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An Evolutionary Approach to
Regional Systems of Innovation

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An Evolutionary Approach to Regional Systems of Innovation

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Abstract

This article examines how the birth and the development of regional systems of innovation are connected with economic selection and points to implications for regional-level policies. The research questions are explored using an evolutionary model, which emphasises geographical spaces and production of intermediate goods. In particular we are concerned with how cooperative behaviour of technology producers is affected by the need to protect technological secrecies and of being financially constrained by firms demanding innovative input. Based on the theoretical model, we provide an analysis using computer simulations. The primary findings are, firstly, that the model generates predictions suited for empirical research on how economic selection influences cooperative behaviour of innovative actors. Secondly, we demonstrate how a region's entrepreneurial activity and growth can be controlled in a decentralised way by regions

Keywords: Regional system of innovation, intermediate goods, economic selection, organisational capital

JEL Classification: L24 O33 R38

1 Introduction

In the Nelson-Winter evolutionary model, innovations depend on R&D expenditures, which grow and decline with the growth and decline of firms (Nelson & Winter 1982). This approach does not fully take into account recent insights into the organisation of the innovative process mainly provided by geographers (Cooke & Morgan 1998; Saxenian 1994; Scott 2000; Storper 1997). The inclusion of geographical spaces improves the organisation-theoretic foundation of the evolutionary model in different ways. An extended model takes account of the vertical disintegration of large firms and the production of intermediate goods.

In this paper we focus on the production of innovative input within regional systems of innovation, which join together infrastructure (in particular knowledge infrastructures such as universities and R&D facilities) and innovative behavior (Werker & Athreye 2004). Many studies of regional innovation systems are motivated by beliefs that the relation between technical advance and regional growth depends on the amount of technological knowledge in a region. Yet, the connections between the body of knowledge and the knowledge that is economically exploitable (economic knowledge) are awkward, which has been discussed by Kline and Rosenberg (1986) and more recently by Audretsch and Keilbach (2004). Cantner and Graf (2004) focus on efficient organisation of knowledge creation in regions and find that regions that are technologically moderately specialised with regard to kind of knowledge and degree of sophistication show the highest number of research cooperations. Their approach is inspiring, but they have no explicit reference to economic selection. In the following, we try to introduce geography in an evolutionary model and, at the same time, examine questions of how Cantner and Graf's analysis of regional innovation systems can be connected with Audretsch and Keilbach's approach to economic selection.

We note that the Lisbon Strategy launched by the EU raises interesting policy questions about connections between technical advance and regional differences in growth. For a long time, it appeared as if the European regions converged, but more recent evidence challenges this perception (Cappelen et al. 2003). The notion of a regional system of innovation incorporates policy variables (institutions for higher education, technology advisory centres), which in part are controlled through regional-level policies. Inquiries into this system may improve the understanding of decentralised (regional) approaches to the realisation of the Lisbon Strategy. The primary aim of this paper is to examine if evolutionary modelling, which highlights relations between geographical spaces, regional systems of innovation and competitive selection, generates patterns with empirical relevance for research on regional involvement in EU technology policies on regional growth. Inspired by recent discussions about improvements of the first generation of Nelson-Winter models (Malerba et al. 1999; Sloth Andersen 2001), we thus propose an evolutionary model and a computer simulation program for logical exploration of causal relations that, hopefully, will improve the arguments put forward in future empirical research.

The first finding of our study indicates that an evolutionary model that admits production of intermediate goods provides insights into how regional systems of innovations are born and develop. In vertically disintegrated production systems, the technology producers perceive a need to protect technological secrecies and they are financially constrained by the demand for innovative input by downstream firms. With reasonable assumptions about these perceptions and conditions, our simulations produce sensible development paths for the system of innovation. The second finding suggests that the development path can be controlled in a decentralised way by regions that take actions to affect the interaction between technology producers; either by changing the degree of specialisation or by an exemplary model - a key entrepreneur - who perceives market needs and initiates business opportunities. If a regional policy-maker takes these actions to create favorable conditions for cooperative behavior within a region, it will usually help the finance of the entrepreneurial activity and the growth of the same region. However, the simulations made for this paper suggest that a zero-sum game is going on between the regions unless the regional-level policies are coordinated with the knowledge management strategies of large firms (with affiliations in different regions).

Section 2 is devoted to a discussion of the evolutionary model we use to explore our research questions. Production of intermediate goods is included through the regional system of innovation, which produces and sells new technology to firms in the region (national firms) or to firms with affiliations in different regions. These firms invest in facilities to produce for product markets. Section 3 describes how the model is applied to illuminate issues on regional involvement in policy-making. Here we show how our approach for examining cooperative behavior of innovative actors differs from research on innovative behavior based on specialisation. The simulations are reported in section 4, which also includes appropriate interpretations. Section 5, finally, contains a few concluding remarks.

2 The model[1]

The geographic dimension of evolutionary modelling is seen through the lens of vertical disintegration and production of intermediate goods. It is also built on the work of Audretsch and Keilbach (2004), who argue that the selection of economic knowledge from the whole body of knowledge is the result of entrepreneurs, who increase regional growth by starting new firms. They argue that entrepreneurs place a high value on knowledge, which is not valued as highly by hierarchical decision making organisations in incumbent firms. Entrepreneurs start new firms to appropriate this value. This perspective is broadened in our paper, firstly, by separating knowledge in national firms, which develop by learning in regional spaces, from knowledge in multinational firms (MNEs) unfolding by learning in supra-regional spaces. It is an urgent task to describe the implications for innovative behavior of a larger capacity of MNEs to develop, orchestrate and integrate a wide variety of technological knowledge. Secondly, the perspective is broadened as the entrepreneurs also rely on technological knowledge created in regional innovation systems.

Our approach emphasises changes in the industrial structure due to vertical disintegration of large firms leading to increased growth of a small business sector (cf. Carree & Thurik 1999). This approach is in the spirit of scholars arguing that the so-called new growth theory is unable to explain why large investments in R&D do not always result in rapid economic growth (Carlsson et.al. 2007). By neglecting the difference between economic knowledge and the whole body of knowledge, this theory do not only disregard the importance of the "knowledge filter" preventing knowledge from becoming economically useful,

[1] For a complete description of our model, please contact the authors.

but it also neglects entrepreneurship that converts economic relevant knowledge to economic activity. In our paper, we deal with entrepreneurship by noting a new kind of technological regime, where the translation of basic research into commercial knowledge is carried out by small firms in industries with a large share of large firms (see Carlsson et.al. 2007 for more details about this regime).

Stable states of small firms are contradictory to belief that small firms are inefficient and therefore are eliminated by competitive selection. But, as Carree and Thurik (1999) conclude, small firms can compensate for cost disadvantages by creating networks or other inter-firm linkages. From this perspective, entries into and exits from a small business sector can be seen as changes in regional systems of innovation. This sector develops new technology for technology markets and the producers become patent-holders and sell patents and licences to other firms, which invest in new facilities to produce for product markets.

Literature on industrial districts argues that social networks constitute the foundation required for the creation of business-oriented regional networks (Lechner & Dowling 1999). Regional networks constitute the small business element of an innovation system. The institutional set-up (infrastructure) of a region affects opportunities for mobilising pockets of available resources in the social network, which depends on the presence of a key entrepreneur or scientist (Lechner & Dowling 1999; Gerybadze 1998; Sternberg 1996). In our model, there is one key entrepreneur in each region, who initiates business opportunities. The inventors start to learn about a business opportunity when the key entrepreneur "perceive(s) a market need" (Kline & Rosenberg 1986, p. 289). The conditions for learning about new interests are favorable when the individuals share a common professional background (Checkel 2001), i.e. the chance for a regional network to appear within the social network is good.

In the spirit of DeCanio and Watkins (1998), we imagine an inventor as persuaded to participate in the development of a business opportunity. The probability of him/her joining a business-oriented regional network increases if the number of colleagues in the social network he or she is connected with, who argue in favour of the business opportunity, is sufficient. Before he/she becomes an advocate of a business opportunity, the different aspects of the opportunity must be understood and information received from colleagues must be digested thoroughly. This requires the use of information-processing capacity, which is limited for the individual inventor (this kind of limitation is fully explored by Simon, 1981). Difficulties with dense social networks are also discussed by Burt (1992), who points to redundant contacts, which lead to the same people and, thus, provide the same messages. The most favorable conditions for the creation of regional networks are associated with multiple agents competing for the occupation of structural holes, which connect non-redundant contacts.

Drawing on De Canio and Watkins, we suggest the following relationship between the probability for an inventor to individually consider a business opportunity, his or her information processing capability and the structure of the social network:

$$P_i^g \left(d_i^g(t) = 1\right) = \frac{1}{1 + e^{-\frac{\left[x_i^g(t) - \frac{\beta_1}{\alpha_2}\right]}{\frac{\beta_2}{\alpha_2}}}} - \frac{1}{1 + e^{\frac{\beta_1}{\beta_2}}}, \tag{1}$$

where P_i^g is the probability for an inventor i in region g to consider a business opportunity, and $d_i^g(t)$ is a random variable with either the value of one or zero, according to whether the inventor does or does not consider the opportunity. While β_1 and β_2 are constants, α_2 is a parameter introduced to represent the processing power. Furthermore,

$$x_i^g(t) = \frac{\sum_l Y_{il}^g(t)}{Z_i^g(t)}. \tag{2}$$

$Y_{il}^g(t) = 1$ if inventor i is connected to inventor l (in the sense that he or she is informed about l's situation) and l considers the business opportunity at t. $Y_{il}^g(t) = 0$ if the inventor is connected to l, but the latter does not consider the business opportunity. $Z_i^g(t)$ is the total number of inventors inventor i is connected to. An inventor with a large number of contacts with other members of the social network is unable to digest all information he or she receives. Since a business opportunity will not be considered, information will not be diffused, impeding the development of the regional network.

The structure of the social network changes over time (new contacts are established and old ones are broken). The establishment of new contacts at t depends on the interaction between inventors and on the chance that the interaction will lead to a contact. The chance varies between regions according to, for instance, the degree of specialisation. The number of meetings of i and l at each point in time - n_{il} - is associated with infrastructures that orchestrate the dialogues among technical workers (e.g., technology information centres, regional science and technology societies, supplementary education). The probability that i and l will exchange information at a meeting - p_{il} - depends on variation in knowledge and sophistication among the technology producers. The probability for a meeting between two inventors to lead to exchange of information is high, if they perceive their competencies as equal, and low in other cases. In addition, high probability requires that the kinds of knowledge held by the inventors are complements rather than substitutes.[2] h refers to the minimum number of meetings, where information has been exchanged between i and l, required to establish a contact. Moreover, t' is the point in time when inventors i and l begin to establish connections after social contacts have been broken or when a business opportunity last failed for i or l . $t' = 0$, if i and l have never broken a contact or been involved in a business opportunity.

The sequences of meetings are considered independent Bernoulli trials, i.e. for $n_{il}(t - t') \geq h$ the probability for a contact to establish between inventors i and l in region g at t is determined by the binomial formula:

$$P^g_{il}(Z^g_{il}(t) = 1) = \sum_{r=h}^{(n_{il})(t-t')} \binom{(n_{il})(t-t')}{r} (p_{il})^r (1 - p_{il})^{(n_{il})(t-t')-r}. \tag{3}$$

If $n_{il}(t - t') < h$, then $P^g_{il}(Z^g_{il}(t) = 1) = 0$.

The technological knowledge in a region derives from different sources: 1) from inventor activities within the region, 2) from spill over received from other regions and 3) from knowledge channelled through multinational enterprises

[2]This pattern of variation in p_{il} is defined in the spirit of Cantner & Graf (2004), who consider the probability of cooperation as dependent on kind of knowledge and on the degree of sophistication.

(MNEs). Technology from 3) crosses supra-regional spaces within the organisational spheres of MNEs. By calling attention to this source, we want to emphasise the importance of knowledge management by MNEs. While 1) and 2) provide public knowledge, knowledge from 3) depends on how MNEs link corporate strategies with changes in the organisational capital which is technological information that belongs to the firms. By suitable knowledge management, MNEs gain from geographic specialisation and from the ability to orchestrate supra-regional technology diffusion and, thereby, achieve competitive advantages over national firms. At the same time, they master "information stickiness", which our model treats as a barrier to 2) ("spill over received from other regions").[3]

Inspired by Weitzman (1998), we consider the research process to be recombinations of old ideas in new ways to create new ideas. Consequently, technological knowledge can be measured as all possible combinations of product specific knowledge. If s^g represents the number of product models produced in region g, then 2^{s^g} represents the number of all possible subset combinations (including the null set) that can be formed out of the product specific knowledge in g (cf. Weitzman 1998).

The diffusion of a technology starts with an invention leading to a new product model, which afterwards induces a series of additional innovations based on the same technology. Our model depicts the diffusion of product models invented and produced in two regions (g^* and g), and supplied in one market. The technology gap between the regions can be measured as $2^{s^{g^*}} - 2^{s^g}$, where $s^{g^*} > s^g$. Due to "stickiness", only a portion (α_1) of the difference in technological knowledge is transferred from g^* to g external of the MNEs. Moreover, the ability to interpret and to understand information received (the absorptive capability) in g decreases when the gap between the regions increases. Thus, the net spill over between regions g^* and g, which is not channelled through MNEs, is

$$H^{g^*g}(t) = 2^{s^g(t) + \frac{\alpha_1\left[s^{g^*}(t) - s^g(t)\right]}{2 - e^{-\left[s^{g^*}(t) - s^g(t)\right]}}} - 2^{s^g(t)} . \quad (4)$$

[3] An interesting discussion of "information stickiness" is found in von Hippel (1998).

The first term to the right of the equity sign shows the technological knowledge available in g, when the spill over is included. However, due to less absorptive capability in g, only part of the technology spill over can be recombined with new ideas, which is taken into account by the expression in the denominator. The spill over between the two regions is found after the knowledge deriving from the inventor activity in the lagging region (the second term to the right of the equity sign) has been subtracted.

MNEs are net-worked in both regions, and information is collected and redistributed through internal systems for information and knowledge management. Accordingly, all employees in a MNE have access to the same information and the same number of recombinations of old ideas can be formed ($2^{s^{g^*}}$).

We may think about the coupling between a regional innovation system and economic selection as preliminary designs, proposed by inventors working together, and examined by firms balancing technical problems and market gains. The probability for an innovation at time t depends on expectations about firm-growth, which vary with changes in the rate of growth of the common market. Whether an innovation derives from inventor activities in region g or in g^* depends on the probability for finding solutions to technical problems, which increases with the number of combinations of product specific knowledge and with the capacity to process information in the respective regions.

After the decision to innovate has been made, the firm has to decide about the location of production. MNEs can fully gain from geographical specialisation, while national enterprises (NEs) sometimes are facing a trade-off between low production costs and access to innovative input. In our model, production costs depend on a spill over parameter expressing the proportion of technological knowledge spilling over from experience accumulated in the production of less advanced goods.[4]

[4] The value of the parameter depends on the rate of qualitative changes from one product variant to another and on the number of types of product-specific knowledge transferred. A wide range of product-specific knowledge requires a large labour market for the recruitment of qualified employees ("economies of a pooled labour force"). The more properties of prior products incorporated in a new product, the more sensitive are the productions costs.

New product variants enter into the market; products produced above average efficiency extend their market shares and below average products lose market shares and sometimes exit from the market. The epidemic model of technology diffusion is applied to depict this evolutionary process through which economic selection proceeds. The diffusion process is described by a complex equation, which is illustrated by the following simple logistic function

$$\frac{dm_{s^j}(t)}{dt} = \eta \left(n - m_{s^j}(t)\right) \frac{m_{s^j}(t)}{n}, \tag{5}$$

where the total number of potential users of a product model, n, is given beforehand. Moreover, $m_{s^j}(t)$ is the number of users of product model s^j at date t, and η is the rate of diffusion. This is a disequilibrium approach, where the process is self-perpetuating: the use of a product is initiated through contacts between users and non-users, which leads to further use. The marketing literature commonly includes external sources of information, such as advertising, implying that the diffusion process no longer is completely self-propagating (see Stoneman, 2002). No position is taken on which type of external intervention the firms use, but we assume that the resources they have for external interventions depend on economic performance.

In our model, management does not know the thorough production costs before entering into the market. This idea is discussed by Jovanovic (1982), who assumes that firms learn about their production costs after starting production. In our model, no entrant knows the true costs, which is a random draw from a normal distribution of costs. Firms making favorable draws can afford low prices and efficient marketing. Our approach to competitive selection also notes that a new product offers improved quality or performance as compared with an older product, which could affect demand across products. These interrelationships between products are taken into account in the sense that a user of product s^j may substitute this product for another product s^i.

Economies of scale explain why young firms exit from an industry (Audretsch 1995). In our model, a product model remains on the market throughout its exploratory stage (products younger than $\bar{t}$) and there are expectations that the minimum efficient plant-size (ms^*) will be attained in this stage. Thus, no product model is eliminated from the market during the exploratory stage. For product models of age $\bar{t}$ and older, the following condition is valid for exit[5]:

$$ms_{s^j}(t) < ms^* \quad , \quad t \geq \bar{t},$$

where the number of users ($m_{s^j}(t)$) has been replaced by the market share ($ms_{s^j}(t)$).

3 Empirical challenges

One question arising is if evolutionary modelling with a geographic dimension generates patterns with empirical relevance. To answer this question, we draw attention to the EU's Lisbon Strategy, which is supposed to make Europe the most competitive knowledge based economy in the world by 2010.[6] In addressing the regional dimension of the Lisbon Strategy, the Commission connects regional disparities in research, innovation and economic growth to Europe's capacity to stay competitive in world markets. Regions are expected to play a "motor" role in the overall context of economic growth, and the achievement of greater cohesion in the EU depends on "the integration of research capabilities in less favoured regions in the European research fabric".[7]

Obviously, more recently the EU Commission has overridden the regional dimension by the globalisation perspective. This is a response to the fact that new scientific and technological powers (China and India) have become attractive for business as a location for R&D investments.[8] Contrary to the seemingly devaluation of regional equalisation by the Commission, our simulation

[5] Empirical evidence shows that both small and large firms disappear from the market after the diffusion of a new technology has culminated; economies of scale, thus, is not an important aspect of high exit rates. Therefore, this condition will be reformulated in future research (cf. Gort & Klepper 1982).

[6] Facing the challenge. The Lisbon strategy for growth and employment. Report from the High Level Group chaired by Wim Kok, 2004

[7] Communication from the Commission. The regional Dimension of the European Research Area, COM(2001) 549 final, Commission of the European Communities pp. 5 and 18

[8] Green Paper, The European Research Area: New Perspectives, COM(2007) 161 final, Commission of the European Communities

model is constructed to address issues on how innovation systems can be used to reduce regional imbalances. This paper, however, focuses on understanding decentralised (regional) approaches to the realisation of the Lisbon Strategy. That is, it is expected to improve the "region-conscious" development model for the organisation of European research, which the EU Commission suggested at an early stage. Since the regions have different profiles, the Commission advocates the reliance on "the self-organising capacity of regions" which it considers a growth factor, and on "territorialisation" implying a "tailor-made" research policy approach that addresses specific territorial conditions.[9]

This can be done because our model admits that the selection of technological designs produced in a region becomes more probable when the amount of knowledge and the research capability of the regional innovation system increase. In addition, the research capability increases with the size of the regional network, which agrees with Cantner and Graf (2004, p. 544), who argue that "cooperation is favorable to innovation". This conclusion is crucial for our study, where it is claimed that the size of regional networks can be affected by regional-level politics. It also sets for a discussion of a strategy for the satisfaction of what the EU Commission defines as a need to overcome the fragmentation of the European research base. Overcoming this fragmentation is believed to help regions to "attract a critical mass of human and financial resources from across the world". We doubt, however, the conclusion drawn by the Commission that concentration and specialisation is necessary to permit the emergence of one group of European centres of excellence and another group of centres which excel in addressing research and training at the national, regional and sectorial levels.[10] We suggest a method to examine if the critical mass can be attracted within the context of the new development model and without regional imbalances.

One implication of vertical disintegration and production of intermediate goods is that large firms may put limitations on the regional research capability.

[9] Communication from the Commission. The regional Dimension of the European Research Area, COM(2001) 549 final, Commission of the European Communities pp. 6 and 7

[10] Green Paper, The European Research Area: New Perspectives, COM(2007) 161 final, Commission of the European Communities, pp. 8 and 14

They may be reluctant to share technological knowledge with external producers of technology. The EU Commission concludes that achieving the Lisbon objectives is facilitated by regional strategies encouraging "dynamic operators coming together in partnerships", but businesses find it difficult to cooperate and to enter into partnership with European research institutions.[11] According to the Commission, these difficulties may depend on businesses that invest in R&D look for adequate numbers of well-trained and mobile researchers and an excellent public research base.[12]

MNEs are not willing to share knowledge that is highly valued by their hierarchical decision making organisations (cf. section 2). Furthermore, the research capability of the regional systems of innovation is changed if the MNEs revaluate technological knowledge. This revaluation implies, for instance, that transferable knowledge about products is transformed to organisational capital which belongs to the firm. Our model spells out the spatial implications of this transformation, which favours the diffusion of advanced technology within an elite of engineers and scientists organised by the headquarters of the MNEs. This elite can be found both in technologically advanced and in lagging regions. At the same time, the technology spill over from the advanced regions to all other technology producers in the lagging regions is reduced. This paper also reports applications of the simulation model that examine how the cooperative behavior of businesses changes with regional system improvements produced by the regional authorities. We imagine the role of regional level policies as a task to affect the context for decision making by technology producers. More specifically, this task is to regulate the exchange relations and to orchestrate the reasoning patterns and the dialogues. As Saxenian (1994) points out in her study of cooperative behavior in Silicon Valley, public forums encourage the development of shared understanding, foster collective identities and trust

[11] Communication from the Commission. The regional Dimension of the European Research Area, COM(2001) 549 final, Commission of the European Communities, p 8 and Green Paper, The European Research Area: New Perspectives, COM(2007) 161 final, Commission of the European Communities, p 6

[12] Green Paper, The European Research Area: New Perspectives, COM(2007) 161 final, Commission of the European Communities, p 7

to support the formation of local networks, and, thus, promote collaboration among local producers.

It has been argued that income per capita will converge among regions with homogenous infrastructures (cf. Caniëls & Verspagen 2001). In our model, production of intermediate goods takes place in regional systems of innovation, which have an institutional set-up of infrastructures (cf. section 1). Therefore, simulations based on this model can provide insight into how investments in infrastructures affect cohesion in Europe. More specifically, they indicate how regional differences in growth can be moderated at the regional level by policy-makers, who use the institutional set-up to affect interactions between technology producers.

Interaction among producers of technology is discussed by Cantner and Graf (2004), who find that regions that are technologically moderately specialised show the highest number of research cooperations. In addition, the more specialised a region is, the more cooperation takes place inside the region as compared with partners in other regions. Cantner and Graf's empirical research is not questioned here, but we try to improve their empirical predictions with the introduction of more factors explaining cooperative behavior. They consider cooperation in the context of positions technical workers have in a technology structure and find that the probability for cooperation depends on the degree to which exchange of knowledge is beneficial to all sides involved. Benefits are associated with properties of the technology embedded in people (kind of knowledge and sophistication). We try to extend this view of cooperation to cover situations where the behavior of the technology producers also depends on their position as producers of intermediate goods. When advancing their commercial interests in the innovative process, technical workers probably feel a need to protect technological secrecies and there is reason to believe that this behavior influences research cooperation. A second type of feedback, working back from economic selection, on cooperative behavior is a financial constraint, which depends on the demand for innovative input by downstream producers. In the following, these two types of feedback will be examined through the lens of our simulation model.

4 Analysis using simulations

4.1 Cooperative behavior

The introduction to this paper mentions the goal of connecting Cantner and Graf's analysis of local innovation systems with Audretsch and Keilbach's approach to economic selection. Lechner and Dowling (1999) argue that the networks of innovators tend to be isolated when economic selection proceeds, which leads to decreased innovativeness. The inventors who survive believe that their success is not linked to the networks they have created. This tendency towards isolation is considered in our model, but our interpretation is that the inventors involved in industrial research are concerned about how to advance their technological designs in markets for technology. They believe there is a risk of imitation. Accordingly, inventors, who are alert to business opportunities, worry about how to protect the technology they develop. When they consider a business opportunity, and connections are established within the regional network, they try to keep technological knowledge secret. Social contacts with inventors, who are not involved in the advancement of the business opportunity, are broken with a certain probability and for a certain period of time (= 1 time step). After this period, new social contacts will be established according to the model presented in section 2. While the key entrepreneur is the only inventor who considers business opportunities all the time, he or she never breaks a social contact.

Lack of finance is also a feedback working back from economic selection, which inhibits the development of a business opportunity within a regional innovation system. In recognising that the average holding-period for a venture capital investment is less than five years (Berglöf 1994), we assume that a business opportunity, to survive, must be rewarded by an innovation within five years. Thus, the technology producers follow a simple rule that a regional network that turns out badly (i.e. is not rewarded with innovations), is terminated after five years. After a business opportunity has failed, the inventors lose prestige in the eyes of colleagues with whom they have no social contacts. The probability for establishing contacts with the failing inventors is reduced to zero. Afterwards, the probability grows according to the model in section 2. On the other hand, social contacts between the inventors who shared the business opportunity will be unchanged, as well as all social contacts of the key entrepreneur.

The empirical predictions of our model cannot be directly measured against the results obtained by Cantner and Graf. We claim that the degree of specialisation (in terms of whether the knowledge of the technology producers complements or substitutes or differs in sophistication) determines the probability that two inventors will exchange information at a meeting (p_{il}). In the spirit of Cantner and Graf, we associate a moderate specialisation with a high probability and a low or high level of specialisation is associated with low probability. That is, our inquiry into a decentralised approach to EU governance raises the question of whether the goals of the EU concerning efficient production of advanced technology and economic growth can be achieved by regional-level policies, which try to increase p_{il} by seeking to attain moderate specialisation.

Our answer to this question is based on properties of the model concerning the establishment of new contacts within the social network. It is claimed that the regional authorities can influence the number of meetings among technical workers - n_{il} - through the launching of technology information centres, regional science and technology societies as well as through the provision of supplementary education. However, specialisation is a property of the purpose of the meetings, which concerns the type and specificity of the knowledge created. Thus, in this paper, infrastructural policies affecting the number of meetings will be held constant (n_{il} is fixed). Instead regional policies on the composition of expertise and counselling delivered by technology societies and information and education centres will be emphasised.

Figure 1 depicts results from our simulations, where the effects of these policies on the cooperative behavior within regional innovation systems are easily imagined. No matter at which stage of the industry life-cycle competitive selection is, the regional network density increases with p_{il}. In recognising the steep increase in density at t = 40, we must admit that the relatively slow development of research cooperation in the beginning of the cycle depends on inventor protection. Early formation of innovative contacts in the regional network implies that contacts in the social network are broken, which has a retarding effect on cooperative behavior. Figure 1 also emphasises the influence of economic selection later on in the industrial life cycle, where the figure becomes "honeycombed". These irregularities predict a tendency towards downsizing of the social network and research cooperation that derive from difficulties the actors in the innovation system have financing their cooperation. When the market for final products becomes saturated at t = 80, the growth of the firms stagnates with a negative effect on the number of innovations. The demand for intermediate goods (innovative input) stagnates, which hurts cooperation.

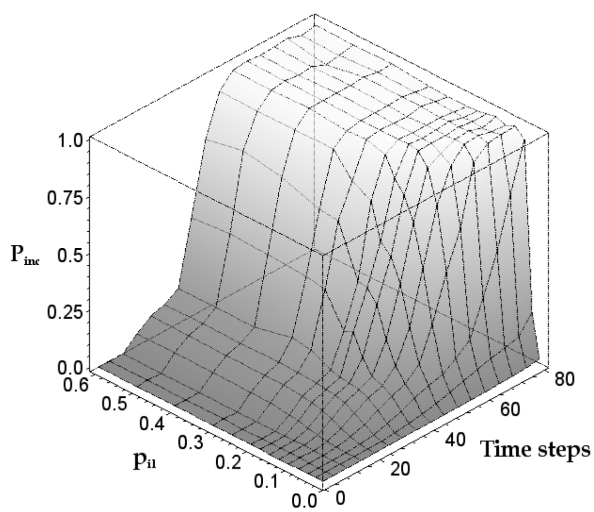

Figure 1) The regional network density (probability of innovative contacts, P_{inc}) for follower entrepreneurs within the lagging region, depending on the probability of inventors exchanging information (p_{il}) and on time.

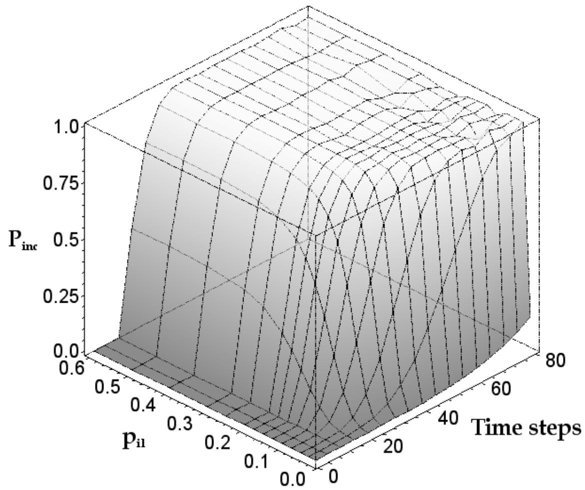

Figure 2) The regional network density (probability of innovative contacts, P_{inc}) for the key entrepreneur within the lagging region, depending on the probability of inventors exchanging information (p_{il}) and on time.

Another result supports findings that networks depend on the presence of a key entrepreneur (Lechner & Dowling 1999; Gerybadze 1998; Sternberg 1996). One of the technology producers plays a missionary role in the model (the key entrepreneur, who considers business opportunities all the time) and thus has no interest in breaking contacts in the social network. Accordingly, he or she is more alert to establishing innovative relations than are the other inventors (figure 2). A comparison of figures 1 and 2 suggests that the major part of the cooperative behavior develops after the key entrepreneur has established contacts with all inventors. Obviously, the key entrepreneur has a crucial intermediate position in the promotion of cooperative behavior.

4.2 Technical advance and regional growth

The "honeycombs" in figures 1 and 2 are associated with financial constraints downstream firms impose on the regional innovation system. Producers of new technology compete for selling designs to NEs and MNEs, which commercialise the designs. Difficulties with cooperative behavior occur when this chain is broken. Accordingly, efficient markets for technology are crucial, where patents and licences are sold to firms in one region, while investments in production facilities sometimes are made in another region. Since technology export from region i to region j contributes to the growth of region i, it should be discerned and analysed separately, which is a task for future research[13].

One question arising is if there are policies to be adopted by the regional authorities, which remove the financial constraints on the innovation system. In answering this question we note that - according to our approach - the number of innovations depends on firms' expectations about growth (cf. section 2). These expectations vary with changes in the growth of the total market for all product variants. That is, a zero-sum game between regions about finance for innovative activities may be avoided by policies that stimulate macroeconomic growth. It is not clear whether this growth effect can be achieved in a decentralised way through regional-level policies on the degree of specialisation of the regional innovation system.

Empirical evidence suggests a positive relation between entrepreneurial activity and growth at the regional level. Regions with high new-firm startup rates gain from higher rates of growth (Audretsch & Keilbach 2004). Our simulations provide some insight into the interrelationships between properties of the regional innovation system and entrepreneurial activities. To begin with, a policy that changes the degree of specialisation (p_{il}) seems to have no significant effect on the growth of the total market for all product variants. We return to this effect below. This finding suggests that the success a region may have in attracting finance to innovations through improvements of the innovation system is achieved at the expense of other regions. Thus, the small increase in the number of entries (in particular by NEs) when p_{il} changes, presented in figures 3 and 4, is the outcome of competition between the regions.

[13] The following measure can be used as an indicator of export of technology from region i to region j: "MNE product inventions in region i, entering in region j divided by MNE product inventions in region i, entering in region i".

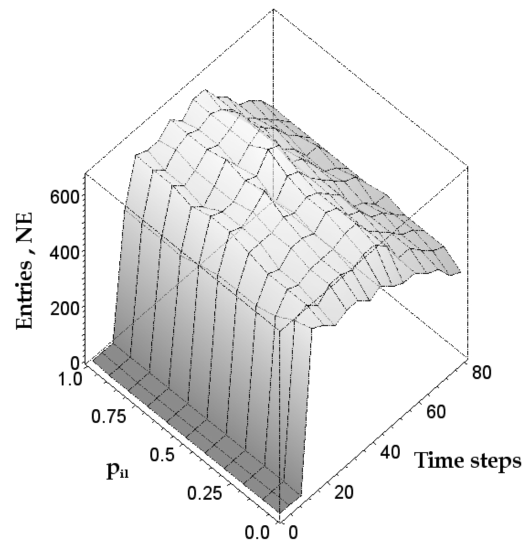

Figure 3) Number of product entries for national enterprises (NE) and for 20 000 simulations within the lagging region, depending on the probability of inventors exchanging information (p_{il}) and on time.

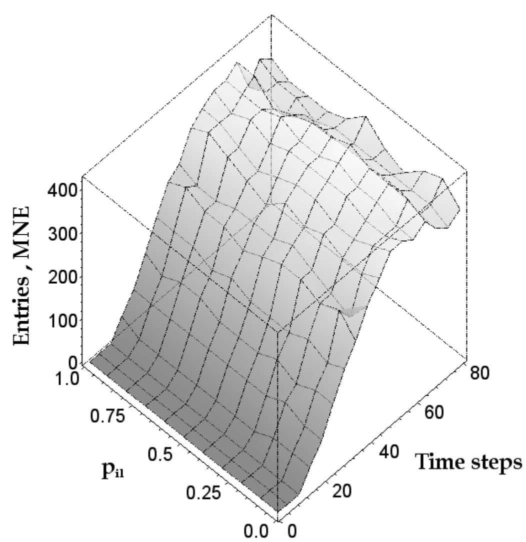

Figure 4) Number of product entries for multinational enterprises (MNE) and for 20 000 simulations within the lagging region, depending on the probability of inventors exchanging information (p_{il}) and on time.

Another result worth noting is a threshold of the innovation system. This threshold is interesting because passing it may not only affect the number of entries by MNEs, but it also has an effect on how MNEs assess their organisational capital. In addition, changes in these assessments may affect macroeconomic growth and the properties of the interregional competition for finance to support innovations. If the conditions for cooperative behavior within an innovation system are poor (small values of p_{il}), improvements increase the number of entries by NEs, while the number of entries by MNEs may fall (figures 3 and 4). Small values of p_{il}, with a low level of networking, imply that the capacity of the innovation system to process information is low. Collaboration between MNEs and regional engineers is inefficient from the point of view of the MNEs. Collaborations by MNEs will not lead to any significant increase in the value of the organisational capital of the MNEs. Improvements of innovation systems with low capacity to process local knowledge, therefore, primarily stimulate entries by NEs.

The notion of organisational capital has been used before by Gort and Klepper (1982). It is associated with information on new product technology that belongs to a firm because it has a legal right to it or it depends upon the interdependent actions or information of more than one employee. Now, we hypothesize that policies that improve the innovation systems beyond the threshold portrayed in figures 3 and 4 instead lead to a revaluation of the organisational capital, where it becomes more favorable for MNEs to invest in this type of capital.

One implication of assessing a higher value to the organisational capital is increased information "stickiness" (smaller values of α_1).The share of the technology diffusion between regions, which is external to the MNEs, will be reduced. In our model, a small increase in information stickiness (-$\Delta\alpha_1$) always reduces the spill over between technologically advanced and lagging regions (figure 5). The model takes into account that technology producers in lagging regions have difficulties in decoding technological information coming from the technologically advanced region. Accordingly, figure 5 portrays differences between large

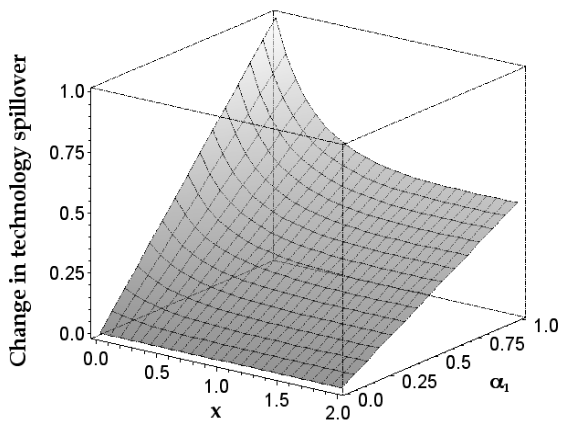

Figure 5) Changes in the technology spillover, depending on the technology gap (x) and on changes in information stickiness (α_1).

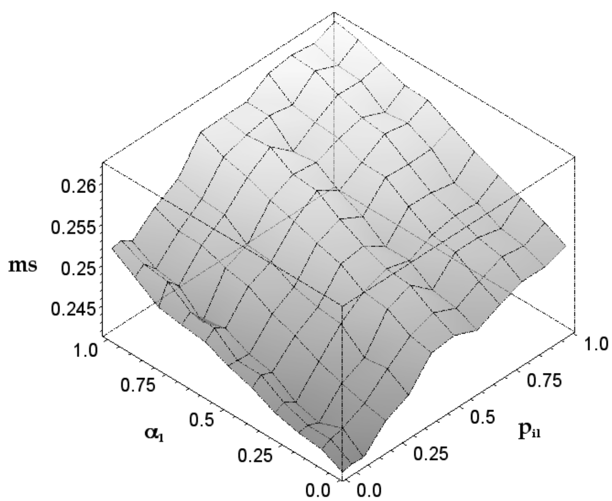

Figure 6) Total market share (all enterprises within the entire market) at time step t=80, depending on the information stickiness (α_1) and on the probability of inventors exchanging information (p_{i1}).

and small technology gaps. In the first case, the change in technology spill over, caused by a small change in the technology gap, is relatively small and independent of the size of the gap. For small gaps, however, the changes in the technology spill over become considerable when the gap changes. The changes in the technology spill over also depend on the amount of organisational capital held by the MNEs. The effect of changes in the technology gap on the technology spill over becomes smaller for small ratios between transferable knowledge and organisational capital. Figure 5 shows that the reduction in spill over will decline with this ratio and this decline is more significant for small technology gaps.

It is interesting to consider whether the regions can avoid zero-sum games between one another by coordinating their policies on the specialisation of the innovation systems with the strategies the MNEs choose for their organisational capital. As soon as the threshold of the regional innovation system is crossed, it becomes more attractive for MNEs to compete for advantageous positions within the system. The organisational capital becomes more valuable and the MNEs may respond and choose strategies to increase the organisational capital.

Overall, figure 6 confirms previously mentioned simulations suggesting that changes in the degree of specialisation within the innovation system seem to have a small effect on the growth of the total market for all product variants. The threshold effect of the innovation system is apparent: changes in p_{il} have no effect on the macroeconomy as long as the conditions for cooperation are poor (small values of p_{il}). If the threshold is crossed, however, policies on specialisation within the innovation system improving the conditions for cooperation among technology producers increase the growth of the total market, but this increase diminishes and seems to disappear for large p_{il}.

Figure 6 also shows that increased cooperation within the innovation system, which provokes the MNEs to increase the organisational capital (reduces α_1: the technology diffusion between the regions external to the MNEs), obstructs this growth effect. The figure also calls this type of response by the MNEs in question. In general, MNEs prefer fast growing markets. While figure 6 shows that the total market share increases with increases in α_1 and in p_{il}, MNEs should have an interest in coordinating their knowledge management with infrastructural investments made by the regions to support a growing market. When regions try to gain from improvements of the regional innovation systems, a zero-sum game can be avoided if the MNEs choose strategies for the publication of technological information, which increases the amount of transferable knowledge.

5 Conclusion

In this paper, we have shown that simulations based on evolutionary models including vertical disintegration (production of intermediate goods) and a geographic dimension (cooperation benefits from proximity, interregional technology diffusion) generate a rich set of predictions suited for empirical research on regional-level technology policy and regional growth.

The topic we currently are exploring is how changes in regional innovation systems are connected with competitive (economic) selection. Our focus is on the technological specialisation of a region, the need of the technology producers to protect technological secrecies and the financial constraints on the innovation system, which depend on the demand for innovative input by downstream firms. For reasonable assumptions about the formation and downsizing of social and regional networks, the simulations suggest that both protection and finance have significant effects on the cooperative behavior by the producers of technology. They also provide a hint for policy-makers about the importance of the key entrepreneurial function: the major proportion of cooperative behavior develops after the key entrepreneur has established contacts with all inventors in the social network.

A pessimistic view of EU's Lisbon Strategy suggests that the promotion of advanced technology will lead to a spatial evolution of European economies, where the production of new technology with skilled and well-paid labour will be concentrated in a small number of fast-growing regions. At the same time, it is likely that advanced technology will diffuse across European regions with high standards of excellence, without any contribution to poor regions (Sharp & Pereira 2001).

As a matter of fact, this is something the EU Commission suggests. It argues that retaining and attracting more R&D in Europe is tantamount to overcoming the fragmentation of public research. This is achieved by letting the European research area "structure itself along the lines of a powerful web of research and innovation clusters" with basis in "shared principles for knowledge transfer and cooperation between public research and industry".[14] The critical question about how the shaping of regional innovation systems can reduce regional imbalances and help the spatial equilibration seems to be of secondary interest. In order to overcome the fragmentation, the Commission also suggests the building of innovative capacity through integrated and networked pan-European infrastructures.[15] One result emerging from the simulations made for this paper is that the public knowledge base and the organisational capital of the businesses should be seen as complementary implying that improvements in the infrastructures and their connectivity can increase the value of the organisational capital. Contrary to the purpose of the Commission to encourage the businesses to cooperate with European research institutions, higher value of the information about technology that belongs to the businesses can make them reluctant to share technological knowledge.

Inspired by simulations, we call attention to the "regional conscious" development model, discussed in the paper. It turns out that regional politicians, who master regional innovation systems of medium conditions for cooperation, are in a position to foster macroeconomic growth and regional balance by improvements of the system. A critical task of the politicians, however, is to ensure an efficient coordination of public investments in knowledge structures and strategies for knowledge management by MNEs.

[14] Green Paper, The European Research Area: New Perspectives, COM(2007) 161 final, Commission of the European Communities, p. 8

[15] ibid

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