one can study the extent to which, why, and in which respects a development is increasingly knowledge-based.

The expectation is that the interacting subdynamics tend towards 'near decomposability' along the different axes, since increasing the spanning of the multi-dimensional space allows the system to process more complexity (Simon, 1969, 1973). The events can differently be projected and provided with meaning along the various axes and planes. However, the mutual information is by definition smaller than the information contained in each of the interacting systems. The reflecting system thus builds upon the reflected ones, but by using an orthogonal axis for the reflection. The systems are reconstructed from a tangential perspective: only the mutual information is available as a window on the other systems (Casti, 1989, at pp. 219 ff. and 1990; Luhmann, 1990b). Since the room for *in*-struction (steering) in the ongoing re-*con*-struction during the self-organization is limited, unintended consequences of interventions can be expected to prevail (Callon, 1998).

The signals received through the windows of interaction provide external references which can be observed, deconstructed, and reconstructed if the receiving systems/subdynamics contain reflexivity. However, each subsystem of the social system is expected to perform its respective internal operations concurrently. Consequently, the mechanisms to reduce uncertainty, such as providing meaning to the (Shannon-type) information—and organizing the various meanings into discursive knowledge—can under certain (e.g., autocatalytic) conditions develop at speeds higher than that of the underlying (since historical) proliferation of uncertainty. When this occurs, the representations no longer have to be materialized at each step, and thus the development of the system tends to become knowledge-based, that is, steered by expectations generated internally at a speed higher than their realizations. In other words, the system henceforth can operate on the basis of discursively codified expectations which have to be confirmed only as instantiations with a frequency sufficient for carrying the inference (Quine, 1953). The disturbance terms, however, remain the source of novelty production. Novelty production can be considered as the goal and purpose of the scientific enterprise. Because of this continuous influx, the system tends to become increasingly knowledge-based.

For the participants, the non-linear dynamics generates an elusive transformation because the agents of change are no longer clearly identifiable. The social system operates in terms of distributions. A specific identification can be deconstructed as a reflexive network effect or, in other words, an attribution by the social system. The historical manifestations fail to inform us sufficiently about the order of expectations. We need a reflexive turn for this. The knowledge base of an economy thus remains in a domain of informed hypotheses. The process is limited and sometimes 'bottlenecked' by the availability of reflexive capacity for the reconstruction, e.g., in scientific discourses and professional practices among human resources. The systems under study remain operational and in transition. Therefore, this perspective on knowledge-based systems can no longer claim to be based in an ontology. Derivatives from the Latin verb *esse* (to be) like 'ontology' and 'essential' give way to derivatives of *frangere* (to break) such as 'fractals,' 'fragments,' and 'fragile.'

In a fragmented reality comprised of different angles of reflection, one can expect more than a single perspective to become codified. The perspectives focus on potentially different subdynamics. Reflections in the scientific discourses provide us with codifications in increasingly orthogonal and therefore potentially incommensurable windows for the appreciation (Kuhn, 1962). The perspective of science and technology studies has reflexively produced as one of its main contributions that the scientific discourses generate epistemic objects by providing specific meaning to otherwise uncertain phenomena. In a knowledge-based order, epistemic objects can be considered as genotypical of the observable phenomena. The discourses provide us with heuristics for competing explanations—that is, provisional stabilizations of understanding—in an order which tends towards globalization because of next-order interactions among the various understandings.

Formalization is required for abstracting from the empirical domain of observables to the epistemic domain of expectations. The expectations remain fallible (albeit theoretically informed) hypotheses. However, a change in the epistemological order is also implied. A knowledge-based system is grounded in reflexivity and discourse. Knowledge operates by translating *a priori* hypotheses into *a posteriori* ones. The foundations of these constructs remain constructs. As Deleuze and Guattari (1987, at p. 15) once noted, in Amsterdam the foundations are also constructed (by driving pillars into the underlying sediment without the hope of a rock bottom). The foundations of knowledge-based systems have analogously been constructed over longer periods of time. A grounding in existential premises might lead to the erronic inference that something could exist because it can be imagined. Individual imaginations are needed for the production of knowledge claims, but communication is needed for the validation of results as a social phenomenon. Existence remains a necessary, but different and therefore increasingly tangential subdynamic; historical manifestations can be considered as the cases that happened to occur among other possible ones given the hypothesized system of reference.

