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The Random Part in Network Evolution

Thomas Grebel*

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Economic behavior strives for efficiency. Therefore, also evolving network structures should be a result of such a goal-oriented behavior. Traditionally, networks were assumed to be only temporary phenomena, since the prevailing organizational forms that comply with the efficiency postulate are either firms or markets. Having a goal in mind, however, does not incur a set of unique choices of action, especially in situations under high uncertainty when engaging in invention networks. Consequently, there is no uniqueness in network structures. There is a random part in network evolution driven by generic mechanisms. A percolation model is used to model the generic development of invention networks. A Monte-Carlo simulation underlines the expectable patterns of network evolution. Moreover, it is tried to align the generic part of the story to the operant level where entrepreneurial behavior and market selection takes over the dominant role in network formation.

Keywords: R&D cooperation, percolation theory, knowledge diffusion, networks.
JEL-Classification: A10, B10, B21, B25, B41, B52, C15, D03, D85, I10, O10, O33

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1 Networks and Economics

The Strength of Weak Ties of Granovetter (1973) shows the importance of loose ties in everyday life. Without weak ties (acquaintances) individuals would be isolated from others and deprived from a lot of important information such as job openings, business opportunities or just fashion (Granovetter 1983). The organizational form of networks in economics is still a fairly young discipline. *The Theory of the Firm* as stressed by Williamson (1975) basically focuses on two forms of organizational structures: markets and hierarchies, the former coordinated by price, the latter by authority. However, in a dynamic environment, Burns and Stalker (1961) claim, an *organic* organizational structure might be more effective than a bureaucratic one.

Whereas social network analysis (Granovetter 1983) is fairly little interested in efficiency, network analysis as it is used in economics is. The incentive for firms to cooperate are to overcome shortages in certain resources; in other words, to economize on costs (Combs and Ketchen 1999). Also for efficiency reasons firms cooperate with other firms, with customers, suppliers and also with universities and research laboratories (Powell 1990).[1] In game theory, for example, network analysis is applied to test network stability (Jackson and Wolinsky 1996). Graph theory, thereby turned out to be a helpful tool and inspired a lot of research work in this field (Jackson 2008, Jackson and Watts 2002, Newman et al. 2006). Moreover, the diffusion of knowledge is also extensively investigated (Cowan and Jonard 2004). In this context networks with *Small World* properties represent the most efficient network structure according to Cowan and Jonard (2003). Diffusion processes in networks are often modeled via percolation theory, a theory drawn on also in this paper. Hohnisch et al. (2008) model product diffusion using this technique. Silverberg and Verspagen (2005) deliver an interesting percolation model on innovation in complex technology spaces.

The transfer of the social network concept, as primarily discussed in sociology to economics, does not go without some concessions. Economic behavior traditionally strives for optimal resource allocation. That what actors do, they do in order to reach a state of optimality. It is to discuss, whether they actually hit the target (perfect rationality) or come short and settle for the achieved (bounded rationality). Even more, the profit maximization hypothesis of Friedman (1953), who maintained that firms behave *as if* they were maximizing, has been largely put into perspective (Winter 2005). Nevertheless, goal-oriented behavior and *natural selection* (Friedman (1953, p. 22) cited in Winter (2005)) by markets has become manifest in economic theorizing. In its strictest sense this holds for a neoclassical-type of equilibrium analysis and in the broadest sense for evolutionary economics as well. Without a goal in mind, no kind of rational behavior is performed. Still, the question remains how far reaching the power of market selection is. Someone selling French Fries amongst many sellers in some food corner, the market will select the one selling for minimal costs, ceteris paribus. Comparing similar food places in a larger region, price differentiation beyond transportation costs seem very likely (e.g. lack of information), so that it is very likely that an equilibrium price does not occur. Nevertheless, despite inefficiencies in the market, it is plausible to assume that there is a limit for excessive price differentials. Market selection still has its coordinating power, even though to a lesser extent. It seems obvious that this should also be the case for networks: market power coordinates the evolution of networks.

What if markets failed or did not even exist? Admittedly, the latter is a very rare case. But for theoretical reasons, it can be constructed. Arrow (1962) points out the specificities in the production of knowledge. Optimal resource allocation is illusive for several reasons such as increasing returns, inappropriability and uncertainty. Knowledge/information can hardly be traded. Its production is a trial and error process with an uncertain outcome. Performing the creative process of invention can not be coordinated by the forces of the market, even if the

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[1] Compare Graf (2006) for an overview.

inventor has in mind a certain problem to solve. The epistemological reservation that something new can not be known in advance, holds the more for basic research. Markets do not tell how to invent. As an exmaple, medical researchers – as an archetype – have rather less market selection in mind than the search for an effective medical treatment. Above all, this kind of orientation is not desired by society at all. Nevertheless, medical research networks emerge across hospitals and research labs.

