

Informal networking

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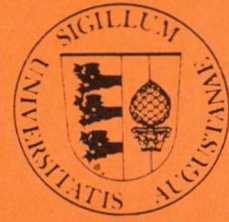
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Informal Networking

von

Andreas Pyka

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Abstract:

Modern technical solutions are characterized by an increased interrelatedness between heterogeneous actors and knowledge-fields. No single firm can keep pace with the development of all relevant technologies. Therefore, firms have to get access to external knowledge sources. Informal networks or cooperative environments are an organizational device for external learning. In the paper the master-equation approach is applied to model the evolution of an informal network. Using this method, we can totally dispense with the rigorous assumption of perfect rationality, usually employed when modeling cooperative behaviour. Our results show, that under a regime, where technology is of major importance, know-how sharing and the emergence of informal networks is possible via self-organization.

JEL-Classification: O34

1. INTRODUCTION

Firms operating in technologically intensive environments are increasingly confronted by a growing number of bodies of knowledge. This is due to a feature of modern economies characterized by strong technological development in which information flows dominate over physical flows of commodities (Clark and Juma (1987)). Therefore, the evolution of those economic systems essentially depends upon patterns of information diffusion and information access.

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Firms actively engaged in R&D endeavours are the most important sources of new information. Consequently, modern innovation theory emphasizes the role of appropriability conditions and technological spillovers in the innovation process. In this paper we develop a model in which firms sometimes voluntarily share know-how. In doing this, we draw back to the hypothesis of R.R. Nelson (1992), *"that the public aspects of technology are there not simply because of unavoidable holes in proprietary shields, but because in many cases firms deliberately leak and share knowledge"* .

The paper proceeds as follows: In the second part, the theoretical background of the phenomenon of informal networking is discussed. Thereby, the changing requirements of the modern innovation process are emphasized. No single firm can keep pace with the development of all relevant technologies and consequently, they have to access external know-how sources. And in turn, the firms themselves constitute the most important external knowledge sources. One way of organizing these information and know-how flows are informal networks where individual complementary contributions reinforce each other.

In the third part of the paper we present a model, based on a synergetic framework. In particular the master-equation approach is used to model the evolution of an informal network. Using this method, we can totally dispense with the rigorous assumption of perfect rationality, usually employed when modeling cooperative behaviour. Our (simulation) results show, that under a regime, where technology is of major importance, know-how sharing and the emergence of large informal networks can occur via self-organization.

2. INNOVATION AS AN INTERACTIVE PROCESS

New technological solutions have increased the interrelatedness between different actors and knowledge-fields. To manage the innovation process successfully, the firms' R&D strategies and attitudes have changed. Most important in this respect is the need for flexibility¹ and the positive attention paid to external knowledge sources, especially technological spillover effects.

¹ "Flexibility ... acquires an active (dynamic) character: 'to increase' the options for the future.", Amendola, M., Gaffard, J.L. (1988), p. 43.

2.1 THE MODERN INNOVATION PROCESS

New theory of innovation emphasizes besides discoveries in sciences, the technological influence of firms which are intensively engaged in R&D. Industrial technology development exhibits increasing complexity and cannot be explained without explicitly considering the growing number of heterogenous actors, their different knowledge-bases and their special interrelationships. That is why the technological development is described as a 'cultural evolutionary process'².

- *technological opportunities*

Besides intensive technological opportunities, which shape 'normal' technical progress along a technological trajectory, there are extensive technological opportunities which describe the potential of a technology arising from often yet unknown relations with other technology fields (Coombs (1988)).

An important feature of those intensive technological opportunities is that they decrease continuously with further progress along certain technological trajectories, because further improvements become more and more difficult to achieve. The reason for this stepwise exhaustion of the intensive potentials are chemical and physical laws which constitute a growing number of technological constraints and bottlenecks. Further improvements on a specific technological trajectory cost increasing amounts of time and money. In the literature this relationship is often referred to as 'Wolff's Law'.

This, however, does not imply that progress comes to rest whenever the intensive opportunities are depleted. The different technological trajectories and their technological opportunities do not co-exist unrelatedly but they are connected by several influencing devices and feedbacks. Therefore, a single technology cannot be explained in isolation, but should be understood in a broader framework. Improvements in one technology can create totally different applications in other technologies or even totally new technological opportunities. Accordingly, nearly exhausted trajectories can be influenced by other innovations and technology fields which open up new opportunities. These relationships between different technologies and the corresponding possibilities of a fruitful enlargement of the developmental potential are described by the extensive technological opportunities of a technology.

² Nelson, R.R. (1988).

- systemic character of technological innovations

Recent developments in new technology' fields like information technology, advanced materials, biotechnology etc. have significantly changed the structure of the modern innovation process. Freeman/Perez (1988) even introduce a new Kondratieff-cycle called the 'information and communication-Kondratieff. Energy-intensive large-scale industry production will more or less be displaced by more flexible and integrated production systems heavily determined by micro-processor-technologies³. It follows that a greater variety of different technologies and an increased number of technical relationships characterize modern innovation processes.

Most new technological solutions are composed of a large number of different technologies based on a multitude of knowledge fields. Besides the mere technological know-how the firms have to acquire the knowledge of the interplay between these different technologies, often referred to as 'architectural knowledge' (Henderson/Clark (1990)). One important consequence of this systemic character are constraints which arise in these different technology fields in the course of time. A bottleneck in a certain technology may inhibit the whole innovation process, despite some other successful innovative endeavours in complementary technology' fields. Dahmen (1989) uses the notion of 'structural tension' to describe this phenomenon in the technological development which exhibits strong relationships and complementarities between different technologies.