In the final chapter I return to the philosophical implications of these reflections for the empirical studies and simulations presented in the other chapters. The reflections can be considered second-order because the scientific discourses needed for the constructions provided us already with first-order reflections containing substantive knowledge in different paradigms. For example, the biological metaphor of evolution is used throughout this study as a heuristics for the specification of a cultural evolution. However, a second-order perspective is generated by abstracting from the specifically biological content of the (first-order) theorizing. This formalization will enable me to specify mechanisms (like cultural evolution) other than biological ones. This operation is very similar to Husserl's (e.g., 1929, 1939) *epoché* in transcendental phenomenology as an abstraction from empirical psychology. However, the elaboration of the mathematical theory of communication provided us with a set of tools for studying intersubjectivity and communication as a non-linear dynamics grounded in interactions *among* subjective intentionalities: the structure and the dynamics of interhuman communications transcend individual contributions, but they can be reflected in a sociological discourse which is methodologically guided (Leydesdorff, 1997a, 2001b, 2006b).

Furthermore, the operationalization of reflection as a recursion of selection along a different axis allows me to formalize reflexivity without reifying it. The various reflections stand in orthogonal relation and not 'meta' or at a next-order level. The reflexive perspective along an orthogonal dimension remains 'epi' (nearby). One can no longer assume a one-to-one relationship between simulation results and empirical data. Empirical data exhibit states in a phase space of possible states. The bridge between the two perspectives is constructed reflexively by using relevant theories. The task remains eventually to explain and demonstrate why and how a knowledge-based or strongly anticipatory system constructs and continuously reconstructs its own basis in potentially self-reinforcing loops. These loops at the supra-individual level enable us increasingly to reorganize the underlying variation, that is, the limits of our own understanding.

Acknowledgements

This book integrates a number of previous projects. Some of the chapters have been written on the basis of articles and reports with coauthors. The original communications are listed below. I thank for the various coauthorship relations: Wilfred Dolfsma, Daniel Dubois, Henry Etzkowitz, Michael Fritsch, Iina Hellsten, Andrea Scharnhorst, Peter van den Besselaar, Gerben van der Panne, and Paul Wouters. I am also grateful to Gretchen Dee, Franz Hoegl, and Caroline Wagner for their long-term commitment to this project and their comments on previous drafts of the manuscript. I am indebted to Gene Moore for patiently correcting my English and the Amsterdam School of Communications Research for providing a stimulating environment. Can this also be a proper place to thank Margaret Traudes for our life-long project?

List of original communications

Chapter 1: "The Knowledge-Based Economy and the Triple Helix Model." Pp. 42-76 in Wilfred Dolfsma and Luc Soete (Eds.), *Understanding the Dynamics of a Knowledge Economy*, Cheltenham: Edward Elgar, 2006.

Chapter 2: "The Construction and Globalization of the Knowledge Base in Inter-human Communication Systems," *Canadian Journal of Communication* 28(3), 2003, 267-289.

Chapter 3: "Anticipatory Systems and the Processing of Meaning: A Simulation Inspired by Luhmann's Theory of Social Systems," *Journal of Artificial Societies and Social Simulation*, 8(2), 2005, Paper 7, at http://jasss.soc.surrey.ac.uk/8/2/7.html

Chapter 4:
- Loet Leydesdorff and Daniel Dubois, "Anticipation in Social Systems," *International Journal of Computing Anticipatory Systems,* 15, 2004, 203-216;
- "Meaning, Anticipation, and Codification in Functionally Differentiated Social Systems," in: Thomas Kron, Uwe Schimank, and Lars Winter (Eds.), *Luhmann Simulated – Computer Simulations to the Theory of Social Systems*. Münster, etc: Lit Verlag, 2006 (in preparation).