This does not mean that there is no market selection going on in the innovation process of the medical sector. In an early stage market selection may not have a say. Many research networks focus on topics that look – from a pure economic point of view – little "profitable". As I said, this is not as much as I hope the principle objective by the actors in the health sector. The closer research comes to a technological application, the more market selection takes over the coordinating role. And thus, influence the future dynamics of research networks.

The point made in this paper is that there is a generic part (Dopfer et al. 2004) of network formation, which is not based on pure market selection. But there are generic elements which spur certain patterns in network evolution which would reject the random hypothesis with market selection being absent. This distinction is usually not made in the economic literature on networks, although it is implicitly addressed when it is talked about the random aspect of network evolution. Of course, the random part and the coordinating forces of market selection are intertwined. A theoretical alignment will also be given in this paper.

This paper contributes to the implications of random network evolution in evolving inventor networks. Percolation theory serves as an instrument to derive implications. Section 2 discusses knowledge as a commodity and the difficulties involved in its specificities concerning tradability and invention incentives. Based on this section the subsequent section 3 argues the adequate organizational form of the production of knowledge. Section 4 illustrates the empirical example of emerging network structures among inventors (heart surgeons and cardiologists) of heart valve technologies. Section 5 explains the term generic level as it is used in this paper. Section 6 discusses knowledge diffusion within networks and the incentive and propensity to invent and cooperate, respectively. Percolation theory, section 7, describes which evolving network structures have to be expected in the course of time and derives the implications of the Monte-Carlo simulation study and aligns the generic level of network evolution with the network evolution driven by market selection. Section 8 concludes the paper.

2 Invention – the Production of Knowledge

In his seminal work Arrow (1962) pointed out that invention is the production of knowledge. The allocation of inventive resources and activities is subject to high uncertainty, to increasing returns and inappropriability. The first is obvious by definition, the second is due to the fact that the reproduction of knowledge involves little to no costs; the difficulties in making knowledge/information[2] a private good renders invention a risky venture to its producers.

Arrow (1962) looked through the lense of welfare economics, stating that it basically is the technological characteristics and the functioning of the market for knowledge that guarantees optimality, given *well-defined* utility and production functions. Well-defined means having convex functions with non-increasing returns. If the production of one unit of knowledge incurs positive marginal costs, its reproduction tends to be zero. Hence, as a first-order condition, the price of one unit of knowledge must be zero, too. Conclusively, there is a difference between private and public costs: high costs for the knowledge producer and little or no costs for the public.

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[2] There is an important distinction between knowledge and information. The point made in this paper holds without qualifying this difference.

Moreover, information becomes a commodity as soon as there is uncertainty. When a firm or an individual discover a new bit of (useful) information, e.g. a new business opportunity, they are better off in terms of future profits. To actualize those profits, however, the underlying information must either be used internally to the firm or it must be traded, both require the characteristics of knowledge as a private good. Internal usage might be adequate in some specific cases to keep the information secret within the firm or secret to the inventor. When trying to trade the information, the appropriability of innovation rent burns down to zero.

Patents reconcile the protection of intellectual property rights to a certain extent. But they protect technical solutions rather than explicit knowledge. Patents take only effect, if a piece of knowledge is identifiable when embodied in technologies used or goods and services traded. Otherwise, protection is impossible. The indivisibility of this commodity makes trading even more difficult. The consumer is only willing to pay for new information if he/she can value its usefulness. Therefore, the consumer needs to know the information, which makes it no longer necessary to pay.

As a consequence, there is little incentive to do research, i.e. to produce knowledge or information, when high uncertainty, increasing returns and a high propensity of inappropriability is to be expected. As a matter of fact, inventive activities are exerted in economy, knowledge is generated and dispersed over economic actors, although market failure is predominant. Arrow concluded in this respect:

> When the production of information is important, the classic economic case in which the price system replaces the detailed spread of information is no longer completely applicable (Arrow 1962, p. 619).

To sum up, knowledge, not yet applied in some technology, is a valuable input factor and thus becomes a valuable commodity, even if a short-run reward is unlikely. Its protection is limited. How then the production of knowledge is expected to be organized, when its appropriation is truly uncertain. Arrow resumes that it must rather be large firms that can afford to bear the risks of doing research. They can afford initiating a portfolio of many, small-scale projects to minimize the risk of failure (Arrow 1962). This organizational discussion will be led in the following section.

3 Organizational Forms in Knowledge Production

Holmström and Roberts (1998), two organizational economists, linked the importance of the organizational form to the role of the production of knowledge and information.

> Information and knowledge are at the heart of organizational design, because they result in contractual and incentive problems that challenge both markets and firms. Indeed, information and knowledge have long been understood to be different from goods and assets commonly traded in markets. In light of this, it is surprising that the leading economic theories of firm boundaries have paid almost no attention to the role of organizational knowledge. (Holmström and Roberts 1998, p. 90)

The Theory of the Firm (Coase 1937, Williamson 1975, Penrose 1959) in its simplest version suggests that it is transaction cost (Coase 1937) that tells you to *make* or *buy*. The specificities of knowledge and information as a commodity combined with the necessity for innovation as a competitive advantage, knowledge production should be performed in-house. According to Williamson (1975) *hierarchies* are to be preferred when transactions or any kind of exchanges are uncertain and require time and money.

This sounds very mechanistic and raises the question whether knowledge production confined within the boundaries of a firm sufficiently spurs the creative process of invention? Indeed, the dichotomy of markets and hierarchies in economic thinking has gradually been dissolved. The rigidity in firm organization tends to stifle creativity. Hierarchies collect contractually bounded (dependent) employees that interact in a routinized way (Nelson and Winter 1982). Markets coordinate the economic interaction of (independent) actors via prices and thus reduce the incentive to invent. As mentioned above, the specificities of knowledge and the difficulties in trading knowledge calls for an intermediate organizational form. Both organizational forms hierarchies and markets neglect the reciprocal relationship in economic interactions as reality shows (Powell 1990). On the contrary, networks put the emphasis on the cooperative relationships across firm and geographic boundaries (DeSanctis and Poole 1997).[3] Networks are more flexible than firms, since there are no strictly hierarchical norms. This opens up opportunities for a fruitful interaction in the invention process to access external knowledge on the one hand and to increase the chances to keep novel knowledge secret within the network so that eventually the likelihood of the appropriability of innovation rents is increased.

4 Empirical Motivation

To motivate the story empirically this section shows the network evolution of heart medicine physicians who do research in heart medicine. To recall, the reason this example was chosen is that by tendency, physicians are the least influenced in their research by market conditions. This gives reasons to assume that the generic element, which is not driven by market selection, is prevailing in the network evolution, although in later stages in the evolution of a technology field, market selection takes over the coordination of network formation, since they learn about possible business opportunities and start collaborating in applied research with medical researchers to develop a marketable technology/product.

To illustrate the network evolution in heart medicine, patent data is used. Patents document newly generated knowledge. At the same time, they reveal the cooperation of inventors in the course of time. The patents used here are taken from the patent data base provided by the European Patent Office ranging from EP-A-0000001-1871158 (20 Dec. 1978 - 26 Dec. 2007) to WO/78/000001-07/150079 (19 Oct. 1978 - 27 2929 Dec. 2007). The focus is put on IPC-code "A61F224" which stands for inventions in heart valve research. We identified 330 patents with 468 inventors. It is mainly cardiologists and heart surgeons doing research in the treatment of defective heart valves. This supports the assumption of a delimited homogenous set of actors that have a relative proximity to each other: local proximity within their hospitals and even inter-hospital proximity via conferences. There are several heart medicine conferences, of which some international conference gathers more than 20,000 cardiologists and heart surgeons. Although patents do not reveal the complete structure of existing networks, they can be used as an apporximation, since the inventors that co-occur on the patent can be assumed to have established a link between each other and thus hold a tie in a network. The ties usually last for a longer time. The inventors identified on first patents in heart valve replacement are still alive and it is very likely to assume in the sense of Granovetter (1973) that by regular conference participlation, weak ties still exist. Therefore, a simplifying assumption is to assume that once established ties last for the whole time span of observation.

Figure 1 shows the evolution of cooperative networks (clusters) in heart valve research. The patenting history of heart valve technologies, in terms of patents in IPC class "A61F2/24", basically started in the mid 1980s when first patent applications were filed. From 1986 onwards more and more physicians engaged in the investigation of heart valve treatments. More small

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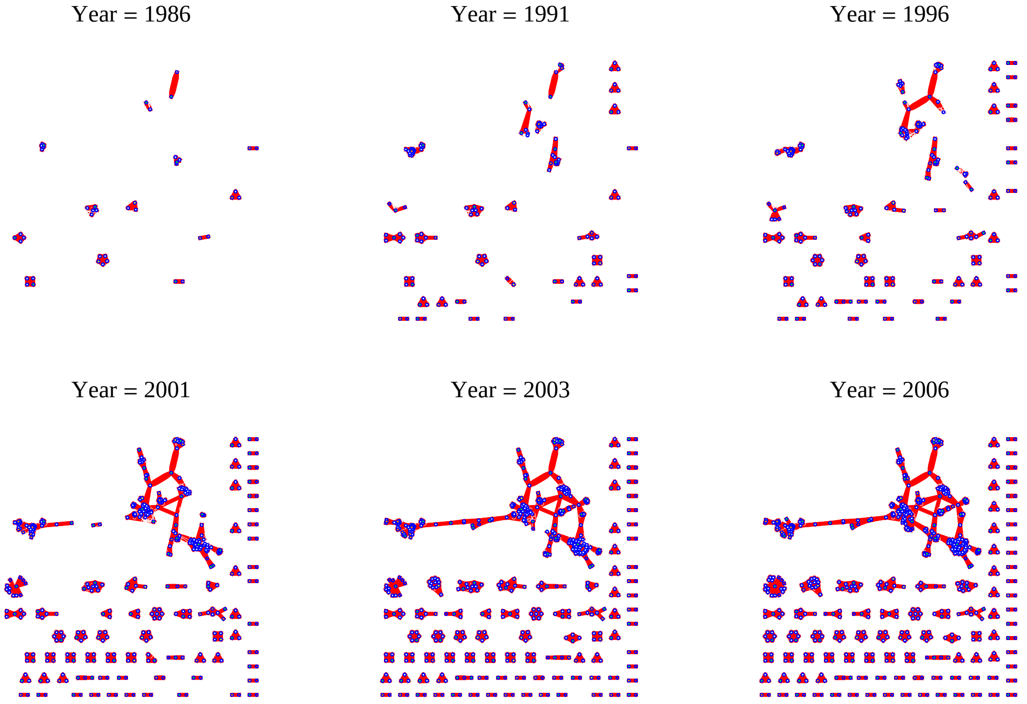
[3] Foss (2002) delivers a rich discussion on what *New Organizational Forms* are.

Figure 1: Network evolution in percutaneous heart valve replacement



networks came into existence till the beginning of the 90s. While new networks were still emerging from the mid 90s onwards, there was also a number of networks that got connected to a bigger cluster. The biggest cluster was definitely shaped by market conditions, because after the year 2000 more and more firms were founded and began to develop marketable technologies/products.

The two underlying network forming processes are the generic one, which is not driven by pure market power, and the operant one (Dopfer et al. 2004, Dopfer 2006) which is induced by market conditions. Firms are alert to new business opportunities and try to bring new technologies/products to the market. As it is the aim to focus on the former, the generic level of network evolution, the next section will discuss the concept of the generic level.

5 The Generic Level of Network Evolution

The fundament of economic theorizing is rooted in goal-oriented behavior (compare sections 3 and 2). In traditional theory agents behave optimally according to their utility function; equilibrium analysis is the methodological counterpart and entails further restrictive assumptions. The debate about its adequacy is a long lasting one in evolutionary economics. Evolutionary economics also relies on a selection criterion as a coordinating force of economic behavior. Mutation, variation and selection has become the metaphor to stress the dynamic, discontinuous process of change. Though this definitely is a slightly relaxed assumption about the characteristics of economic agents, its goal-oriented behavior also incurs the assumption of a selection mechanism. Logical for economists is to search this selection mechanism in the market conditions. It is indisputable that without some selection criterion, in other words, without goal orientation, human behavior is not generalizable. And a theory based on arbitrariness is no theory. The dilemma in economic theorizing and in particular, in the attempt to build a theory on the emergence of novelty is deeply rooted in this discrepancy: without a selection criterion, we identify theories as ad hoc; with market conditions as the selection criterion every behavior is assumed to be driven by its normative power. Irrespective what economics is all about though, it is about the creation of theories. In Neo-Schumpeterian economics or evolutionary economics, respectively, the focus is on the emergence of novelty as the driver of economic change. And the pursuit for coming closest to the abyss of arbitrariness keeps on going.

An approach which reveals this issue quite well can be found in the concept of Meso-Economics as suggest by Dopfer et al. (2004) and Dopfer (2006, 2004, 2001). Basically they point out the story from above in a more elaborate way. Economists usually are preoccupied with the *operant level*. The operant level subsumes all changes we observe in economic development/performance. Economic actors make use of some opportunities and exert *operations* on *commodities*. Efficiency is the keyword that guides economic behavior. From a methodological point of view, it makes no difference whether the economic actors actually reach efficiency in an equilibrium point by maximizing their utility (neoclassical approach) or whether they behave as if they wanted to reach efficiency but never do so because of their imperfections (Neo-Schumpeterian/evolutionary economics approach). In this respect both approaches primarily focus on the operant level. According to Dopfer et al. (2004), all what we observe on the operant level simply is the actualization of some *generic rule-based* behavior. The *generic level* thereby is the source of novelty, the origin of novel ideas, the creation of new knowledge and the cognitive seed of human behavior. On this level market conditions do not play a dominant role. Market selection may erase all inefficient behavior on the operant level but does not erase the underlying knowledge applied in such behavior. The creation of knowledge does not need to be exclusively driven by market conditions (Grebel 2009). Some of it can simply be a result of a random process subject to a path-dependent context.

As well, the formation of networks is to a certain part random and contingent to their context.

On a purely operant level, firms may strategically form alliances to increase their market power. The context of such a decision will probably involve little randomness. It may be a logical consequence in order to reach monopoly power at its best. Then, an operant level theory on such behavior is sufficient. When it comes to innovation, however, there are many contingencies with regard to which action to take. In the case of incremental innovations operant-level explanations might still suffice to a certain extent, such as explaining the means and ends to make a micro chip smaller and faster. In the case of radical innovations a purely operant-level perspective will not hold. Many generic rules or ideas have various operant-level representations. In Dopfer's words there is oneness and manyness. The idea of a means of transportation can be represented in the actualization of a car, a bus or a bike and so it is with the engine type. Networks that are based on research work, especially in basic research, the outcome may have the potential for future innovations, their formation are to a lesser degree influenced by market conditions.

There are implications to be derived from the generic level. There are generic rules – although they are not directly related to market conditions – which induce the evolution of certain structures. Concerning the evolution of inventor networks, collaboration is a possible rule to increase one's inventive output. Therefore, there is an incentive to cooperate in the invention process.

The incentive to invent and to cooperate depend on the originality of a new technology field and the number of researchers/networks that are already engaged in this field. Therefore, the role of knowledge diffusion, the incentive to invent and cooperate in a network context is the next topic to discuss.

6 Knowledge, Diffusion and Networks

Suppose we have a set of n actors in some research discipline.[4] For an empirical motivation in section 4 heart medicine serves as an example.[5] Let us assume that a new research field is emerging and a small number of physicians get interested and start doing research on e.g. percutaneous heart valve replacement. The incentive to cooperate is given by the fact that cooperation increases the propensity of a successful research via synergy effects. From an epistemological stance, the "ingredients" of the pieces of knowledge for a new invention are unknown. At the most, there might be a hunch about the possible ingredients but no precise knowledge. Research is a trial and error process (unfortunately, also in medicine). If one of those early researchers starts to search for possible cooperators, there are several determinants for cooperation: personal attitudes, institutional frames and, among other things, local proximity (von Hippel 1994). Cross-fertilization to occur in the creation of knowledge, requires a face-to-face contact (Berry 1997), a close interaction, so that the cooperating partners profit from mutual knowledge. Closeness can also be accomplished by participating conferences and medical workshops, but this would be a second step. Initially, local proximity matters. The tacitness of knowledge (Polanyi 1958) asks for a close interaction to initiate learning effects. Aside from the characteristics of knowledge, whether it is *sticky* to a person (von Hippel 1994) or codified and therefore easier to transmit, the actual occurrence of spillovers also depends on the *absorptive capacity* of another person (Cohen and Levinthal 1990).[6] In the words of Eliasson (1990), one might not have sufficient *receiver competence*. Further determinants that catalyze knowledge diffusion are named by Levin and Reiss (1984). To simplify the model, suppose all actors have enough receiver competence, and knowledge is not sticky to anyone of the cooperating researchers, but it is sticky within the boundaries of the network. As time passes on and more and more researchers

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[4] Grebel et al. (2006) investigate knowledge-intensive sectors as an example.

[5] The medical sector was chosen because of assuming with the Hippocratic oath that marketability of medial products is not predominant in hospital researches.

[6] Cohen and Levinthal (1990) use this term on a firm level. To avoid neologisms this analogy seems acceptable.

notice that there is a new technology field emerging[7] the incentive to engage into research in the same field gradually increases according to a sigmoide diffusion path of researches being activated (Grebel 2004). Therewith, the possibility to cooperate with other researchers interested in this field augments, too, and the proximity of actors grows. Simultaneously, the number of emerging networks increases and, with the proximity to other activated researchers, also the propensity to cooperate with a researcher that already belongs to a network in this technology field increases. Note, under the assumption that market selection has no impact at this stage, network formation is a partially random process driven by proximity and the incentive to engage into a new technology field. The incentive to engage depends on the number of activated researchers and the size of networks. The larger a network the lower the reputation effect involved with novel knowledge. On these grounds, the incentive curve should be hump-shaped.

Using percolation theory, this concept of generic network evolution is modeled in the following.

7 Percolation Model of Generic Network Evolution

Percolation Theory

There is a multitude of applied percolation theory[8] in economics. Product diffusion models are the most prominent ones (Hohnisch et al. 2008). In marketing concepts it is used for evaluating a product's possible adoption process (Chandrasekaran and Tellis 2007) and thus incorporate theories about the demand side such as consumer preferences (Witt 2001), other also take path dependence (David 1985) and communication patterns (Ratna et al. 2008) into account. Thereby, social learning´processes (Young 2007) are as much relevant as the underlying externalities (Allen 1982). Accordingly, different market structures occur such as a double peaked structure as suggested by Solomon et al. (2000).

Percolation models of technology diffusion work similarly. The difference simply lies in the "entity" what actually diffuses. It is no longer a tangible commodity but the intangible driver of technological progress: knowledge. As already pointed out in a previous section, knowledge has specific characteristics with a tremendous influence on economic behavior (Witt et al. 2007). Whereas product diffusion models rather focus on a static picture where the actual adoption of a good by consumers already draws the actual diffusion path, models on knowledge diffusion often ask for a consequential economic action. Understanding a new technology may activate an individual to undertake entrepreneurial actions (Grebel et al. 2003, Grebel 2004). With respect to inventive behavior, whether other economic actors are able to adopt new knowledge or not is crucial for the incentive to engage in inventive activities. Localized knowledge (Antonelli 1996) can be safeguarded by an inventor, a firm or by a network of firms or inventors. In this case, the incentive to cooperate in technology invention is bigger than in the case of non-localizable or generic knowledge. Within a technology cooperation network, network externalities and the prospects of appropriability of innovation rents go along in a symbiotic manner. Antonelli (1997, p. 144) calls these networks *technology clubs*: "(...) institutionalized systems of technological relationships among firms which aim at internalizing technological externalities (...)." This holds also on the inventors level, medical researchers have to decide whether to join a network or not, they have to evaluate the trade-off between the profits and losses implied by cooperation. This trade-off has to be evaluated within a network and also on a general level: the number of networks (cluster, technology clubs) which already exist within a certain technology field. The more actors already engaged in a certain technology field, the less attractive it is to undertake

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[7] This itself is a diffusion process. The fact that this type of information about an upcoming research paradigm (Kuhn 1962) diffuses does not automatically induce knowledge spillovers.

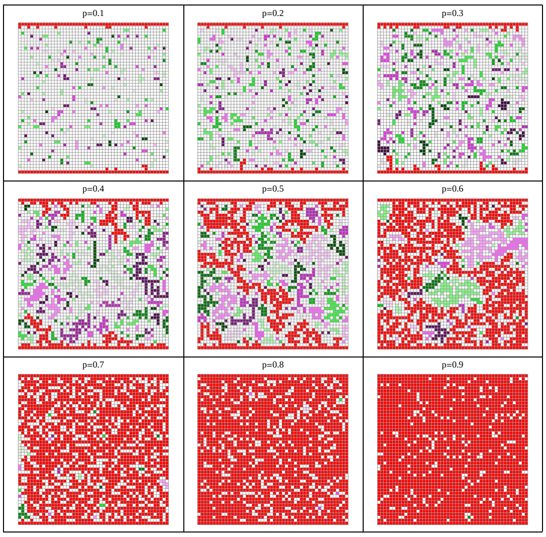
[8] Stauffer and Aharony (1994) provide a detailed overview on possible applications of percolation theory.

inventive activities oneself.

Research in general is the attempt to structure the random process of knowledge creation as much as possible. Researcher may come across a subject matter such as percolation theory and happen to detect the analogies to diffusion processes in economics. In a scientific community the members are usually well-informed about what others do research in. Though one may start using a new approach, not all will jump in at the same time. Researchers have to – and they do – stick to a certain research paradigm (Kuhn 1962) and local research departments as a sub-community do have a significant influence on that. Nevertheless, research focuses on novelty and so there is room for change. Untilled research fields are therefore of interest to every researcher. However, the probability of high reputation of a scholar on a stand-alone basis is very low. So researches need to form networks. Evolutionary Economics subsumes one of such networks among economists. Though the term evolutionary economics labels the overarching entirety, there are many other networks within this network doing research in different fields. These subnetworks underly a continuous restructuring process, a process which is also vulnerable to some sort of academic fashion. Each research field experiences its own diffusion path until it gets established. And this holds for all disciplines of research.

This common process of network formation is something to be expected in nature. Percolation theory illustrates this scenario quite well and shows what network structure over time – and subject to the degree of knowledge diffusion – has to be expected.

Figure 2: Random network (cluster) evolution.



Let n be the number of researchers or actors located on a torus with four neighbors in an von-Neumann-neighborhood each.[9] Suppose a new research topic is coming up initiated by some scholar. Others may follow over time and start doing research in this field as well. Moreover, let us assume that this research topic diffuses over time. The way how this diffusion is substantiated via interaction is not the focus here. We simply assume that an increasing fraction of researches get interested in this field and those researchers are randomly distributed on a square lattice.[10]

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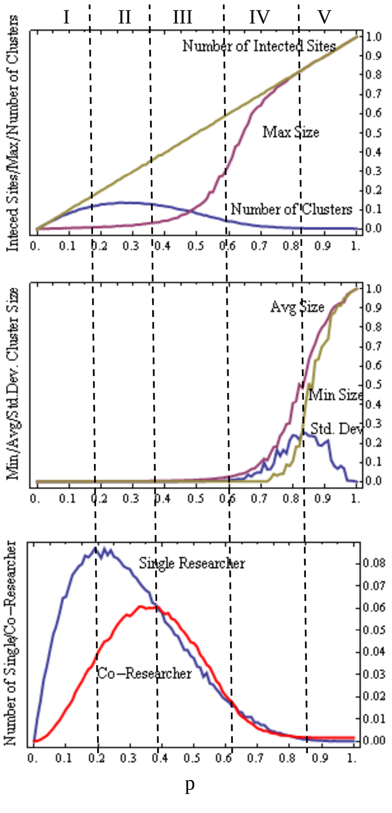
[9] A Moore-neighborhood would also be feasible without significantly changing the results.

[10] Grebel (2004) gives an example how to implement such a bimodal diffusion process: the diffusion of knowledge

Initially, only few researchers are engaged in this field and, assuming random dispersion, they may be isolated from each other. Though the incentive to cooperate may be given, the probability to run into a researcher with the same field of interest is lower. But over time, with more and more followers it becomes more likely that networks (clusters) emerge because it is more likely that two researchers with this new research topic are located in their neighborhood.[11] To emphasize, it is of no interest whether an actor moves or strategically watches out for "good" ties, since we explicitly focus on the random aspect in network formation.

Let p be the fraction of actors working in the new research field and n the number of total actors on the torus. Figure 2 illustrates an example of the random formation of networks subject to the permeation, i.e. the fraction of actors active in the same research field. In an early stage almost no networks (clusters) emerge. Sites with the same color belong to the same network. With p increasing (e.g. $p = 0.4$) more networks come into existence. The percolation threshold, as the point where a lattice-spanning cluster occurs, is $p = 0.5927$ (Sahimi 1994). This becomes obvious when comparing $p = 0.5$ and $p = 0.6$. In the former, the number of isolated clusters is still high and rapidly falls with $p = 0.6$. Then, a lot of networks get connected to one big cluster. From $p > 0.6$ a global community is established.

Figure 3: Monte-Carlo simulation on the evolution of network structures.



Running a Monte-Carlo simulation delivers the results given in figure 3. The usual network statistics suggest a typical evolutionary process, a process based on random behavior. The diagram in the top illustrates the number of infected sites, actors (researchers) that are engaged

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and the diffusion of entrepreneurial actions.

[11] Note, a tie is only assumed if the neighbor is located in the von-Neumann neighborhood.

in a certain research field (bisecting line).[12] All curves are weighted with the total number (n) of actors. In addition, this diagram also graphs the number of clusters and the size of the biggest cluster. The horizontal axis indicates p as the fraction of actors engaged in the research field. The diagram in the middle depicts the minimum and average size of the emerging networks, and the standard deviation in size. The diagram on the bottom shows the evolution of the number of single and co-inventors.

The number of networks (clusters)[13] is increasing with p. The number of isolated actors is increasing till $p = 0.2$ and dominates the number of clusters with minimum size 2 (phase I). The likelyhood that actors, i.e. activated researchers, are isolated falls from $p = 0.2$. In return the probability of emerging networks with size > 1 augments and exceeds the number of single actors at $p = 0.4$ (phase (II)). The maximum number of networks lies at $p = 0.3$. In phase (III) the number of actually collaborating actors is bigger than the number of isolated ones. The maximal cluster size is still very low. At the percolation threshold ($p = 0.593$) the picture changes rapidly in phase (IV): the number of clusters decreases, the size of the biggest cluster skyrockets. With the highest standard deviation of cluster size, which sets the beginning of phase (V), almost all actors are connected and finally only one single network remains.

As already mentioned, strategic behavior is omitted in this picture and we simply try to find out to what extent randomness plays a role in network formation. The implications derived in the following explicitly focus on the generic level of human behavior (Dopfer et al. 2004, Dopfer 2006), which deliberately neglects the selective power of markets in order to reveal the generic base of network evolution (Grebel 2009).

Implications from Percolation Theory

In phase (I) the incentive to work in a new, interesting research field is high and so is the incentive to collaborate because of synergy effects. Other researchers may know about what kind of research which researcher does; the actually produced knowledge, however, is bound by the researchers' network. Since there are many isolated networks, the incentive to invent should also be high. The chances for collaboration increase with the number of actors engaging in the new field so that more and more networks emerge (phase (II)). In phase (III) consolidation takes place. Network size increases while the number of networks goes down and with this the incentive to invent, since the chances to keep newly generated knowledge secret to a small number of people gradually fall. In phase (IV) the percolation threshold is reached, which means that there exists a lattice-spanning network which implies that newly generated knowledge is almost common knowledge. The incentive to invent is low and should come down to zero in phase (V).

Table 1: Generic implications on network evolution derived from percolation theory.

percolation phase		**phase (I)**	**phase (II)**	**phase (III)**	**phase (IV)**	**phase (V)**
generic	incentive to invent	↑	high	↓	low	nill
	incentive to collaborate	high	high	↓	low	nill
	chances to collaborate	low	↑	high	high	high
operant	technology life cycle phase	pre market	emerging market	growth	maturity	decline
	market structure	no market activity	Schumpeter mark I	Schumpeter mark I/II	Schumpeter mark II	Schumpeter mark II

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[12] Diffusion curves usually have a sigmoid shape so that all curves in figure 3 should be skewed according a s-shape.

[13] For simplicity, also single actors are treated as a network of size 1.

In contrast to the incentive to collaborate, which should be high from the very beginning and start to fall in phase (III), the chances to collaborate are low at the beginning, increasing in phase (II) and high till the end of phase (V) (compare table 1). The chances to collaborate depend on the number of active actors. Starting out from low chances (phase I) such opportunities increase over time and remain high because of the high number of active actors. Faced with the incentive to collaborate, the emergence of networks should be highest in phase (II) and (III) at least from a purely generic-level perspective.

The evolution of this structure is so to say a self-expressing generic structure that emerges out of generic rules with no link to market conditions. Obviously, from an empirical point of view, this generic story can hardly be observed in its pure structure, since it is always hidden under operant-level effects. Table 1 summarizes the generic-level implications and adds an operant-level perspective. At the beginning of a new research field, there are yet no tradable technological actualizations, networks evolve without an operant-level feedback effect. In other words, network formation is driven by randomness and generic rules. In phase (I) few (isolated) researches are interested in the new research field, the incentive to collaborate is big but the chances to cooperate very low. Gradually in phase (II) more researchers get interested and also more networks evolve, since the incentive to cooperate is high and the chances to collaborate increase. First feedbacks from the operant level occur which is due to the formation of first-mover firms. In the third phase the incentive to invent and collaborate is high, though falling; the chances to cooperate are high and a growing market increases the selective power on the network formation. After phase (II) when first Schumpeterian enterpreneurs/innovators entered the market, market conditions rapidly become the coordinating forces of network formation, the strategic element in networking prevails and the generic aspect of network evolution diminishes.

8 Conclusion

In this paper the random part of network formation is addressed. Market selection in early phases of novel research fields not necessarily is the prevailing coordinating force in such evolutionary process. Instead, there are generic aspects in their formation. A Monte-Carlo simulation of percolation theory shows a specific, emerging structure subject to the diffusion of the interest of researchers in this field. Several phases can be identified. These phases are stylized phases from a purely generic-level perspective in the sense of Dopfer et al. (2004). The detection of purely generic-level phenomena turns out to be a difficult task since the evolution, as it is the case in researcher network evolution, is overlaid by the operant-level market conditions. An empirical part served as a motivation. The future task to do is to disentangle the generic-level processes from the operant-level processes. Basically it burns down to the question where and when market conditions are the dominant coordinating force in economic dynamics and to what extent rule-based behavior as put forward by a generic-level perspective offers an explanation to evolutionary processes. Nevertheless, the example of this percolation model shows that there is a generic element that suggest a certain emergence of network structures, which need not necessarily be attributed to market conditions. The reciprocity between the two levels, generic versus operant, makes it difficult to isolate the generic-level from the market-induced (operant-level) influence. But in case we succeed in doing so, we will shed light of the scope of the explanatory power of market selection, which is not comprehensive but simply relevant as far as it deviates from generically induced phenomena.

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