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AVOIDING EVOLUTIONARY INEFFICIENCIES IN INNOVATION NETWORKS

Andreas Pyka

Universität Hohenheim | Forschungszentrum Innovation und Dienstleistung

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Andreas Pyka

University of Hohenheim, Faculty of Business, Economics and Social Sciences, Institute of Economics, D-70593 Stuttgart, Germany, Tel. +49 711 459 24481, Fax +49 711 459 24488, e-mail a.pyka@uni-hohenheim.de

Abstract

Innovation policy is in need for a rational which allows the design and evaluation of policy instruments. In economic policy traditionally the focus is on market failures and efficiency measures are used to decide whether policy should intervene and which instrument should be applied. In innovation policy this rational cannot meaningfully be applied because of the uncertain and open character of innovation processes. Uncertainty is not a market failure and cannot be repaired. Inevitably policy makers are subject to failure and their goals are to be considered as much more modest compared to the achievement of a social optimum. Instead of optimal innovation, the avoidance of evolutionary inefficiencies becomes the centrepiece of innovation policy making. Superimposed to the several sources of evolutionary inefficiencies are so-called network inefficiencies. Because of the widespread organisation of innovation in innovation networks, the network structures and dynamics give useful hints for innovation policy, where and when to intervene.

Keywords

Innovation policy, innovation networks, uncertainty, exploration and exploitation, evolutionary inefficiencies, policy rational

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1. Introduction

Today innovation networks, innovation clusters and innovation systems are an integral part of innovation policies worldwide (e.g. EU Commission 2008, OECD 2009, World Bank 2010) which enjoy an increasing popularity in practical innovation policies since more than 20 years. Although frequently applied in practice, from a theoretical point of view, the effects of innovation networks are still debatable. The reason for these difficulties of theoretically integrating knowledge exchange in networks and deviating policy conclusions focusing on network structures are to be seen in the theoretical body of mainstream economics, which considers innovation as a part of *normal* economic activities and decision-making following the idea of optimization. For economic policy making this calls for a policy rationale allowing for the evaluation of innovation network policies within the standard efficiency-oriented framework.

Since the 1990s the idea of Innovation Systems (IS) has become very prominent in modern innovation economics and innovation policy. The proponents of innovation systems underline that the neoclassical market failure approach can be dismissed to justify technology policy. Instead, the variety of institutions and actors that are involved in innovation and the resulting complex interactions among them give room for technology policy without referring to market failures in order to justify the non-market parts of the system (Nelson, 2009). This switch from the neoclassical to the systemic evolutionary view opens up new possibilities of envisaging policies focussing on innovation and in particular on innovation networks within a theoretical framework in which innovation processes are considered as collective learning, experimenting and problem-solving processes.

The innovation systems literature developed a comparative institutional approach on the level of National Innovation Systems (NIS) (Freeman, 1987, Lundvall, 1992, Nelson, 1993), on the level of Sectoral Innovation Systems (SIS) (Malerba 2004) and on the level of Regional Innovation Systems (RIS) (Cooke and Morgan, 1998). An important common ingredient of these innovation system approaches is the rejection of the linear view of innovation processes in favour of the systemic view (e.g. the *chain-linked model* of Kline and Rosenberg, 1986) where the functional as well as dysfunctional and bi-directional relations between the various phases of the innovation process and the different actors involved are crucial. The major message of the systemic view is to understand that new knowledge does not spillover automatically among the different actors involved in innovation processes. To understand the knowledge creation and diffusion processes on the national, the regional as well as the sectoral level one has to understand that the various actors (which besides commercial firms explicitly encompass all other actors that are involved in the innovation process) are interlinked in *innovation networks*.

Most basically, innovation networks consist of actors and linkages among these actors (for a general overview on economic theories of innovation networks see Pyka (2002); in Buchmann and Pyka (2011) a survey on the recent literature on innovation networks can be found). The idea of actors is conceived very broadly and encompasses besides firms, individuals, research institutes and university laboratories also venture capital firms and standardization agencies. Links among the actors are used as channels for knowledge and information flows as well as financial flows as in the case of venture capitalists. The links among actors can either be formal (R&D joint ventures, strategic alliances, research consortia etc.) or informal, based on personal contacts and recommendation. In essence, innovation networks provide the networking actors with knowledge that might be complementary to their own knowledge as well as with other resources necessary to run an enterprise and to survive in innovation competition. Accordingly, innovation networks are a means for the industrial organization of research and development, which is particularly relevant in knowledge-intensive industries with high requirements concerning the competences of involved actors, e.g. fast development of new knowledge, design of interfaces between different (modular) technologies, combinatorial (complex) innovation etc.

The establishment, manipulation and governance of innovation networks therefore are considered to be appropriate contact points for an innovation policy aiming to create prolific conditions for a dynamic innovation-driven economic development. From this the question arises how the network-based innovation policies are to be designed and evaluated. The aim of this paper is to develop a framework which justifies policy interventions from a dynamic network-based angle. This framework will allow for a rationale for innovation policy in general and highlight the role of innovation networks in particular.

In the following section, the efficiency-oriented neoclassical approach is analyzed on its applicability for this purpose. It turns out that severe problems arise if innovation processes are considered as true uncertain processes, which is constitutive in the systemic and evolutionary view. In the third section dealing with knowledge-generation and -diffusion processes, the prerequisites of a future-oriented economic development are identified. These processes are threatened by several evolutionary inefficiencies which substitute the idea of an efficient innovation processes underlying the neoclassical rational and offer a new target for innovation policies. In section 4 the concept of evolutionary inefficiencies and their avoidance are used to derive guidelines for an innovation policy design focussing on innovation networks.

2. "Repairing Market Failures" - the Rational for Innovation Policy?

Economic policy in general aims at the manipulation of structures in order to provide the prerequisites for an improved allocation of resources and allowing for a prosperous future-oriented economic development. Within the mainstream neoclassical framework, a widely accepted benchmark for policy interventions is the so-called *social optimum*, the reference case which is achieved in an economic system by a *benevolent social planner* who considers the individual welfares of all market participants (e.g. Arrow, 1951). Due to *substantial rational* individuals the market participants automatically realize the welfare optimum in a static setting. And due to perfect foresight the market participants are also able to realize an inter-temporal welfare optimum because they take into account all future impacts of their economic decisions.

However, for such social optima to be realized a number of prerequisites are to be fulfilled which in reality are not guaranteed and which are responsible for so-called *market failures*. Therefore, policy interventions are considered as correctives which restore optimal individual incentives for economic decision making in order to achieve the social optimal outcome as suggested by the benchmark.

Does this normative policy concept also work in the case of innovation policy? And why is innovation policy an important application of economic policy and therefore subject to economic considerations? To answer the latter question first: Technological change and more general innovations are considered to be the decisive factors determining economic growth (Solow, 1956, 1957). For this reason, latest since the 1950s, the attention of economic policy encompasses also innovation processes. As deficiencies or market failures incomplete incentives of market participants to be engaged in innovation are detected on a static level. Because of free-rider problems which stem from imperfect appropriability conditions of new technological knowledge, the individual incentives to invest in research and development (R&D) are below the social optimal incentives (Arrow, 1959). In this case the guideline for innovation policy says: Restore the individual incentives until the marginal return of R&D equals the marginal costs of R&D (e.g. by R&D subsidies). The dynamic goal of innovation policy foresees an economy to grow along its equilibrium trajectory and to achieve the maximum growth by inter-temporal cost-minimization. Transitions from one technology to another (i.e. structural change) are smooth processes taking into account e.g. the vintages of production technologies and their requirements for an adjusted depreciation or the adjustments of the educational infrastructures in order to create the required human capital. Like in the static case, the installation of new technologies is easily done due to the fully developed competences of market participants. Innovation policy is intervening only when achieving this cost-minimizing path is endangered by e.g. sunk costs which make a retreat from obsolete markets difficult (e.g. tax policies) or frictional problems due to the required shift in human capital (e.g. educational policy).

To design and to evaluate innovation policy instruments in this vein, the costs of innovation policies are to be confronted with the rewards of the innovation policies. For this purpose, cost-benefit considerations are applied which provide for several efficiency measures. In general, these efficiency measures set in relation the amount of resources which are to be invested in order to achieve a certain outcome. As the outcome is (well) defined by the social welfare optimum, the policy instrument is chosen that allows for achieving this goal with a minimum requirement of resources. Innovation policies focussing on the optimal incentives to invest in R&D are evaluated according to a *static efficiency* concept relating the costs of the policy intervention (i.e. the input of innovation policy) to the achievement of the optimal incentive level (i.e. output of innovation policy). Various instruments (e.g. R&D subsidies, R&D tax credits, institutional adjustments like e.g. patents) are then compared and the most efficient one i.e. the one with the best cost-benefit relation is chosen. In a similar way the *dynamic efficiency* concept is applied by relating the costs of policy instruments with the given goal of achieving the well known and ex-ante specified inter-temporal cost-minimizing path.

To summarize: In neoclassical welfare economics innovation policies are treated similar to any other kind of economic policies: Within its particular set of assumptions (substantial rationality and equilibrium) market failures are repaired. The task for policy makers is to restore the optimal incentives for an efficient allocation of resources in a static and a dynamic perspective. Due to well-defined economic decision problems the choice of policy instruments follows standard efficiency considerations.

Beginning latest in the mid of the 1970s the neoclassical framework was criticized of being not suited for the analysis of innovation processes and their impact on economic development. The proponents of this fundamental critic refer to the ideas of Joseph Alois Schumpeter (1912) who conceived innovations as the force which endogenously destroy the *circular flow* (i.e. economic equilibrium). The central point of this upcoming criticism focuses on the assumption of *substantial rationality* which completely is in conflict with the very nature of innovation processes, namely *true uncertainty* (Knight, 1921). Innovations are characterized by true uncertainty which cannot be approximated by probability distributions over a known state space. In other words: If an innovation would have been known ex-ante, it would not have been an innovation. Instead, the state space itself is unexpectedly modified by its innovative extension. Accordingly, the application of optimization calculus, even in the form of the maximization of expected values, is no longer possible. Erdmann (1993) coined the notion of *pathological pessimism* of neoclassical economics with respect to innovation because a *homo oeconomicus* would always prefer an extremely small pay-off against a true uncertain pay-off of an innovation, how large it ever might be.

Consequently, if true uncertainty is considered to be a constitutive feature of innovation, the concept of substantial rationality is misleading and counterfactual as innovation processes would no longer take place. If innovation processes are treated realistically, they are no longer to be envisaged as optimization processes. This fundamental disability to integrate innovation processes into the standard economics program leads to the emergence of an understanding of economic development driven by innovation as a cultural evolutionary process (Nelson and Winter, 1982). Innovation processes are now considered as complex experimental processes with a high probability of failure, or more generally, innovation processes become trial-and-error processes where learning and acquiring of competences of economic actors are central. Instead of substantial rationality the concept of a *procedural rationality* (Simon, 1976) has to be applied which offers scope for learning and imperfect knowledge bases of economic actors.

3. Consequences for Innovation Policy – the lost Benchmark

This consideration of true uncertainty has strong implications for innovation policy. Uncertainty is qualitatively very different from market failures which are central in the neoclassical justification of innovation policies designed to repair market imperfections. Uncertainty instead is a condition-sine-qua-non of innovation processes and cannot be repaired. On the contrary, also the social planner is confronted with uncertainty and therefore comes with incomplete knowledge on future developments and a high probability to fail with his interventions in innovation processes.

For innovation policy the consideration of true uncertainty has the painful consequence that the benchmark of a social optimum is inevitably lost. And related, also the efficiency concepts in their traditional interpretation are no longer applicable to design and to evaluate innovation policies. Economic evolution in principle is an open process which does not follow an ex-ante given and well specified goal. In Dosi's (1988) words: "Almost by definition, what is searched for cannot be known ex-ante with any precision before the activity itself …, so that the technical (and, even more so, the commercial) outcomes of innovative efforts can hardly be known ex-ante.” In innovation processes failure and inefficiencies have to be accepted to be on the order of the day (Metcalfe, 1994). Of course, in some situations better prerequisites for economic development can be identified than in some other situations. The goals for an innovation policy then *only* can be to identify and support prolific conditions for innovation processes and to avoid bottlenecks for a future-oriented economic development. The epistemological caveat of true uncertainty is always present and relativizes every ex-ante selection. Instead of focussing on well specified goals, innovation policy has to focus on the innovation process in its own.

For the design and the evaluation of innovation policy instruments follows: If economic development driven by innovation is considered as an evolutionary process, efficiency concepts are no longer applicable because no well specified goal can be derived ex-ante. Instead, and much more modestly, innovation policy has to be designed and evaluated according to the ability to avoid *evolutionary inefficiencies* whenever possible. As *evolutionary inefficiencies* we define situations which clearly restrict potentials for future development.

3.1 Prerequisites of a Future-Oriented Economic Development: Knowledge Generation and Diffusion

What are the prerequisites of a future-oriented economic development which give a hint on possible interventions of innovation policy? For sustainable innovation processes the origination of knowledge is decisive: The appearance and application of new knowledge stands behind the intentional introduction of all kinds of novelties. Therefore, knowledge generation and diffusion processes move into the centre of interest of innovation policy.

Basically new knowledge originates in two different ways: (i) In the tradition of Adam Smith’s (1776) emphasis on division of labour and specialisation, a first stream in the literature focuses on the need of concentration on a narrow subset of knowledge in order to excel. (ii) Rather contrary, in modern innovation economics learning from diverse knowledge bases is considered to be an equally important source of new knowledge. The re-combination of heterogeneous knowledge-bases continuously leads to new knowledge (Simon 1985). Accordingly, the larger the diverse knowledge pool in an economy is, the better are the prospects for innovation.

Within modern management theories this tensioned relationship between the variety of knowledge fields and specialisation within single knowledge fields has become famous under the heading *exploration* vs. *exploitation* (Cyert and March, 1963). Exploration includes the discovery of new techno-economic opportunities, thereby increasing knowledge variety. For this purpose the whole space of opportunities is screened for new promising alternatives. Exploitation instead focuses on the advancement in a well defined technological area. In other words, exploitation deals with the achievement of a high degree of sophistication which can only be reached by specialization.

Both knowledge generation mechanisms in isolation will not allow for a sustainable generation of new knowledge. Exploration only, i.e. the discovery of new technological opportunities, is not sufficient for economic development, because without advancing and excelling in the new technologies, the economic rewards will not be realized. Exploitation only, i.e. the mastering and improvement of a new technology, also is not sufficient for a sustainable innovation process, as the techno-economic opportunities of a given technology are only limited and technological opportunities will sooner or later be exhausted. As a consequence the innovation process and with it the economic development will come to a rest (Coombs, 1988, Dosi, 1982).

These considerations on the firm level also hold on the economic level: For economic growth, Saviotti and Pyka (2004) show that for the structural transformation of economies indeed increasing productivity in a single technology (i.e. industry) and the emergence of new industries are to be considered as complementary for economic development. By increasing the productivity in older industries, an economy earns the resources which are necessary to discover new techno-economic opportunities which again are necessary for the emergence of new industries. Without the search for new techno-economic opportunities the economy will end up in stagnation; without increasing the productivity in existing industries, the economy will run short of resources which are to be invested in the search for new techno-economic opportunities.

Therefore, the question to focus on exploration or exploitation opens up an important dynamic dimension in the evolution of knowledge and economic development (e.g. the cycle of discovery, Gilsing and Nooteboom, 2006). In the course of an industry life cycle the answer on which activity to focus on, will turn out differently. In the opening phase of a new industry, innovation-driven entrepreneurial entry usually is combined with the exploratory search for promising technological trajectories with a positive effect on knowledge variety and the creation of niche markets. In more mature stages of an industry life cycle, however, the research and development activities become focused on the exploitation of specific opportunities in order to improve competitiveness. This leads to a decreasing variety of knowledge fields and to a strong accumulation of specialized knowledge. The knowledge base of the industry under consideration necessarily locks-in to a rather small subset of knowledge fields. In this sense, *evolution consumes its own fuel*, as variety is decreasing with the advancement along certain technological trajectories (Metcalfe, 1995). Without a replenishment of the knowledge base through e.g. basic research activities and the entrepreneurially implementation of the new knowledge, the economic development runs the risk of coming to a halt.

A further obstacle for knowledge evolution and the related innovation-driven economic development has to be seen in a potential lack of diffusion of the new knowledge in the population of firms. Obviously, without a wide diffusion of the new knowledge, innovation will be an insular phenomenon without any macroeconomic effects on income per capita, productivity and economic growth. Sources of this lack of diffusion are to be searched again in dependence of the exploratory and exploitative phases of knowledge generation. In the exploratory phase knowledge diffusion might be constrained by a malfunctioning knowledge transfer between actors and institutions engaged in basic research and the population of firms. A similar negative effect on the diffusion of new explorative knowledge stems from an underdeveloped entrepreneurial activity caused by lacking venture capital or by a missing future orientation of an education policy which not early enough manage to move into the new fields in order to provide the competences required by the companies (Hanusch and Pyka, 2007).

Also in the exploitative phase of knowledge generation the diffusion can be strongly restricted by missing links among the firms in an industry. Today's technological solutions are most often characterized by a high degree of complexity which means that the variety of different knowledge fields which are relevant for a new technology is considerably large. Teece (1988) coined the notion of *combinatorial innovation* in this context. This means that hardly any firm is able to master all technological areas which are relevant for a new technology, not to mention to push ahead the development of the respective knowledge fields. Without a dense network of linkages with other actors engaged in the innovation process, the knowledge cannot diffuse widely and rapidly enough to unfold its positive impacts in an economy.

To summarize: the following four issues are identified as necessary conditions for an innovation-driven economic development: (i) Exploration of new techno-economic opportunities in order to increase the variety of knowledge fields. (ii) Exploitation of techno-economic opportunities to realize the economic benefits of innovation processes. (iii) Mastering the dynamic trade-off between exploration and exploitation activities in order to provide for a rich variety of knowledge assets in the long run and simultaneously excel in a small subset of knowledge fields in the short run. From a dynamic perspective, the economic system has to balance an adequate mix of explorative activities, where new techno-economic opportunities are discovered, and exploitative activities, which foster economic growth and income development. (iv) For the knowledge generation and diffusion processes to work adequately and to unfold the beneficial effects for an economy, the relevant actors are to be interlinked, so that the knowledge can travel among the various agents and the various phases of the innovation process and thereby get improved and increasingly applied.

3.2 Evolutionary Inefficiencies

Each of these four prerequisites is endangered to be not fulfilled and to jeopardize innovation-driven economic development. Accordingly, four different sources of evolutionary inefficiencies can be derived: (i) exploration inefficiencies, (ii) exploitation inefficiencies, (iii) balance inefficiencies and (iv) network inefficiencies.

(i) A situation where *exploration inefficiencies* hinder economic development can be detected when the prevailing research orientation in an economy is biased towards an applied orientation. Sooner or later the intensive technological opportunities (Coombs, 1988), i.e. the specific opportunities of a certain technology are depleted and technological progress considerably slows down or improvements of a similar magnitude become increasingly expensive because of missing extensive opportunities (Coombs, 1988), i.e. the opportunities which arise from cross-fertilization with other technologies. A similar negative effect for economic development can be traced back to an underdeveloped attitude to found new companies in the economy or by administrative hurdles hindering entrepreneurial activities. Without start-up companies which advance new knowledge into innovations, the transfer of knowledge from basic to applied research is considerably hindered.

(ii) Whereas exploration inefficiencies can be found in situations where the economic actors are none the less intensively engaged in R&D, *exploitation inefficiencies* are caused by a too low research intensity. The missing research activities of firms can be traced back to either a missing awareness of the companies that they are confronted with innovation competition, e.g. not-invented-here-syndrome (Katz and Allen, 1982) or missing absorptive capacities (Cohen and Levinthal, 1989). Yet another reason might be a shortage of adequate competences in the labour force, which restricts access to the new technologies. Without a sufficient level of R&D as well as by a mismatch of the competencies available and requested on the labour market, the accumulation of relevant knowledge in new industries very likely is too slow and cannot trigger the innovation dynamics necessary to survive in the global competition for new industries.

(iii) Although the fast accumulation of knowledge is a prerequisite for new industries to develop, it bears a significant danger concerning long-run developmental potentials. A too early concentration on a particular set of knowledge (i.e. exploitation) excludes promising alternative fields of knowledge and might lead to *lock-in effects* which in a dynamic perspective drastically reduce the possibilities of development. In consequence, not all promising alternatives are followed up and significant techno-economic opportunities are not explored. These *balance inefficiencies* stem from a patchy mixture of exploration and exploitation activities which lead to a too early rejection of promising new knowledge. Simultaneously, the economic actors do not get rid of exhausted techno-economic opportunities in time and stay for too long in the previous successful technologies (Eliasson, 1991).

Quite opposite, balance inefficiencies might also be caused by a too high variety of competing knowledge fields when a new industry has to move into the exploitation stage. Without the development of a dominant design (Abernathy and Utterback, 1975), the agreement of interfaces which allow for complementarities among different technologies and industrial norms, new industries run into trouble in their early periods. Without reaching a certain size of the industry, the new technologies cannot diffuse as rapidly and widely as it would be necessary in order to exert an economic impact.

(iv) *Network inefficiencies,* finally, stem from missing and/or malfunctioning links among economic actors participating in innovation processes. Network inefficiencies in the sense of missing links among actors hamper the diffusion of new knowledge and hinder the discovery of cross-fertilization opportunities among seemingly disconnected knowledge fields. But not only missing links cause network inefficiencies. They might also be caused by too large networks which imply too high coordination efforts or by an imbalance of linkages among actors which opens up possibilities for strategic control of knowledge flows within the innovation networks (e.g. gatekeepers and structural holes, Burt, 1992, Ahuja, 2000), or by decreasing network dynamics which exclude actors with dissimilar knowledge. In these cases not only the sheer existence of linkages among actors is relevant for innovation policy but also their distribution as well as their qualitative features.

Network inefficiencies are to be considered as a general concept which is superimposed to the other inefficiency concepts. Due to the complex nature of modern innovation processes the knowledge required for successful innovations is dispersed and the relevant actors do have to exchange and combine the knowledge in networks in order to successfully innovate. Innovation processes organised in innovation networks therefore shift the attention of innovation policy to the network inefficiencies. The following interactions between network inefficiencies and the other evolutionary inefficiency concepts are possible:

Concerning the exploration inefficiencies, not only a missing basic research orientation of economic actors can be made responsible for exhausted economic growth potentials, but also missing links among universities and other basic research-oriented institutions and applied research-oriented firms. Without being embedded in suited network structures which connect these different groups of actors, the necessary knowledge transfers fail to appear. New achievements in basic research literally stay disconnected and never reach the applied dimension with strong negative effects on long-run innovation performance.

However, strong and encompassing innovation networks might cause exploitation inefficiencies. This is the case of malfunctioning network ties which hinder the discovery of novelties and the creation of new techno-economic niches. The organization of industrial R&D in innovation networks runs danger of a knowledge selection within the innovation network which repeats the Not-Invented-Here-Syndrome on the network level.

From this also follows that network inefficiencies can appear together and aggravate the balance inefficiencies by supporting the emergence of lock-in effects, thereby excluding promising alternatives at a too early stage. In cases where the entry into innovation networks is blocked or potential members are excluded because of an assumed incompatibility of their knowledge base, the knowledge of the members of the innovation network increasingly aligns and makes novel combinations within the innovation network less likely.

However, and contrary, if the balance inefficiencies are caused by missing norms and standards, the negative effects on industrial evolution are aggravated by missing links among actors. As innovation networks offer the channels for communication and knowledge transfer, they are considered to be the ideal organizational form for the development of common standards and norms necessary to spur industrial development in the transition between the explorative and the exploitative phase of industrial evolution.

The evolutionary inefficiencies discussed in this section threaten economic development (Pelikan, 2003): Economic development might be blocked because of lock-ins into inferior technologies (exploration inefficiencies). Also, excessively wasteful developments due to the inability of the economic system to trigger sufficient industrial dynamics might restrict prolific economic development (exploitation inefficiencies). Finally, economic development can become misdirected because of a wrong balance between the exploration and the exploitation orientation (balance inefficiencies). Because of the outstanding role innovation networks play in complex innovation processes, network inefficiencies are clearly superimposed to these evolutionary inefficiencies and therefore offer promising starting points for innovation policies.

4. Innovation Policy and Innovation Networks

The consideration of true uncertainty in innovation processes unpleasantly implicates the loss of a benchmark which might have offered a point of reference for the design of innovation policies. What remains instead of a goal-orientation in innovation policy, i.e. the achievement of ex-ante well specified situations, is a process-orientation, i.e. taking care of prolific conditions for an innovation-driven economic development. This process-oriented view, which is in line with the systemic and evolutionary approaches in innovation economics, advises a rationale for innovation policy which focuses on the avoidance of bottlenecks for economic development, i.e. evolutionary inefficiencies.

As uncertainty in innovation is ubiquitous, also policy makers cannot escape it and therefore permanently run the risk of failure in their attempts to manipulate innovation processes. Focussing on well-specified technological goals in a mission-oriented policy design (Ergas, 1987, Cantner and Pyka, 2001) inevitably provokes misdirected developments. Although failure per se cannot be excluded, the risk to waste public money is considerably smaller when the focus of innovation policy is on knowledge generation and diffusion i.e. follows a diffusion-oriented design (Ergas, 1987, Cantner and Pyka, 2001).

In the efforts to govern innovation processes useful hints for the design of innovation policies can be found in the structures and dynamics of the underlying innovation networks. The complex and combinatorial nature of innovation catapults innovation networks into the centre of alertness of innovation policy: first, innovation networks are a widely spread organisational form for innovation processes and second, network inefficiencies are superimposed to the other evolutionary efficiencies and therefore can be considered as the entrance point for endeavours to manipulate innovation processes.

In general, innovation networks offer a flexible environment for innovation processes by horizontally and vertically interlinking the involved actors. The linkages in the networks can be considered as channels for knowledge transfer that are essential in complex innovation processes where different fields of knowledge are relevant and the actors are specialised in a small subset of knowledge fields only, namely their core competencies. Vertically, innovation networks connect the different steps in the value chains (resource industries, investment good industries, producers and customers) as well as the different phases of innovation processes (i.e. basic- and applied-oriented research). Horizontally, in innovation networks the actors within industries are connected to exchange knowledge, mutually learn, develop standards and norms and advance the underlying technologies. Although one could principally expect these innovation networks to emerge and to develop in a self-organisational way, obstacles in their emergence, misguided developments and malfunctioning links cannot be excluded (e.g. Pyka and Windrum, 2003).

This is where the *network inefficiencies* enter as a target for policy intervention. The creation, the growth and the closure of innovation networks can be influenced by innovation policy instruments. Policy can offer incentives to enter into R&D collaborations which then serve as a kernel for network evolution. Also, policy programs can be implemented which focus on knowledge transfer between basic and applied research by strengthening university-industry-linkages. Public actors themselves can enter innovation networks and play important roles as network facilitators, network triggers etc. by inviting other actors to join the innovation network, by increasing the coverage of different knowledge fields and by taking over important coordination tasks.

Obviously, claiming that innovation policies' concern should only be about the creation of innovation networks and the strengthening of linkages among actors within an economy would not be a sufficient guideline for the struggle with evolutionary inefficiencies. Innovation networks are complex organisational forms whose structures are subject to significant changes in time. Structures which are beneficial in exploratory phases might turn out as obstacles in the exploitative stages of the innovation process and vice versa. In the literature indicators from graph theory and social network analysis like the centrality of actors in networks, the average path length among actors, the density of networks etc. are discussed which describe particular occurrences of network structures and their meaning for the functioning of innovation networks (see Buchmann and Pyka, 2011 for a survey).

An example will help to illustrate these network dynamics: Saviotti and Catherine (2008), for instance, analyze time series of innovation networks in the bio-pharmaceutical industries and found characteristic patterns in density and centrality indicators which, because of the strong innovative performance in these industries, might be considered as exemplary for other knowledge intensive industries. In the early exploratory phases of the industries the observed networks are characterized by a decreasing density. The networks are joined by a growing number of firms which bring in their specialised knowledge, thereby increasing the variety of knowledge fields accessible in the network for exploration activities. The linkages in this growing innovation network, however, are not frequent and therefore its density decreases (see fig. 1). In exploitative stages, when the knowledge base in the innovation network already matures to some extent, the network stops to grow and instead the linkages among actors become much more frequent, i.e. the density of the network increases again (see fig. 1). This increasing density indicates strong knowledge transfers among actors in order to increase the efficiency of an innovation process along a well-defined technological trajectory in the exploitative stage.

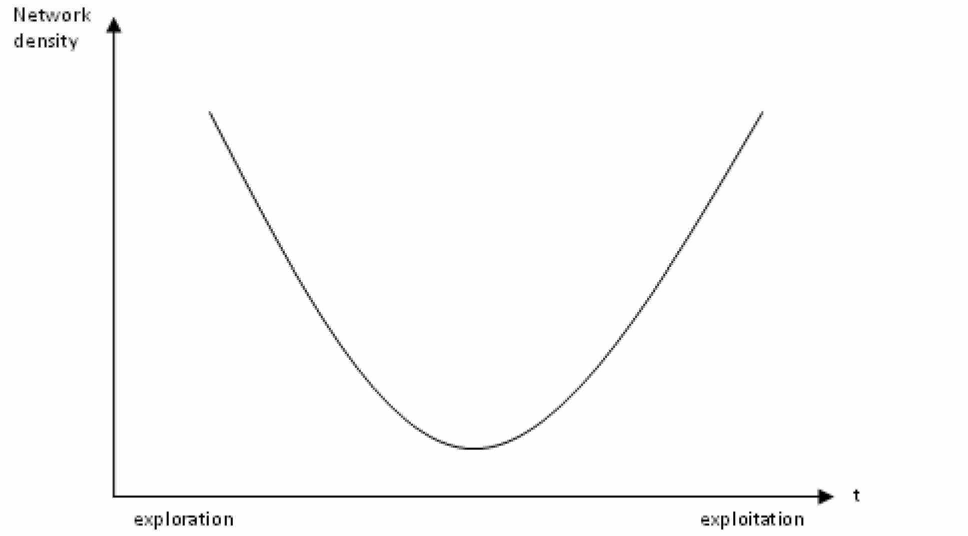

Figure 1: Decreasing and increasing network densities during the industry-life-cycle

In a similar vein, the centrality in the network, an indicator which measures the distribution of linkages among actors, varies systematically (see fig. 2). In early explorative stages, centrality measures are small, indicating a more or less equal distribution of network activities. In later stages, however, the centrality is strongly increasing and the innovation networks even show to some extent scale-free attributes (Barabasi and Albert, 1999). The reason for this change is to be seen in the two different populations of firms which basically create the innovation networks in bio-pharmaceuticals, namely small start-up companies specialised in a small subset of biotechnology competences and large pharmaceutical companies with large and diversified knowledge bases. The large pharmaceuticals entertain a lot of cooperative relationships with the small companies in the exploitation stage, whereas each small company generally has only a small number of linkages in the network. In the early explorative stages of the industry life cycles such differences do not appear.

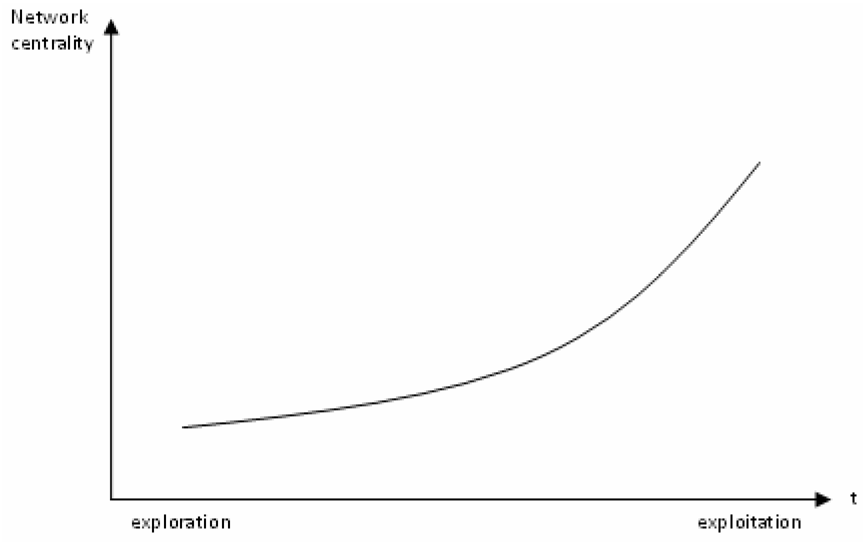

Figure 2: Increasing network centralities during the industry-life-cycle

The example illustrates that the structures and dynamics of innovation networks are characterized by specific patterns which are observable through a number of indicators describing networks. In a process-oriented perspective, innovation policy can infer from these indicators and their development during the life-cycle of a certain industry to decide whether and how to intervene in order to avoid potential network inefficiencies. In the early explorative stages of a technology, technological variety can be considered more important than dense relationships within the innovation network. If the entry rate in the network starts to decrease, innovation policy is asked to intervene and to create conditions which allow for a broadening of the underlying knowledge base. Similarly, in exploitation stages a stagnant network density might indicate that the industry has difficulties in developing a dominant design. In this case, innovation policies focussing on increasing relationships within the network will support the creation of common standards and norms and thereby emphasize and accelerate industry evolution. In the first case innovation policy will avoid exploration inefficiencies by taking care of the network inefficiencies; also balance inefficiencies which might stem from a too early lock-in into a certain technology or by the 'not-invented-in-the-network' phenomenon, are avoided. In the latter case exploitation inefficiencies are avoided by smoothing out network inefficiencies.

Because of the unavoidable true uncertainty in innovation processes, failure cannot be excluded and accompanies firms as well as policy actors. In particular, to identify the passage from exploration to exploitation activities causes severe difficulties and unique patterns in the evolution of the innovation networks are not to be expected.

Nevertheless, by focussing on innovation processes instead of well-specified innovative outcomes and by observing the development of the underlying innovation network structures, potential evolutionary inefficiencies are figured out in time and allows for counter steering of innovation policy.

5. Conclusions

In practical innovation policy an increasing focus on innovation networks cannot be neglected. Although popular in application, the rational for innovation networks as well as their evaluation is not clear from a theoretical perspective. We argue that the focus on market-failure is not applicable in innovation policy because of the true uncertainty of innovation processes. Therefore, innovation policy has to apply a much more modest rationale which abandons the possibility of optimal solutions and instead takes care to avoid situations which hamper economic development.

Because of the outstanding importance of innovation networks in the organization of R&D processes, they offer a promising starting point for a process-oriented innovation policy. Network inefficiencies are superimposed to other evolutionary inefficiencies and therefore are to be considered as a primary target for innovation policy. In this perspective, the structures and dynamics of innovation networks become the focus of attention as well as the starting point of action in innovation policy.

Obviously, such an innovation policy requires substantial information on the innovation networks, their architectures and their dynamics. So far, only limited knowledge on specific patterns of innovation network dynamics is available. Furthermore, unique patterns which easily can be drawn upon to deviate suited actions of innovation policy are not to be expected because of sectoral and technological specificities. From this follows for the future research agenda, to emphasize the empirical research on innovation networks, to create new data bases on innovation networks and to improve the indicators for the analysis of complex innovation networks.

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Universität Hohenheim
Forschungszentrum
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Fruwirthstr. 12
D-70593 Stuttgart
Phone +49 (0)711 / 459-22476
Fax +49 (0)711 / 459-23360
Internet www.fzid.uni-hohenheim.de