Chapter 5:

- "Technology and Culture: The Dissemination and the Potential 'Lock-in' of New Technologies." In D. M. Dubois (Ed.), *Journal of Artificial Societies and Social Simulation*, 4(3), 2001, Paper 5, at http://jasss.soc.surrey.ac.uk/4/3/5.html;
- "Hyper-incursion and the Globalization of a Knowledge-Based Economy," *American Institute of Physics Proceedings of the Seventh International Conference on Computing Anticipatory Systems CASYS'05*, Liège, Belgium, August 8-13, 2005 (forthcoming).

Chapter 7: "The Evaluation of Research and the Evolution of Science Indicators," *Current Science*, 89(9), 2005, 1510-1517.

Chapter 8: "The Mutual Information of University-Industry-Government Relations: An Indicator of the Triple Helix Dynamics," *Scientometrics* 58(2), 2003, 445-467.

Chapter 9: Loet Leydesdorff, Wilfred Dolfsma, and Gerben van der Panne, "Measuring the Knowledge Base of an Economy in terms of Triple Helix Relations among 'Technology, Organization, and Territory'," *Research Policy*, 35(2) (2006) 181-199.

Chapter 10: Loet Leydesdorff and Michael Fritsch, "Measuring the Knowledge Base of Regional Innovation Systems in Germany in terms of a Triple Helix Dynamics," *Research Policy* (In print).

Chapter 11: "Luhmann's Communication-Theoretical Specification of the 'Genomena' of Husserl's Phenomenology." In: Edmundo Balsemão Pires (Ed.), *Public Space, Power and Communication*, University of Coimbra, Portugal (In print).

Chapter 1

The Knowledge-Based Economy

Few concepts introduced by evolutionary economists have been more successful than that of a 'knowledge-based economy' (Foray and Lundvall, 1996; Abramowitz and David, 1996; OECD, 1996a). 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."[4]

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 poorly defined as the knowledge base of an economy? Should one consider this concept merely as a rhetorical reflection of the optimism regarding the potential impact of ICT and the Internet during the 1990s (Godin, 2006)? How would a knowledge-based economy be expected to differ from a market economy or a political economy?

In this study, I shall 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 which is endogenous to the system.

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[4] See the Conclusions of the EU Presidency at http://europa.eu.int/comm/research/era/pdf/com2000-6-en.pdf (European Commission, 2000 and 2005).

1.1 What is the knowledge base of an economy?

In an introduction to a special issue on this topic, David and 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 argue that the transformations 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 and Foray, 1997; Cowan, David and Foray, 2000).

The focus of most economic contributions to the topic has hitherto been 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 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 the historical transition to a knowledge-based economy and its impacts; on the contrary, my argument implies that knowledge-based dynamics can be expected to provide a coordination mechanism that is 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 transformation? Furthermore, what can function as an indicator of the knowledge base of a system?

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

1.2 The emergence of a knowledge base

Knowledge enables us to codify the *meaning* of information. Information can be more or less meaningful given a perspective. However, meaning is provided from a system's perspective and with 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. In other words, knowledge can be considered *as a meaning which makes a difference*. 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 would expect to be increasingly selective in terms of the information to be retained.

The knowledge base of a social system can be further developed over time by ongoing processes of theoretically informed deconstructions and reconstructions (Cowan *et al.*, 2000; Foray, 2004). Knowledge operates by informing expectations in the present on the basis of previous operations of the system. Informed expectations open the discourse towards future events and possible reconstructions. A knowledge-based economy is driven more by codified anticipations than by its historical conditions (Lundvall and Borras, 1997). In other words, science-based representations of possible futures (e.g., 'competitive advantages') feed back on historically manifest processes (Nonaka and Takeuchi, 1995; Biggiero, 2001).