To keep pace with technological progress or to catch-up to the technological frontier, a single firm has to master a great number of different knowledge fields. In other words, with growing complexity of the innovation process it becomes increasingly difficult to use immediately all the relevant new scientific and technological insights. Malerba (1992) states in this respect: „*This complexity has meant that multidisciplinary knowledge has become necessary for the generation and development of new products. In the computer industry, for example, the disciplines involved in the innovation process may range from solid state physics to mathematics, and from language theory to management science.*“ So called 'go-it-alone-strategies' or 'conservative strategies' which means that a firm relies only on its own R&D-endeavours, cannot be successful in such a complex technological environment.

■ Related concepts are the 'complex integrated production process' (Eliasson, 1995) and the 'information intensive production system' (Willinger, Zuscovitch, 1988).

- appropriability conditions and external knowledge sources

Imperfect appropriability conditions are the reason for technological spillovers, which make knowledge generated in the R&D laboratories of firms available for others. Accordingly, as traditional economic theory states, the incentives to invest in R&D are reduced. But are these spillovers only caused by imperfect appropriability conditions or, could firms actively influence their formation? In other words, are they unplanned spillovers (Chesnais (1996)) with incentive reducing effects or, purposefully initiated organizational devices? It would be far beyond the scope of this paper to discuss all the phenomena with respect to spillovers. In the following we confine ourselves on how spillover effects arise and investigate the different external knowledge sources, their origins and the persistence of cooperative environments, because these sources are responsible for the delivery/supply of technical information.

The main argument for imperfect appropriability conditions are the 'latent public good' features of newly generated technological know-how. To a great extent this knowledge is only partly excludable and non-rival, making R&D laboratories of firms the potential source of mighty spillovers. Accordingly, this has different impacts on the incentives of R&D. On the one hand, other firms can eventually use the new knowledge, and this will of course reduce the respective incentives to undertake costly innovative endeavours. On the other hand, this leakage of own know-how is compensated for by the opportunity to use know-how of other firms. The latter argument underlines the complementary character of R&D and is based on the assumption of bounded rational behaviour of agents which leads to the perception that innovative activities do not follow a common optimizing concept but they are to be taken as local search processes where specific cumulative experiences, knowledge, and competences as well as lock-in effects play an important and determining role.

Even within a branch this necessarily leads to a significant heterogeneity of firms which follow quite different technological paths. Because of this 'technological pluralism' the specific R&D projects are not only substitutes but often there are synergies and complementarities. The transfer of knowledge and spillover effects between firms can help to create new technological potentials - technological progress becomes collective⁴ with beneficial effects for all participating innovative firms.

⁴ Allen (1983) states in this respect: 'The essential precondition for collective invention is the free exchange of information about new techniques and plant designs among firms in an industry. ... In this line fruitful lines of technical advance were identified and pursued.' (p. 2).

Therefore, Firms themselves are in different respects a prominent source of external know-how. One set of firms struggles on the same technological trajectory, applies quite similar technological approaches, and therefore researches in the same direction. These firms constitute the intra-technological external knowledge-sources. Other firms are engaged in other technology fields and their research endeavours can accordingly provide with complementary know-how. These firms constitute the inter-technological external knowledge-sources.

2.2 INNOVATIVE ENDEAVOURS IN A NETWORK-PERSPECTIVE

Because of the more systemic character of present-day technological solutions the technological development necessarily becomes a complex interactive process involving many different ideas, heterogeneous actors, and their specific interrelationships. Now, the interplay of different actors, changes in the R&D patterns, and external knowledge sources play a fundamental role. Also the diffusion of new technological knowledge is identified as an essential part of technological development, which cannot be separated from the phenomenon of technological spillovers⁵. The essential value of this diffusion results out of using and re-combining new technologies in novel ways, thereby exerting influence on the extensive technological opportunities. In this process, however, technological spillovers are not restricted to adjacent innovation avenues. Accordingly, new ideas in one field can influence the technological opportunities in a total different technology via spillover effects⁶. This essentially delays the consequences of Wolff's Law. Hence, the capability of the innovative actors to distribute new know-how for re-combining and re-using becomes a prominent issue for the technological development of economies⁷.

- inter-firm-learning

The potential technological proximity of different innovative and imitative actors have stimulated new mechanisms of collective action and several ex-ante coordination mechanisms are already in existence. They include besides more formal forms like R&D joint-ventures or the establishing of anticipated technological standards, more informal practices, such as reverse engineering, and information exchange networks among engineers and scientists⁸. Reverse engineering means the unvoluntary leakage of new technical information, whereas informal

⁵ See Eliasson (1995).

⁶ In the literature those effects are called "cross-fertilization-effects", see e.g. Mokyr, J. (1990), p. 280.

See e.g. Watkins (1991), Foray (1995a)

⁸ See Foray (1995a)

communication in networks could be understood as a voluntary information exchange. Von Hippel (1990) introduced the concept of informal know-how trading and found empirical evidence for this in several industries. Informal know-how trading is the voluntary exchange of technical informations and could be interpreted as a process of actively initiating technological spillovers. Nelson (1988, p. 318) states in this respect: "*However, in some cases firms take positive actions to make their proprietary knowledge available to others*". These new inter-firm-learning activities signal the changing nature of the technological progress and the declined ability of single actors to struggle alone with complexity.

Von Hippel suggests that one property of the kind of informal know-how trading is the reciprocity of what is exchanged, which results in a bilateral structure of the activity⁹. Nevertheless, the possibility of a reference to third parties which opens up a multilateral knowledge network is included if the requested knowledge is not available on one side of the exchange process. Inter-firm-learning is not necessarily bilateral and based on the quid-pro-quo-norm of reciprocity¹⁰. The notion '*informal networking*' seems to be much better suited to describe this phenomenon. Zuscovitch/Teubal (1995) compare this situation with trade theory and conclude that in network structures the gains resulting from cooperative behaviour are higher in the same way as multilateral trade is superior to the sum of bilateral trade.

What are the reasons for these knowledge-networks? Why do firms show cooperative attitudes? Informal networking can lead to positive sum games in internal activities for firms participating in the respective networks¹¹. Besides better meeting the requirements for adaptations due to evolving technologies and improving the efficiency in times of change, the firms expect synergistic benefits with respect to their cooperative attitudes. The amalgamation of different knowledge fields often results in the creation of something totally new, helping all involved actors to overcome the restrictions imposed by Wolff's Law. To realize these synergistic benefits it is not enough, only to *know-what* others do, but the firms need even to *know-how* the respective technologies function and work together. And, for this inter-firm-learning of often long-ranged cumulative, tacit and specialised know-how, a stable and long

⁹ The reason for this restriction on the bilateral case can be seen in the analytical framework von Hippel uses. A two-persons-prisoners'-dilemma is applied to describe the structure of the informal know-how-exchange.

¹⁰ See e.g. Zuscovitch/Teubal (1995), Kobayashi (1995), Fusfield, Haklisch (1985), Hagedoorn, Schakenraad (1990). "... supply is not necessarily to those who have provided information, but can be to a network of which they are only a part.", Macdonald, S. (1992), p. 55.

¹¹ Dodgson (1994), p. 286 speaks of 'the improved ability to deal with complexity'.

lasting cooperative environment is necessary¹². Clark and Juma (1987, p.85) introduced the notion of 'evolutionary articulation' characterized with an essentially resonating feature to describe this context: *"In order to achieve the status of useful knowledge it [the information flow] needs to undergo a process of evolutionary articulation between supplier and recipient"* . In a complex innovation process, networks are a new type of industrial organization capable of better dealing with this learning under high know-how requirements. Informal networking is an important mechanism for innovation diffusion and therefore an essential enabling factor of technical progress¹³.

- informal networking

But how does this process work? Informal networking means any action that can contribute to knowledge disclosure, dissemination, transmission, and communication. Many different methods such as talking, listening, showing, debating etc. at different occasions like exhibitions, conferences, and even telephone calls can be employed in some haphazard way to convey and to receive knowledge and the underlying concepts¹⁴. The informal network is founded when at congresses, conferences or other technical and business-meetings the entrepreneurs or the respective engineers make assessments of the other participants with respect to their technological fields and capabilities. They build a list of possible useful contacts on which they draw when struggling alone with reached technological bottlenecks no longer seems promising¹⁵. In this respect also information technology (IT) gains importance for the establishment of informal networks. IT offers totally new means for a rapid exchange of information and data on which firms already heavily draw via electronic mail, internet etc.¹⁶ During this process of mutual contacting, an informal network of useful technological relations will be established. This network formation is supported by the feature of non-rivalry of technological know-how which is responsible for the most salient aspect of informal networking, the acceleration of the diffusion of new technological know-how⁷ by people communicating and learning what others know.

These learning possibilities are a strong motive to behave cooperatively, which trade-off the opening up of extensive opportunities, and the acquisition of knowledge against potential

¹² Kodama, F. (1992), "... technology' fusion grows out of long term R&D-ties with a variety of companies across many different industries."

¹⁴ See Zuscovitch/Teubal (1995).

¹¹ See Kobayashi (1995).

¹⁵ See von Hippel (1990), p. 158.

¹⁶ "Information technology is a networking technology par excellence. Frøeman (1991), p. 509.

losses due to cheating and opportunism¹⁷. The increasing complexity of technological know-how forces firms to seek access to external knowledge sources with the important consequence, that they also have to be such an external knowledge source in a broader context. Through the knowledge exchange processes a stable cooperative environment can be created. According to the respective share of cooperative attitudes this increases the chance of a realization of surplus.

Besides this non-rivalry aspect, the non-appropriability feature of new technological know-how has to be mentioned again. If new knowledge leaks out because of the impossibility to appropriate the innovation rents, informal networking would not be of interest, the respective spillovers would occur anyway. Then, in a regime of total non-appropriability, firms have no possibilities to restrict access to their new ideas. But the non-appropriability problem arises only partly and there certainly are possibilities to avoid leakage of new knowledge. Other characteristics of new knowledge, already emphasized above make it, at least partly, excludable. New technological know-how is tacit, firm-, and technology-specific, and built-up in a long-ranged cumulative process. Without experience in these fields the integration and use of this knowledge is rarely possible. And, moreover, the access to new ideas can sometimes simply be restricted by keeping the respective knowledge secret. In a study by Levin et al. (1987), especially for process innovations, secrecy was found to be an effective measure to appropriate new know-how. Therefore, firms can actively, at least partly, appropriate new know-how, influence the creation of technological spillovers and for example even disclose only parts of their knowledge. They can decide for a cooperative attitude and actively participate and support the constitution of a cooperative environment by following a strategy of both sharing and secrecy.

Finally, I want to mention a strong relationship between the concepts of 'development blocks' (Dahmén (1989), Carlsson (1989)) and informal networks. An entrepreneurial innovation may be precisely the creation of new information which opens the possibility of a cross-fertilization. But because of the complexity of present-day technologies in absence of a cooperative environment the required complementarities are not available for the entrepreneur and his innovation has to fail. But if the innovator could join an informal network the missing knowledge elements could be supplied by others and thus new business opportunities can be

¹⁷ See Mody (1993).

created by this development block. This way new information emerges by the interaction in the network.

- *empirical evidence*

In the recent literature empirical evidence can be found for an increasing significance of this form of inter-firm-learning. In an investigation of the semi-conductor industry, Irwin and Klenow (1994) found that because of the sheer size of the external knowledge pool, spillover effects essentially contribute to the learning of firms. Deliberate know-how sharing could be one explanation for the existence of this large spillover pool. Mansfield (1985) found that the speed of diffusion of new know-how is in fact very high, for process innovations somewhat lower than for product innovations. Recently, Caballero and Jaffe (1993) found that this rate of diffusion even increases over the last years. Technological spillover effects have become a more and more important ingredient in the cultural evolutionary development.

Whereas one can argue that this leakage of new knowledge in the form of technological spillovers is an unvoluntary process, other studies¹⁸ e.g. von Hippel (1990) found evidence for the voluntary character of this know-how exchange¹⁹. In his study nearly all of the interviewed firms reported routinely trading technological knowledge, sometimes even with direct competitors. Jagger and Miles (1989) in an investigation of the British industry found evidence for informal information flows. The interviewed research scientists underlined the advantages of informal networks because of the easier management relative to more formal agreements. Hakanson and Johanson (1988) found in a study of cooperation between firms in technical development, that more than two thirds of this relations were informal. Informal relationships were also identified in the software industry by Malerba and Torisi (1992). Freeman (1991, p. 500) surveying the empirical literature states: *"Although rarely measured systematically, informal networks appeared to be most important. Multiple sources of information and pluralistic patterns of collaboration were the rule rather the exception."* Consequently, one can conclude that, at least in some industries, this form of learning is actively included in the firms' R&D routines. This means that external effects become more and more important in the

¹⁸ Building on the concept of informal know-how trading recently several empirically studies (Schrader, S. (1991), Quintas, P., Guy, K. (1995), Folst er, S. (1995), Harabi, (1995)) were conducted, founding positive evidence for this phenomenon. Senker and Faulkner (1996) found strong networks of informal links in biotechnology, parallel computers and ceramic industries.

¹⁹ " In particular, what often appears to be an involuntary flow of knowledge between firms may be nothing more than a pair of draws from a narrow but common pool shared by a group of agents with a common set of problems ", Geroski, P.A. (1995), p. 85.

innovative strategies not just as involuntary leakage of know-how, but as a device for technological learning in a collective innovative process.

3. INFORMAL NETWORKING - A SYNERGETIC MODEL

In the literature there are several attempts to model the phenomenon of informal knowledge-exchange. Usually game-theoretic²⁰ and transaction-costs²¹ approaches are applied. Especially the game-theoretic models have become a very sophisticated technique for modeling cooperative behaviour and its changes. However, all these models exhibit some very restrictive features with regard to the information assumptions. All possible alternative strategies as well as the comparable payoffs have to be known. With respect to innovations the assumption of perfectly informed and optimizing actors is very questionable. The innovative process is reduced to the predictable reactions of the actors and the possibility of change is made exogenous²². There, the tension between short-term profit maximization regarding existing products and known technologies and learning about new technological opportunities is actually not regarded. Firms engaged in R&D certainly always face an essential problem of uncertainty and try to deal with it using means, which can hardly be managed, ex-ante, with optimizing criteria²³. Instead, they apply 'routines' for their decisions, which are deduced mostly from past experience and future expectations. These routines (Nelson, Winter (1982)) are believed to shorten the average search for solutions of the problems of survival and profitability. Informal networks may thus be regarded as industrial organizational routines²⁴ adopted by firms under changing information requirements and changing dynamic environments.

3.1 THE MODEL'S STRUCTURE

As opposed to these mainly neoclassically oriented models our synergetic approach, the master equation²⁵, avoids the mentioned restrictive assumptions. Whereas under certain circumstances

²⁰ The game-theoretic approaches can be subdivided into two different classes: The first class of models draw's back on Axelrod's seminal book (1984), 'The Evolution of Cooperation', using the famous prisoners' dilemma, e.g. von Hippel (1989) who uses a two-persons-prisoners* dilemma, Foray (1995b) who uses in a similar context a multi-persons-prisoners'dilemma, and Cabon (1995) who enlarged the approach using Markov-strategies. The other class of games could be described as special applications of patent races, e.g. de Fraja (1993).

²¹ E.g. Watkins (1991).

²² See Hutter (1995), p.50.

²³ See Aoki/Dosi (1992), p.56.

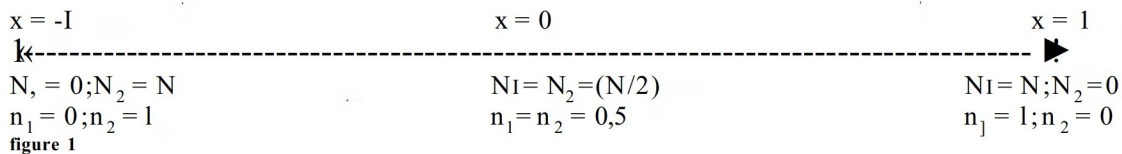
²⁴ See Niosi, J. (1996), p. 99.

²⁵ The fundamental reference of this kind of models is Haken (3rd edition, 1990) p.333. Other, economic applications of this model can be found in Woeckener (1992), Weise/Eger (1987), and Weise (1992).

in game-theoretic models the agents realize cooperative situations via the optimization of their individual utility functions, our approach focusses more on the opposite effect. The macro-structure, constituting the respective cooperative or non-cooperative environment, establishes a feedback mechanism, determining the actors' behaviour. Applying this analytical framework the collective aspects of a cultural technological evolution is emphasized.

- some basic remarks

First, some analytical tools have to be introduced. In the following we regard N firms, which undertake R&D endeavours. These N firms could behave according to either a cooperative attitude 'c' or a non-cooperative attitude 'nc'. The firms which choose the cooperative attitude are counted by N_1 and the other firms by N_2 ($N=N_1+N_2$). The relative share of either group of firms is labeled $n_1=N_1/N$ and $n_2=N_2/N$ respectively. The variable $x \in [-1,1]$ indicates the deviation from an uniform distribution²⁶ of both attitudes ($x \sim n_2 - 0.5$). Figure 1 shows some values of x and the respective values of N_1 , N_2 , n_1 , and n_2 .



The master-equation is used for the description of systems, which are composed of many actors, whereas for the individual behaviour only stochastic distributions and no deterministic rules are known. This method explicitly considers feedbacks from the macro- on the micro-structure. Because of the uncertain character of the innovation process and the resulting non-optimizing behaviour of the individuals, only probabilistic patterns of behaviour with respect to the participation in an informal network connected with the decision for a cooperative attitude can be formulated. Additionally, the environment of single actors, whether cooperative or not, will significantly influence their decisions. Therefore, the master equation approach seems to be well suited to describe the phenomenon of the evolution of informal networking.

This formalism explains the continuous development of a discrete state-space. In our model the state-space is represented by the vector x , describing the distribution of cooperative vs. non-cooperative individuals. For every single time-period according to the changes in the individual attitudes, the probability of the different states $P(xjt)$ is calculated. With respect to the

²⁶ The deviation of x with respect to n_1 or n_2 is straightforward: $x = 2(n_1 - 0.5) = -2(n_2 - 0.5)$

Markov-assumption, only one move from cooperative to non-cooperative ($c \rightarrow nc$) or vice versa ($nc \rightarrow c$) is allowed for an infinitesimal small time interval dt . Figure 2 is a schematic representation of the development of a single state x , the states $x_{-\varepsilon}$ and $x_{+\varepsilon}$ label the adjacent neighbours ($\varepsilon :=$ distance between to states):

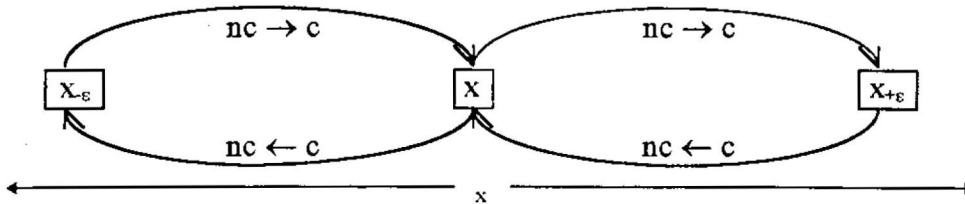


figure 2

The development of an informal network can be viewed as a sequence of states according to the attitudes taken by the involved firms. Those firms respond to their changing environment, having different motives in mind and taking into account their currently perceived technological constraints and successes. Those interrelated decisions in such a complex system constitute the basis of the dynamic evolution of the informal network. The next question to answer is, what determines the attitudes of firms on the micro-level?

- the individual transition rates

At every instant t , a non-cooperative firm has the possibility to change its attitude and join the informal network ($nc \rightarrow c$). The decision of this firm is influenced by the probability of the prevailing macro-structure $P(x/t)$, which represents either the cooperative or non-cooperative environment. In the case of the latter only a small pressure is exerted on the firm to change its attitude and to behave cooperatively. The probability of taking advantage due to participating in the network and to find a helpful partner with complementary knowledge in the likewise small informal network is low. But in a more and more cooperative environment this probability of a beneficial cross-fertilization-effect increases. Two reasons are responsible for this: first, with a growing number of participants in the informal network the absolute size of know-how available in the cooperative environment increases; second the variety and therefore the quality of this know-how also increases. With growing quantity and quality the probability to combine seemingly inconsistent ideas increases. And the missing know-how to detect the beneficial dynamic synergies is captured with this original defective firm, entering the network.

Informal networking leads companies to turn to the external reservoir of knowledge and technology and to develop linkages in a cooperative environment that are generating additions to the reservoir. To represent formally this tension of a non-cooperative firm to behave cooperatively we use a simple linear-relationship: $p \cdot x$. This tension increases with increasing network size. The parameter p represents the intensity of R&D-endeavours. A larger p value labels a growing technology intensity. This could also be interpreted as P representing technological uncertainty whereby we refer to the assumption, often found in literature, that with increasing R&D intensity the uncertainty also increases.

The relation between the intensity of the cooperative environment i.e. the size of the informal network and the incentive of a single actor to change her/his attitude determines the individual transition rate, one of the basic components of a master-equation. The individual transition rate $q_{nc \rightarrow c}(x)$ expresses the probability of changing from a non-cooperative to a cooperative attitude dependent on the prevailing macro-structure, in the literature, for transition rates usually an exponential formulation is used (a : = scaling parameter). The transition rate $nc \rightarrow c$ reads as follows:

$$(1) \quad q_{nc \rightarrow c}(x) = a \cdot e^{p \cdot x}, \quad x \in [-1, 1], \quad p > 0;$$

We assume that the advantages of the cooperative attitude are the disadvantages of the non-cooperative attitude and vice versa, therefore, transition rates are symmetric. In an overall non-cooperative environment the pressure to change the cooperative attitude ($c \rightarrow nc$) and behave defectively is likewise large. On the one hand, the potential disadvantage of falling behind through disclosing own know-how' and the defective behaviour of others has to be considered. On the other hand, the probability to find complementary know-how and realize the beneficial effects of the extensive opportunities is quite small in a more or less defective environment. But the incentive to behave defectively decreases in an increasingly cooperative environment. The transition rate $c \rightarrow nc$ reads as follows:

$$(2) \quad q_{c \rightarrow nc}(x) = a \cdot e^{-(p \cdot x)}, \quad x \in [-1, 1], \quad p > 0;$$

Figure 3 shows the respective curves of the transition rates. The exponential function normalizes the respective values to the positive area, necessary because of representing transition-probabilities.

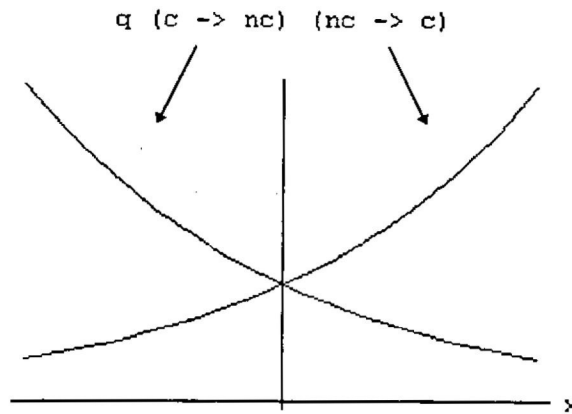


figure 3: the transition rates

This exponential formulation further ensures the effect of short-term self-enhancing and wide-range attenuation²⁷: first the growing network-size supports the beneficial effects of the cooperative environment. But in the long run two reasons are responsible for an attenuation of this effect. On the one hand, there is a growing probability that the firms in the network already realized the opportunities another firm outside the network can offer. On the other side, the heterogeneity of firms in the network will decrease because they will become technologically closer by sharing their know-how²⁸. But heterogeneity of actors is a necessary precondition for high informational contents of knowledge spillovers.

- the master-equation

After having introduced the transition rates, the master equation, describing the evolution of our system can be formulated. To avoid disintegration of the system, for this equation the so-called normalization condition $\sum_x P(x|t) = 1$ must be fulfilled²⁹. The change of the prevailing

macro-structure $\dot{P}(x|t) = \frac{dP(x|t)}{dt}$ is obtained by:

$$(3) \quad \dot{P}(x|t) = q_{nc \rightarrow c}(x_{-\varepsilon}) * P(x_{-\varepsilon}|t) + q_{c \rightarrow nc}(x_{+\varepsilon}) * P(x_{+\varepsilon}|t) - q_{nc \rightarrow c}(x) * P(x|t) - q_{c \rightarrow nc}(x) * P(x|t)$$

²⁷ Eger and Weise (1995) and Weise (1993) referred to Gierer (1981) in this respect.

²⁸ Dodgson, M. (1996), p. 67: "If firms in a network extensively share knowledge over a longer period, then they will increasingly come to resemble one another with detrimental consequences for novelty and innovation."

²⁹ The most important consequence of the normalization condition is that the respective equations for the margins of the state-space must be formulated separately, because they can only be reached from one side.

The first two terms on the r.h.s. of the equation indicate the probability-flows from neighbour-states into x , whereas the other two terms describe the flow which leaves the respective state. Therefore, the master-equation could be interpreted as a kind of profit&loss account of a single state.

In our model the transition-rates, describing the probability of a change in the firms' attitude, are time-independent. In these cases a stationary ($\dot{P}(x|t)=0$) and ergodic solution always exists³⁰. From a macro-perspective the transitions of the system come to rest in such a situation. This, however, does not indicate that the movements on the micro-level are also finished. There are still some firms changing from non-cooperative to cooperative and vice versa. But these movements are now mutually compensating. The ergodic feature means, that the respective stationary solution will be reached anyway, irrespective of initial conditions.

- the mean-value-equation

In the literature mean-values are often used to find first insights in the system's development. In a unimodal evolution the mean-value quite well approximates the stationary solution. But in other cases, where more extreme situations are possible, the mean-values could describe the most unlikely solution. But even in these cases, nevertheless, general tendencies of the system's evolution can be predicted.

The mean-value-equation of our system looks as follows:

$$\begin{aligned}
 (4) \quad \dot{x} &= \frac{dx}{dt} = n_2 * q_{NC \rightarrow C}(x) - n_1 * q_{C \rightarrow NC}(x) \\
 &= n_2 * \alpha e^{(\beta * x)} - n_1 * \alpha e^{-(\beta * x)} \\
 &\text{(using the formulation of footnote 25)} \\
 &= (1/2 - x/2) * \alpha e^{(\beta * x)} - (x/2 + 1/2) * \alpha e^{-(\beta * x)} \\
 &= \alpha \sinh(\beta * x) - x * \alpha \cosh\{-(\beta * x)\}
 \end{aligned}$$

In a stationary solution, there are no longer any movements of the macro-state. We define x^* as the value of x where $\dot{x}=0$ is the case. Using (4) we obtain

$$(5) \quad x^* = \alpha \tanh(\beta * x)$$

³⁰ See Haken (1990), p. 108.

After having fully specified our model, we are able to investigate the model's behaviour in different scenarios.

3.2 THE MODEL'S RESULTS

The evolution of an informal network depends on the prevailing cooperative or non-cooperative attitudes of firms. These attitudes are determined by the individual transition rates which themselves depend on the respective macro-structure as well as on the technology-intensity. In the model this technology-intensity is expressed by the factor β . Figure 4 shows the transition rate $q_{nc \rightarrow c}(x)$ for different β -values.

$q \text{ (nc} \rightarrow \text{c)}$

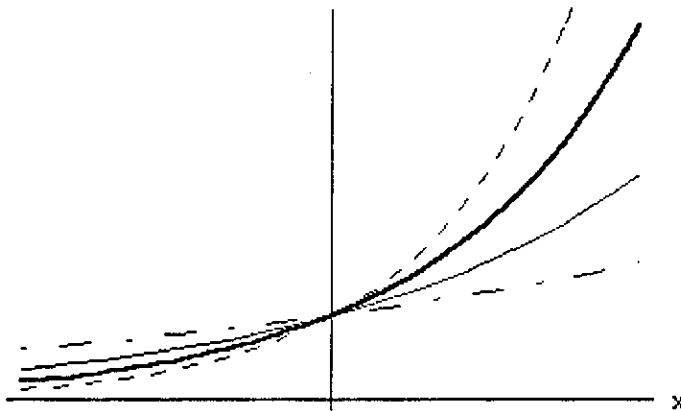


figure 4: $\beta = 0.5$ (dashed and pointed line), $\beta = 1$ (bold line), $\beta = 1.5$ (normal line) $\beta = 2$ (dashed line)

For $\beta < 1$ the respective transition probability underproportionally increases, the impact of the short-term self-enhancing and wide-range attenuating effect becomes stronger³¹. For $\beta > 1$ the respective rates overproportionally increase. This seems to be plausible, because the argument used above to derive the transition rates is emphasized in a technology regime, characterized by higher technology intensity. The pace of progress is faster, the respective technologies are more complex and therefore, external knowledge sources become more important. And this enormous increase of the transition rates for larger cooperative environments, diminishes the wide-range attenuating effect in this scenario. Here one could expect a changed pattern in network formation.

Therefore, the system's development is highly dependent on technological-intensity. In order to understand this feature of the model, we investigate in the following the mean-value-

³¹ It holds that $\left| \frac{1-x}{2} \right| > |\alpha\beta e^{P_n}|$.

equation with respect to different technological regimes and discuss the consequences for the evolution of an informal network. In figures 5a-d different graphs of the mean-value-equation (bold line) and their intersection with the 45°-degree line (dashed line), indicating equilibrium-solutions x^* are depicted. Additionally, the master-equation is simulated numerically³² and the respective results are illustrated graphically.

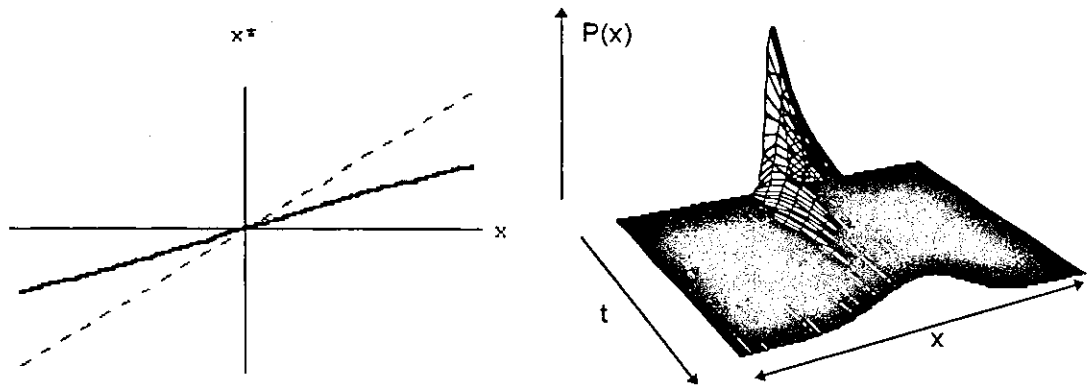


figure 5a) $\beta = 0.5$

A quite low value of β (figure 5a), indicating low technological intensity, leads to a unique solution of the master equation ($\dot{x}=0$). In this regime no dominant cooperative or non-cooperative solution emerges. We find a unimodal probability-distribution of the state space. The most probable value of x is zero and divides the firms into two same-sized groups, one acting cooperatively, the other defectively ($n_1=n_2=0.5$). In an environment, where new technologies are not of major importance, the possibility of larger informal networks is by and large neglected by the respective firms.

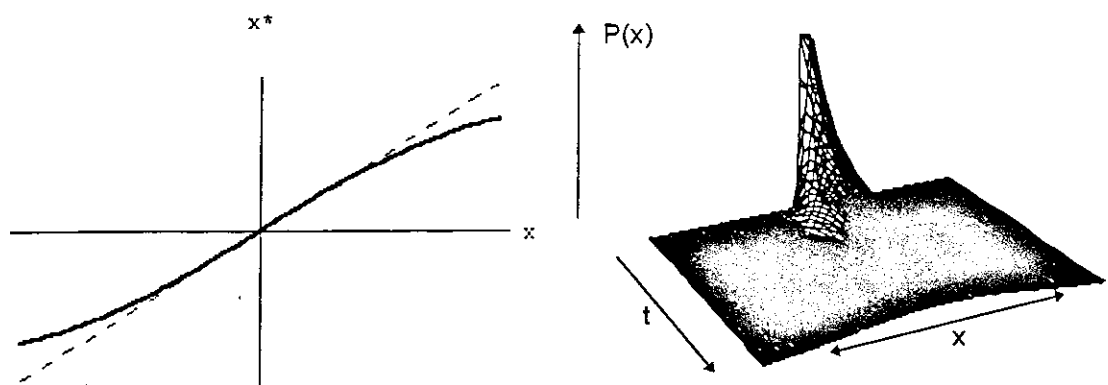


figure 5b) $\beta = 1$

But this situation changes for increasing technological intensities. In figure 5b) the respective β -value amounts 1 and this time, there can be seen not only one point of intersection with the 45°-degree line, but a far wider domain around $x=0$ is the most probable solution. Besides a lot of intermediate solutions the establishment of an informal network with considerable size

³² The initial imposed condition for all simulations is: $P(0,0|0)=1$.

becomes possible. This could also be seen, regarding the simulated probability distribution. A much broader range of states becomes propable under this regime where the impact of wide-range attenuation is diminished.

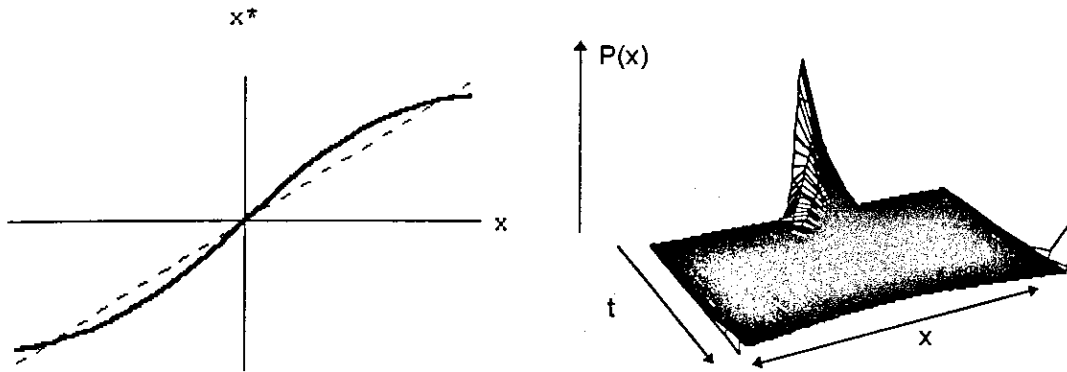


figure 5c) $\beta = 1.5$

Figures 5c) and d) show the mean-value-equations and probability-distributions for even larger β -values. Here two different possible solutions can clearly be discriminated. There is a maximum in probability for a solution where defective behaviour dominates. Despite the requirements of a cultural evolutionary technological progress, no larger network formation seems to be possible. But this maximum is not global, on the other more cooperative side of the graph, a second local maximum can be found, the probability-distribution shows a bifurcation. This solution describes a large informal network, where the respective cooperative firms partly share their technological know-how and large technological spillovers are actively initiated.

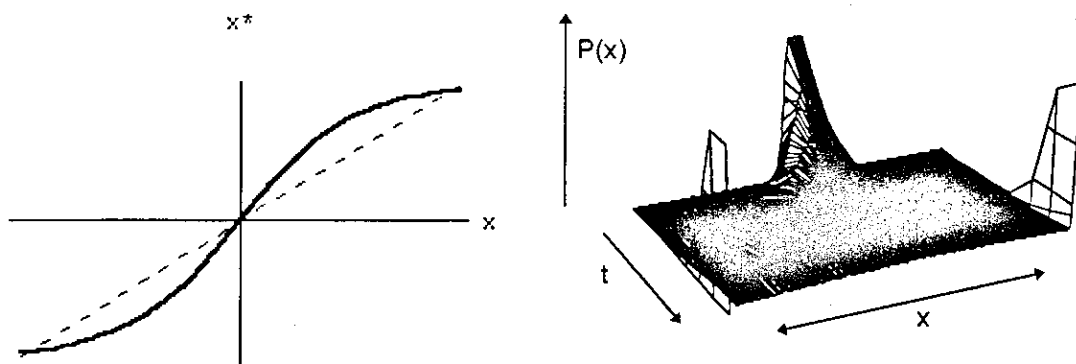


figure 5d) $\beta = 2.0$

Which solution actually establishes itself depends on small fluctuations and cannot be predicted ex-ante. In situations where technology matters, the development of cooperative or non-cooperative structures is characterized by a phase-transition. Here, besides the short-term self-enhancing feature additionally a long-run impact makes the original stationary solution unstable

and leads to a new stationary structure with quite different characteristics³³. The formation of informal networks with a firm strategy of actively initiating spillovers is as probable as the formation of isolated firms with more traditional attitudes towards the impact of technological spillovers.

4. CONCLUDING REMARKS

In a technological development characterized as a 'cultural evolutionary process' cooperative environments can emerge via self-organization. The requirements of the modern innovation process demand new forms of industrial organization and the phenomenon of informal know-how exchange is probably a very promising one³⁴. Our model is able to demonstrate the possible evolution of an informal network, thereby not using traditional analytical tools with the criticized restrictive assumption of perfect rationality. The synergy in the evolution of an open system, where mutually reinforcing factors create dynamic effects under certain circumstances makes both possibilities, a cooperative and a non-cooperative environment probable. Which solution actually establishes cannot be predicted ex-ante and depends on small perturbations in the course of time. This open feature in the development of informal networks corresponds quite well to the indeterminacy, intrinsic to technological evolution.

However, the different solutions are dependent on the technological intensity; Especially in environments, where technological factors play a major role, a positive probability for the emergence and the absence of a network exists. These results correspond to observations of reality; Although technology is very important in some industries like pharmaceuticals and chemicals, these branches are quite self-sufficient with respect to R&D and the establishment of an informal network is less likely to occur. However, in other industries like semiconductors and aerospace, which are also technologically intensive, the phenomenon of informal networking can be observed more readily³⁵.

Additionally, our model's results can be interpreted in the light of emerging technological paradigms. In early formative periods of new technological systems almost by definition no dominant design and standards exist. These periods are characterized by high technological

³³ This situation shows strong isomorphisms to the wide-ranged correlation of chemical processes, described by Prigogine and Stengers (1993), who also employed this synergetic approach.

³⁴ Clark and Juma (1987, p. 170) state: "Coping with non-linear situations requires effective information flows and systemic organization in which networking plays a significant role."

³⁵ See Eliasson (1995).

uncertainty. Thus, until a dominant design emerges, there are advantageous conditions for the establishment of large informal networks and cooperative environments. In later periods economies of scale and standardization become more and more important and cooperative attitudes diminish³⁶. This indicates a cyclical feature of informal networking with respect to the age of technological paradigms.

Necessarily, the results of our model go far beyond anything previously published and should be considered therefore as quite speculative. To find more evidence, empirical investigations and case studies would be very helpful. They could shed light on the conditions for and structure of informal networks. For example, the measurement of technology flows between different sectors could be used to identify the branches, where informal networking is employed as an industrial organizational device. With respect to the model some remarks regarding the technology' intensity parameter p are necessary. This parameter is, of course, not always constant and exogenous. On the one hand, there exists the plausible assumption that the technology intensity is affected by the formation of an informal network, and therefore, the role of technology⁷ would be dependent on the network-size. On the other hand, under certain circumstances, e.g. public programmes etc., the value of p could change in the course of time. In our framework this would probably indicate a temporary cooperation in informal networks, and other times more non-cooperative-structures. Both empirical investigations and theoretical modifications are on our agenda for future work.

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³⁶ See Dodgson, M. (1993) and Freeman, C. (1991).

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