This reflexive orientation towards the future inverts the time axis locally. However, a local inversion of the arrow of time may increasingly 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 also be globalized (Coveney and Highfield, 1990; Mackenzie, 2001; Urry, 2000). I return to these issues of codification and the inversion of the time dimension in later chapters, but let us first follow the construction of a knowledge base from the historical perspective (Figure 1).

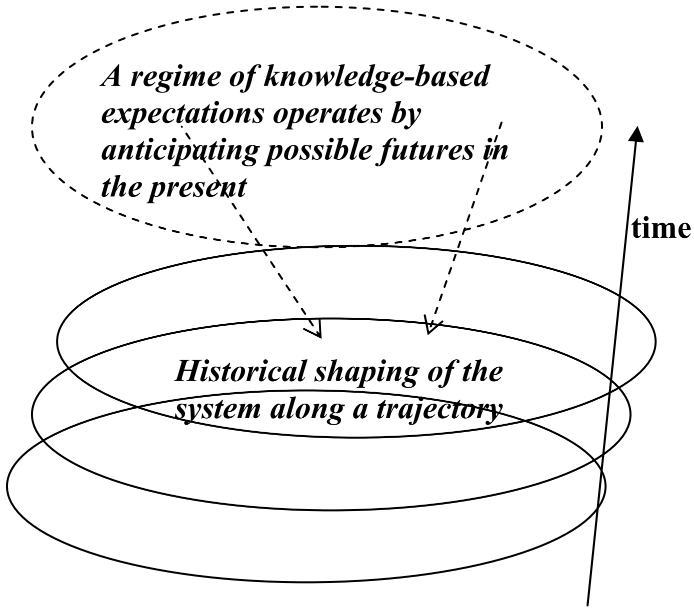

Figure 1.1: A technological trajectory follows the axis of time, while a knowledge-based regime operates within the system in terms of expectations, that is, against the axis of time.

Before the emergence of a knowledge-based economy, the economic exchange of knowledge was first developed as distinct from the exchange of commodities within the context of a market economy. For example, the patent system can be considered as a typical product of industrial competition in the late nineteenth century (Van den Belt and 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 and Trajtenberg, 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 itself has existed as a subdynamic of the socio-economic system in advanced capitalist societies since approximately 1870 (Braverman, 1974; Noble, 1977). Schumpeter ([1939], 1964) is well-known for his argument that the dynamics of innovation upset the market mechanism (Nelson and 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) and technological development (a shift of the production function towards the origin; Sahal, 1981a and b; Figure 1.2). Technological innovations enable enterprises to reduce factor costs in both labor and capital (Salter, 1960).

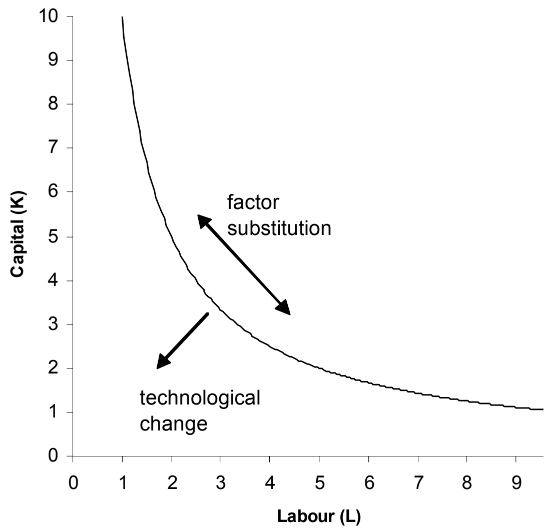

Figure 1.2: Using the production function (Q = c.K.L), factor substitution and technological change can be distinguished as perpendicular subdynamics.

Innovative change *over time* (novelty production) and economic substitution at each *moment of time* can thus be considered as two analytically independent subdynamics. However, these subdynamics can be expected additionally to 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, or retained. Nation-states, for example, can be expected to differ in terms of the relationship between their respective economy and its knowledge base (Lundvall, 1992; Nelson, 1993). Different fields of science are organized nationally and/or internationally to varying degrees (Wagner and Leydesdorff, 2003; Walsh and 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: