Döring, Thomas; Schnellenbach, Jan

Working Paper

What Do We Know About Geographical Knowledge Spillovers and Regional Growth? A Survey of the Literature

Research notes working paper series, No. 14

Provided in cooperation with:
Deutsche Bank Research

Economic

Research Notes

Deutsche Bank Research

October 12, 2004

No. 14

Research Notes

Working Paper Series

What Do We Know About Geographical Knowledge Spillovers and Regional Growth? – A Survey of the Literature

- Geographically limited knowledge diffusion helps to explain clusters of regions with persistently different levels of growth. This paper provides a survey of theoretical and empirical findings on this.
- The theoretical concept of knowledge spillovers is outlined by discussing the different types of knowledge, the spatial dimension of knowledge spillovers, and the geographical mechanisms and structural conditions of knowledge diffusion. Such spillovers lead to dynamic externalities, and to agglomeration effects in the geographical dimension. Both effects constitute path dependencies in the economic growth of regions.
- Existing recent empirical studies mainly support the theoretically derived hypotheses. This applies especially to the importance of knowledge spillovers for regional productivity and innovative behaviour.
- In addition to the large number of surveyed contributions, the paper refers also to unanswered questions, i.e. the normative question whether the theoretical considerations and empirical evidence warrant any economic policy measures actively encouraging knowledge spillovers.

Thomas Döring, University of Kassel and Philipps-University Marburg

Jan Schnellenbach, Philipps-University Marburg

www.dbresearch.com

Deutsche Bank Research
Frankfurt am Main
Germany
Internet: www.dbresearch.com
E-mail: marketing.dbr@db.com
Fax: +49 69 910-31877

Managing Director
Norbert Walter

What Do We Know About Geographical Knowledge Spillovers and Regional Growth? – A Survey of the Literature

Thomas Döring
University of Kassel and Philipps-University Marburg

and

Jan Schnellenbach[*]
Philipps-University Marburg

Abstract

Modern (endogenous) growth theory tells us that knowledge spillovers are crucial for the growth of high-income economies. Against this background the paper provides a survey of theoretical and empirical findings highlighting the question of how geographically limited knowledge diffusion can help to explain clusters of regions with persistently different levels of growth. The paper discusses this topic in two steps: First, the theoretical concept of knowledge spillovers is outlined by discussing the different types of knowledge, the spatial dimension of knowledge spillovers, and the geographical mechanisms and structural conditions of knowledge diffusion. This discussion shows that the literature on knowledge spillovers focuses on the hypotheses that such spillovers lead to dynamic externalities and – in the geographical dimension – to agglomeration effects, both of which constitute path dependence in the economic growth of regions. Second, the paper analyses the empirical evidence for these theoretical findings. Existing empirical work mainly supports the theoretically derived hypotheses. This applies especially with focus on the spatial limited character of knowledge spillovers as well as the importance of knowledge transfer for regional productivity and innovative behaviour.

JEL Classification: R11, R12, R58

Keywords: knowledge spillovers; regional growth; research and development; innovation; diffusion of innovations

---

[*] Corresponding author. Philipps University Marburg, Department for Public Economics, Am Plan 2, 35037 Marburg, Germany. Phone: +49-6421-282 3178; Fax +49-6421-4852; email: schnellenbach@wiwi.uni-marburg.de

1. Introduction

In a variety of discourses, be it among economists, among politicians or in the business world, knowledge as a productive factor is asserted with an increasing influence on competitiveness and growth.[1] This view is in concurrence with neo-classical growth theory and its standard result that, once a steady state is reached, growth in per capita income can only be induced by a growth of knowledge, which leads to the implementation of a more efficient technology of production (Rosenberg 1963: 414f.; Arrow 1985: 104; Malecki and Varaiya 1986: 629f.; Jaffe 1998: 8; Smolny 2000: 2 and 9). This has led more recent contributions to the theory of economic growth to endogenise knowledge-generating processes in order to explain sustained growth, in some cases without employing the metaphor of a steady state.[2] Despite their heterogeneity, these approaches share some common ground in their emphasis on positive externalities produced through diverse processes such as learning-by-doing, the accumulation of human capital or the supply of public goods like publicly funded research. Such positive externalities provide a rationale for the assumption of constant or even increasing marginal factor productivities, and these in turn allow the modelling of sustained economic growth. One particular type of positive externalities are knowledge spillovers, which are often assumed to be a source of positive returns to scale in the aggregate production function.[3]

While traditional growth theory has always focused on processes unfolding in time, the introduction of knowledge spillovers by the new growth theory therefore also implies an interest in processes that are unfolding in time *and* space. Regional

---

[1] Contributions emphasizing the relevance of knowledge from both a micro- and macroeconomic perspective are for example Metcalfe (2002: 3f.), Dohse (2001: 131), Caniëls (2000: 1), Matusik and Hill (1998: 682f.), Carlino (1995: 15), Jaffe et al. (1993: 578), Audretsch and Feldman (1986: 630) and also Nelson (1982: 453).

[2] For early contributions to the endogenous growth theory see Lucas (1988) and Romer (1986); a survey is to be found in Fagerberg (1996). Some representative contributions to endogenous technological progress are found in Tallman and Wang (1994: 102), Jaffe (1998: 8) as well as Caniëls (2000: 2).

[3] The importance of knowledge spillovers has been emphasised, among others, by Keilbach (2000: 8ff.), Smolny (2000: 2f.), Fritsch and Franke (2000: 1), Anselin et al. (1997: 422f.), Henderson et al. (1995: 1067f), Glaeser et al. (1992: 1127), Griliches (1992: 29f.), Grossman and Helpman (1991: 85) and also Barro (1991: 408f).

patterns of knowledge diffusion, as well as barriers to the diffusion of knowledge, feature prominently in explaining the differential growth of production and incomes between regions. This role of knowledge spillovers and the high dispersion of scattered contributions appear to be a good reason to provide a survey of the literature relevant to the problem. Maybe more importantly, spatial knowledge spillovers are of interest to different sub-disciplines of economics, such as macroeconomics, public economics and innovation economics. A survey of the field can therefore also serve the purpose of informing researchers of recent results produced in neighbouring fields. The argument will proceed as follows: *Section 2* provides an overview of theoretical contributions to the economics of knowledge and its diffusion. *Section 3* surveys the related empirical literature and *Section 4* concludes.

2. Externalities in the production of knowledge and regional spillovers

2.1. Some economic perspectives on knowledge

Economists do often speak of knowledge, but often they also have a rather vague understanding of what knowledge is. Put differently, knowledge is a term that is regularly used but seldom defined or explained. Choosing a definition which uses the term in a broad sense, one may state that knowledge comprises all cognitions and all abilities that individuals use to solve problems, to make decisions and to understand incoming information. The terms "knowledge" and "information" therefore denote separate things, and knowledge is understood as a tool that can be consciously used by individuals - although it certainly can also be used subconsciously, a fact introduced into the economic context by Hayek (1945). Hayek has also been responsible for pointing out the existence of dispersed knowledge, a dispersion that can occur between individuals and also in a spatial dimension. Thus, a definition of knowledge ought also to comprehend the modular characteristic of knowledge. Finally, knowledge is also understood as being dependent on time and context (Dohse 2001: 50f.), i.e., it is not static but continually evolving, and the direction of its evolution depends on boundary conditions such as the institutional framework

While such an encompassing definition of knowledge lays an emphasis on heterogeneity of knowledge and its evolution over time, it is usually modelled in a more static way in traditional neoclassical contributions to growth theory. There, knowledge is simply introduced as an input factor into a given production function. In contrast to this simple approach, more recent approaches have however also laid emphasis on a circular causation which allows for learning from given processes of production in order to explain an endogenous accumulation of knowledge. A growth in the stock of human capital from learning by doing and industrial R&D processes is explicitly taken into account (Audretsch and Feldman 1996: 638; Audretsch 1998: 20). These processes are then thought of as being highly path-dependent due to the cumulative nature of the generation of knowledge (see already Arrow 1962).[4] This is important with respect to the abilities of individuals to utilise knowledge that is subjectively new to them: it is conceivable that they cannot make any reasonable use of new, although maybe superior, knowledge simply because they lack necessary complementary knowledge, which they have not accumulated on their learning path.

Beyond such possible incompatibilities on the side of the recipient of (subjectively) new knowledge, difficulties in the diffusion of knowledge may also arise due to the attributes of the observed knowledge itself. A common distinction is made between *explicit knowledge*, that can be communicated, and *tacit knowledge* that is often used unconsciously by an individual and cannot easily be made the subject of verbal communication (Polanyi 1985).[5] If secrecy about explicit knowledge cannot be enforced or exclusive rights for its application through patent protection cannot be ensured, it has the technical properties of a public good (see Romer 1990: 97), which is the case for a large fraction of publicly funded scientific research at universities and similar research institutions. Obviously, the incentives to invest private resources into knowledge accumulation differs greatly depending on such technical and institutional conditions.

Given these distinctions, it also becomes easy to distinguish between knowledge and human capital. Human capital comprehends tacit and explicit knowledge that individuals do indeed utilise, while knowledge itself is a more encompassing

[4] See also Dohse (2001: 131), Caniëls (2000: 4), Dosi (1988: 1126) and Nelson (1982: 464). As Jones (2002) argues, the path of the accumulation of knowledge is however never completely determined by the past, but subject to random shocks.

[5] See also Matusik and Hill (1998: 683ff.), as well as Dosi (1988: 1126) for a distinction of different types of knowledge.

category that comprehends the wealth of information and routines that is principally available to individuals. Here, the distinction of Popper (1972) between objective and subjective knowledge may also be usefully introduced. Objective knowledge is what is written down and waits to be utilised, while subjective knowledge (here: human capital) denotes the stock of knowledge that does indeed affect subjective decision-making. In this sense, only knowledge can be continuously accumulated over time while human capital presupposes a selective learning of knowledge by each new generation of individuals. The important question in our framework is then if and how spatial spillovers of available knowledge do indeed have an influence on human capital across regional boundaries.

2.2. Knowledge in space: approaches to the problem

In endogeneous models of economic growth incorporating knowledge, positive externalities are a common feature of processes of knowledge accumulation.[6] The social benefit of generating knowledge is generally considered to be higher than the private benefit of this activity,[7] which partly follows from the technical properties of knoweldge stated in the preceding subsection: whoever may utilise a knowledge spillover has generally no incentive to compensate the producer of this externality for his beneficial activities. For costly R&D activities this possibility of increasing one's productivity by free-riding on the research of others implies a propensity to underinvest into knowledge-generating activities (Audretsch 1998: 20). In addition to this short-term effect, knowledge spillovers do also have a dynamic component because the magnitude of their effects on productivity depends on the amount of knowledge that was already accumulated in the past (Dohse 2001: 132; Henderson 1997: 450; Henderson et al. 1995: 1068). This should be kept in mind as an additiopnal barrier to the diffusion of knowledge in addition to the spatial distance between the producer of an externality and his potential recipient.

---

[6] See Caniëls (2000: 6), Keilbach (2000: 2), Anselin et al. (1997: 423), Audretsch and Feldman (1996: 630), Carlino (1995: 15), Bernstein and Nadiri (1989: 249), Dosi (1988: 1146) and also Romer (1986: 1003).

[7] For a general treatment of externalities see Baumol und Oates (1979: 75ff.) and already Scitovsky (1952).

In the first pioneering work on the geographical dimension of knowledge with a focus on spatial aspects of innovation diffusion, Torsten Hägerstrand has examined the dissemination of innovations as a spatial process in his 1953 monograph (for a translation of the work initially published in Swedish language, see Hägerstrand 1967). The main hypothesis which lies at the core of his inquiry is that geographic differences of human behaviour must be analysed in terms of the knowledge available to the individual decision-maker (adopter, firm etc.) and thereby analysed in terms of "social network" of interpersonal communications through which the knowledge diffuses. This social network approach was certainly a step ahead of subsequent economic approaches, which often rely on exogenous assumptions on the spatial mobility of knowledge.

Both ends of the continuum of degrees of the mobility of knowledge can be found in the economic literature (Caniëls 2000: 10ff.; Richardson 1973: 22ff.). A traditional neoclassical assumption is to view knowledge as being costlessly available to individuals who, given their propensity to act rationally and the absence of learning costs, have an incentive to use the entire stock of knowledge. Knowledge is entirely disembodied and can be verbally communicated. The implicit assumption of universally costless communication implies that distance does not play a role. A knowledge spillover diffuses instantaneously throughout the entire economy such that technically, it is simply a pure public good. This obviously implies that regional differentials of incomes and their growth rates cannot be explained on the grounds of regional divergences in the stock of knowledge, because any region trailing the other can immidiately catch up by imitating the more successful technology (see Keilbach 2000 for a survey of the discussion in this issue).

On the other hand, there are models of cumulative causation[8] that work with the assumption of a world in which knowledge spillovers simply do not exist. Knowledge is modelled essentially as a private good that can be utilised by a clearly confined group of users, so that spatial spillovers are not of any interest. Relative advantages in the generation of knowledge and, closely related, in productivity can persist because knowledge-related catching up is not accounted for. From this perspective and in complete contradiction to the approaches described

---

[8] See Kaldor (1970: 340ff.), Myrdal (1964: 9ff.) and Malecki and Varaiya (1986: 631ff.).

above, the differential development of regions can then almost entirely be attributed to differences in the stock of knowledge. These are expected not only to persist but even to increase because generating additional new knowledge is assumed to be relatively easier, the higher the stock of knowledge already accumulated is.

Both of these extreme assumptions, complete knowledge spillovers and no knowledge spillovers at all, may be criticised empirically for their lack of realism. The fact that knowledge spreads in the spatial dimension appears to be obvious, but it is equally obvious that such diffusion processes take time and are often incomplete. Theoretical approaches taking this into account usually assume that knowledge is a regional public good with limited spatial range. Two basic types of models working with this assumption can be distinguished (Caniëls 2000: 21ff.; Richardson 1973: 126ff.), namely models of epidemic and of hierarchical diffusion of knowledge. In the first case, every region in the neighbourhood of another region in which new knowledge in generated is asserted a positive probability of being the recipient of a knowledge spillover, i.e. of harbouring individuals or businesses that adopt the newly generated knowledge. The diffusion between regions takes place horizontally, on the level of innovators and potential adoptors. Contrary to this class of models, hierarchical models are primarily interested in diffusion processes that take place between centers (such as industrial agglomerations) and spread to peripheral regions only later, if at all. The simple intuition underlying the higher probability of adoption in centers is the fact that there already are more R&D activities there compared to peripheral regions. Given what has been stated above about the role of complementary knowledge in learning from positive externalities, it is then much more likely that the necessary complementary knowledge is to be found in the center. Empirically, both types of knowledge diffusion can be observed and can even occur simultaneously (Caniëls 2000: 22).

A more sophisticated class of models compared to the two basic types are the so-called leapfrogging models, which synthesise elements from endogeneous growth theory and the New Economic Geography and explain the growth of agglomerations with local learning externalities.[9] Two mechanisms of technological

[9] See Brezis et al. (1993) for a model of leapfrogging. The New Economic Geography is introduced and surveyed in Krugman (1998a und 1998b), Schmutzler (1999), Fujita et al. (2000), Ottaviano and Thisse (2003) and also Baldwin and Martin (2003).

progress are distinguished in these models: an incremental growth of knowledge is resulting from learning by doing, and the growth rate depends positively on the stock of technological knowledge already available. In addition to this incremental growth, there are occasional large-scale breakthroughs which lead to technological paradigm changes and a depreciation of the former stock of knowledge. Furthermore, productivity within the new paradigm exceeds productivity under the old paradigm only after a (possibly rather lengthy) transition period, so that an early change of paradigm is not rational for regions that are sufficiently experienced in utilising the old technology and have reached a high productivity level there. A region that is sufficiently inexperienced under the old paradigm with relatively low productivity and income levels has, on the other hand, an incentive to switch paradigms immediately. Brezis and Krugman (1993: 1) call this a "natural life cycle of urban rise and decline", which hints at the fact that the thus far relatively poor region which is now operating under the new technological paradigm will not only catch up, but will eventually be more productive than the other region, because their incremental learning process now takes place within a relatively superior paradigm.

2.3. Mechanisms of the spatial diffusion of knowledge

The discussion in the preceding subsections has hinted at the fact that knowledge spillovers are of economic relevance because of their impact on regional income growth. Due to the rather sketchy treatment of knowledge spillovers in the approaches discussed above, however, it appears to be necessary to have a closer look at what could be coined the microeconomics of knowledge spillovers, i.e. at the micro-level conditions of the spatial diffusion of knowledge.

One common mechanism for a transfer of knowledge is the mobility of individuals and the trade or transfer of goods, which, in one way or another, carry production-related knowledge with them (e.g. Matusik and Hill, 1998). Another mechanism is the direct transfer of production technologies, which would still necessitate a physical transfer of goods. And finally, it is also conceivable that nothing else than the immaterial knowledge about modes of production spills over from one region into the other: through a licensing of patented technologies, through shared research projects, through scientific publications and so on. The spatial range of these types of knowledge transfers differs because the costs of transferring pure knowledge through communication over great distances are considerably lower compared to the transfer of goods, individuals or even physical production facilities.

Following Caniëls (2000), some more detailed statements on the conditions of knowledge diffusion are possible:

- If the source of new knowledge is in the private sector, it will usually release relevant information more reluctantly compared to a source in the public sector: the latter often have the explicit task to produce knowledge as a public good and therefore tend to circulate the results of their research activities voluntarily.
- The recipient of new knowledge needs to be endowed with the capacities necessary to utilise available knowledge (Cohen and Levinthal 1990), which includes his cognitive capacities, but also his willingness to incur costs of learning new knowledge. The latter can, for example, not necessarily be presupposed if the recipient is a rationally ignorant voter deciding on how to produce a public good (Schnellenbach 2004). In other words, it must appear to be economically rational for the recipient to utilise new knowledge (Cohen and Levinthal 1989: 128). If one argues within a model involving not maximisers but rational satisficers, then a dissatisfaction with the results produced within the status quo stock of knowledge is necessary to induce a willingness to learn.
- The relationship between the recipient and the source of new knowledge is also of some relevance for the diffusion process. Only explicit knowledge can be communicated over great distances, while the transfer of tacit knowledge, if possible at all, involves direct interaction and therefore close spatial proximity (Anselin et al. 1997: 423).[10] We can therefore expect that explicit knowledge spreads much more rapidly over great distances compared to tacit knowledge.

[10] Regarding the importance of direct (e.g. face to face) communication, see also Cappelin (2001: 121), Dohse (2001: 131 and 1996: 3f.), Antonelli (2000: 536ff), Caniëls (2000: 8), Audretsch (1998: 21), Henderson (1997: 449), Audretsch and Feldman (1996: 630), Audretsch and Stephan (1996: 651), Feldman and Audretsch (1996: 4).

This third point hints at the importance of locally confined innovative networks, which are of special relevance for the diffusion of tacit knowledge. Whenever direct interaction is a necessary prerequisite for the diffusion of knowledge, it is obvious that space does indeed matter simply in the sense that the cost of setting up and maintaining direct interaction is likely to rise with the distance between the source and the recipient of new knowledge. This can serve as an intuition to explain why innovative networks often do not stretch across regional boundaries and why they are often relatively stable once they have been established.[11] The specific modes of local interaction between, for example, entrepreneurs, venture capitalists, universities and government agencies leads to specific informal institutions guiding innovative activity. Inforamtion about novelities flows more easily among agents located within the same area, thanks to social bonds that foster reciprocal trust and frequent face-to-face contacts. Therefore, geographical clusters offer more innovation opportunities than scattered locations. Innovation diffusion is also faster (see Breschi and Lissioni 2001: 978). As a result, innovation processes are likely to differ across regions because different routines of interaction are established between the various parties involved in the process.

With these considerations, a gap between this class of approaches and the standard neoclassical literature becomes visible. The theoretical considerations do generally not involve optimising individuals, but boundedly rational agents whose decisions are influenced by informal institutions, understood as patterns of think-

[11] See Wilkinson and Moore (2000). According to Camagni (1991: 3), innovative networks can be defined as „the set, or the complex network of mainly informal social relationships on a limited geographical area, often determining a specific external ‚image‘ and a specific internal ‚represantation‘ and sense of belonging, which enhance the local innovative capability through synergetic and collective learning processes“. See also Bröcker et al. (2003), in which several authors provide a timely and comprehensive picture on location, networks and clusters as an important means in theorectical understanding of regional innovation and the factors influencing regional productivity and regional competitive performance. For a current eximination of the relationship between network architecture and knowledge diffusion performance, see Cowan and Jonard (2004), who model knowledge diffusion as a barter process in which agents exchange different types of knowledge. For the relationship between network density and R&D Spillovers, see Meagher and Rogers (2004). Using ideas from organizational theory, they model how the structure and function of a network of firms affects their aggregate innovativeness. Two main results emerge: On the one hand, the marginal effect on innovativeness of spillover intensity is non-monotonic, and, on the other hand, network density can affect innovativeness but only when there are heterogeneous firms. The latter finding points out the relevance of so-called Jacobs-Spillovers, which are discussed more intensively in the following subsection.

ing and decision-making that are shared among a larger group of individuals. Whether individual decisions yield efficient results or not does then not only depend on technological knowledge (i.e., on the installment of an efficient production technology) but also on the degree to which a certain set of institutions allows for an efficient use and extension of technological knowledge (see, for instance, Landes 1998 for an economic historian's point of view on this problem). In other words, the willingness and ability to absorb knowledge about new production technologies is quite likely to differ between regions, depending on their actual institutional framework. While some innovative regions can be expected to eagerly exploit the information conveyed by knowledge spillovers, others may simply ignore it or lack the adequate institutional framework to transform the received knowledge into actual production technologies. Innovative networks are therefore not only characterised by stable routines to share knowledge internally, but also by routines of receiving and handling incoming knowledge spillovers.

2.4. Knowledge spillovers, agglomeration and regional economic growth

The discussion in the previous subsection has focused on micro-level conditions for and barriers to the spatial diffusion of knowledge. It has been argued that space does matter in the sense that the range of knowledge spillovers may be limited and that regional differentials in the efficiency of utilising knowledge spillovers can be expected. If this is the case, then it is necessary to also have a more detailed look at the effects that knowledge spillovers may in turn have on agglomeration and on regional economic growth. The idea that, beyond the scale and scope of a production facility itself, agglomeration economies may have positive effects on productivity can be traced back at least as far as Marshall (1890/1966). An indication for the relevance of this effect is the observation made by Kahnert (1998: 509) that innovative production facilities with a high knowledge intensity and a high frequency of direct communication tend to be centralised in the core of agglomeration, while standardised, routine-based production facilities are often (re-)settled in more peripheral regions. Micro-level knowledge spillovers that can occur due to spatial proximity appear to be deliberately exploited by clustering the relevant facilities.[12]

The growth effects of agglomeration are therefore twofold. On the one hand, it helps to facilitate knowledge spillovers and decrease the costs of using them. On the other hand, agglomeration leads to a concentration of innovative, research-intensive production facilities, wich are usually seen as the largest contributors to the growth of per capita incomes. Thus, it is not surprising that economic growth in agglomerations tends to be faster than in peripheral regions: a part of this observed tendency is simply a result of this concentration effect (Baldwin and Martin 2003). This is further reinforced if human capital also tends to be concentrated in the agglomerations while routinised tasks for unqualified labour are allocated to the peripheral regions. Given the absence of decreasing returns of learning in agglomerations, knowledge spillovers in agglomerations can be interpreted as a source of stustained regional economic growth (Fujita and Thisse 2002; Glaeser et al. 1992) and an explanation for sustained differential growth rates between different regions with different patterns of agglomeration.

The question of what type of knowledge spillover is most relevant in explaining questions of regional economic growth is, however, still very much subject to debate. A principal destinction is made between a location externality and an urbanisation externality.[13] An example for location industries are the so-called MAR-spillovers. The term MAR-spillovers (Glaeser et al. 1992: 1127), coined after three classical contributions from Marshall (1890/1966), Arrow (1962) and Romer (1986), denotes a spillover between researchers, entrepreneurs and businesses within one industry. An often-cited example is the concentration of suppliers of semiconductors and related technologies in Silicon Valley (Audretsch and Feldman 1994; Carlino 1995). MAR-spillovers lead to learning processes like those described in the preceding paragraph, where knowledge spills over between

---

12 Obviously, there are also other economic arguments in favour of agglomeration, such as natural locational advantages, access to local markets and so on, see Cappelin (2001: 118ff.), Antonelli (2000: 538f.), Caniëls (2000: 26f.), Keilbach (2000: 29ff.), Jaffe et al. (1993: 578) and also Glaeser et al. (1992: 1148ff.).

13 See Glaeser et al. (1992: 1127ff.), Carlino (1987: 4), Partridge and Rickman (1999: 319f.), Keilbach (1998: 3f.), Audretsch (1998: 25), Henderson (1997: 450), Feldman and Audretsch (1996: 21), Carlino (1995: 17f.) and Henderson et al. (1995: 1068f.).

individuals working to solve similar or at least related problems. MAR-spillovers are, therefore, intra-industrial phenomena and allow the exploitation of regional economies of scale: the relatively small technological distance (Griliches 1979) between individuals and firms implies low barriers for knowledge spillovers and is seen as a condition for sustained growth. A testable hypothesis deduced from this approach would, therefore, state that regions characterised by a higher concentration of firms employing similar production technologies ought to, ceteris paribus, have higher income growth rates than regions with a lower concentration of similar firms.

Contrary to this approach, urbanisation externalities denote the effect of the size and heterogeneity of an agglomeration. An example are the so-called Jacobian spillovers (see Jacobs 1970, 1986) which are spillovers between different industries, leading to the exploitation of regional economies of scope. The mechanism in which this type of spillover works can be understood as a widening of the scope of research of individual industries through interaction with other industries. An important difference between the two types of spillovers, as far as incentives are concerned, is that heterogeneous businesses are often not in competition with each other and therefore may be more willing to engage in interactions less reluctantly than in the case of MAR-spillovers. As a testable hypothesis, it follows from research on Jacobs-spillovers that agglomerations with a high degree of diversity ought to, ceteris paribus, enjoy higher income growth rates than regions with a more homogeneous population of firms.

3. Empirical studies of knowledge spillovers

Among the theoretical literature surveyed in Section 2, there are only few instances where the propositions of different approaches completely contradict each other. An example has just been discussed in the preceding subsection. More often, though, the theoretical predictions of different models differ gradually or build on differing assumptions whose empirical relevance is not clear a priori. Thus, it is necessary to complement the survey of theoretical literature on knowledge spillovers with a survey of the results of empirical studies conducted on this issue so far. There is a considerable number of studies intended to deliver an empirical scrutiny of the New Growth literature which takes knowledge spillovers into account.[14] There are two classes of approaches to be distinguished, one observing micro-level data and the other taking a focus on aggregate data. The first class is characterised by the attempt to reconstruct actual paths of knowledge diffusion, for example by means of researching citations of patents and their spatial distribution. This allows empirical statements about the spatial range of knowledge spillovers that have actually occurred. A different micro-level approach are surveys of firms who are questioned about the sources of their stock of knowledge. The second class of studies includes approaches that measure the regional density of innovations, which is often operationalised by measuring R&D investment, the number of employees in R&D departments, the number of patent applications and so on. Using these data in cross-sectional analyses accounting for spatial autocorrellation leads to statements about the range and intensity of knowledge spillovers.[15]

3.1. The impact of distance

The heterogeneity of empirical approaches is mirrored to a certain degree in the heterogeneity of results produced by these approaches. Despite the methodological problems associated with the empirical approaches, however, there appears to be a widespread consensus that spatially confined knowledge-spillovers are an important empirical phenomenon with a significant impact on economic performance.[16] No consensus, however, is reached regarding the spatial range that can be attributed to knowledge spillovers, and in fact the majority of studies refuses to quantify the range at all.

---

[14] For a survey of the earlier literature, see Griliches (1992: 39ff.). See also the papers of Audretsch and Feldman (2004) as well as Rosenthal and Strange (2004: 30ff.), in both of which the literature on knowledge spillovers and the knwolegde resources of agglomeration economies is surveyed from a more current point of view. For a critical re-examination of the empirical literature on localised knowledge spillovers and spatially limited innovation systems, see Breschi and Lissoni (2001). For a useful background discussion regarding the empirical measurement of knowledge spillovers, see Kaiser (2002).

[15] For more information about the empirical tools and methods regarding the econometric analysis of regional growth and convergence processes, see e.g. Anselin and Bera (1996), Anselin (1998), Fingleton (2001 and 2000) or Kosfeld and Lauridsen (2004).

[16] See, among others, Paci and Pigliaru (2001), Funke and Niebuhr (2000), Niebuhr (2000), Fritsch and Lukas (1998), Keilbach (1998), Henderson (1997), Feldman and Audretsch (1996), Audretsch and Feldman (1994) and also Jaffe et al. (1993).

Noteable exceptions are Anselin et al. (1997), Varga (1998) and also Botazzi and Peri (2003). Anselin et al. analyse the impact of university research and private R&D activities on regional innovation patterns for data from high technology firms in the United States. They find a significantly positive impact of university research on innovative activity within a range of 50 miles around the university that is the source of new knowledge. For private R&D activities, however, no significantly positive result could be produced. This supports the theoretical considerations about the different incentives within the public and the private sector to circulate newly generated knowledge. In addition to these results, the study of Varga has shown that knowledge spillovers do not only occur within metropolitan areas. Rather, spillovers into neighbouring metropolitan areas up to 75 miles away also have a significant positive impact on innovative activities in these neighbouring areas. Bottazzi and Peri focus on data for European regions over a period of 18 years up to 1995. For knowledge spillovers resulting from R&D investments and patent applications, a significant positive impact on innovative activities in neighbouring regions appears to exist for a distance of up to 300 km. The magnitude of this impact is, however, relatively small. An increase of R&D spending of 100% in one region can be expected to yield an increase of innovative activities of 80-90% in the home region, but only of 2-3% in a neighbouring region.

The fact that most other empirical studies do not quantify a spatial range of knowledge spillovers follows simply from the decision of their authors to define their units of research in such a way that the distance of spillovers is implied by this definition. For example, Feldman (1994) and Jaffe (1989) are interested in spillovers between states in the USA and Peri (2002) researches the diffusion of knowledge between predefined regions in Europe and the United States.What is of interest then is the effect of a spillover from one predefined region into a neighbouring region, but a quantifiable distance between neighbouring regions simply does not exist. Nevertheless, the limited spatial range of knowledge spillovers can also be shown in studies of this type, as Audretsch and Mahmood (1994) show. In addition to spending on university research and private R&D, they also use the number of research institutions in a city and in a state als independent variables. While the number of research institutions in a city has a significantly positive impact on innovations in that city, the number of institutions in the state does not.

the state does not. The authors argue that this implies that knowledge spillovers are a local phenomenon.[17]

Empirical results supporting this view have also been obtained for German data. Funke und Niebuhr (2000) as well as Niebuhr (2000) show in a cross-sectional analysis for 75 regions that knowledge spillovers predominantly occur between neighbouring regions. They find that the every 23-30 km from the source of a knowledge spillover, the positive effect of this spillover on innovative activities decreases by 50%. In addition, they find supporting evidence for the theoretical prediction that innovative activities are usually concentrated in agglomerations and less relevant for peripheral regions. An increase of productivity as a result of a knowledge spillover from such an innovating agglomeration is found to be restricted to regions in the immediate neighbourhood. Similar results are produced by Badinger and Tondl (2002) in a study on the determinants of regional growth in 159 regions within the European Union. According to their study, an inflow of knowledge has a positive impact on the growth of a region, but this effect has a larger magnitude if neighbouring regions exhibit high growth rates themselves. In this context, studies from the Fraunhofer Institute (2000) and from Greif (1998) are also interesting, although they do not focus on knowledge spillovers in the narrower sense. They do, however, show that indicators for the spatial distribution of knowledge generation such as the number of R&D employees and patent applications, exhibit a high degree of regional concentration.[18] This contradicts with

[17] See Peri (2003) as another expample for this class of studies. Starting with the hypotheses that knowledge flows within and across countries should be carriers of important learning spillovers, he used data on 1.5 million patents and 4.5 million citations to analyze knowledge flows across 147 subnational regions. Peri found out that only 15 pc of average knwoledge is learned outside the average region of origin, and only 9 pc outside the country of origin. In his study, he also shows that, however, knowledge in some sectors (such as computers) flows substantially farther, which is also the case for knowledge generated by technological leaders (top regional innovators).

[18] See also Bode (2004), who analysis the relevance of interregional knowledge spillovers as one of the determinants of innovative activity in west German planning regions in the 1990s. Bode found out that, in general, interregional spillovers are found to contribute significantly to regional knowledge production. Quite interestingly, the effects of knowledge spillovers are found to depend not only on the conditions prevailing in sending regions but also on the conditions in recipient regions. The empirical results show that only a small fraction of the knowledge available in neighboring regions actually spills over whereas only regions with low R&D density benefit from interregional spillovers. For regions with high R&D density they seem to be negligible. With focus on this type of regions, the overwhelming majority of innovative activity and resultant patents is produced by exploiting by exploiting the regions's own ressources.

the assumption of an instantaneous and global diffusion of knowledge, because in this case similar innovative reactions to knowledge spillovers would have to occur in all regions.

3.2 Sectoral differences and firm size

From an even more disggragated perspective, knowledge spillovers appear to be particularly relevant in “young” industries and sectors where new knowledge can be assumed to be of special importance. This effect has, among others, be shown to exist by Feldman and Audretsch (1996) and Glaeser et al. (1992). The intuitively plausible result that sectors with a heavy reliance on knowledge are also more sensitive to knowledge spillovers has been obtained by Audretsch and Feldman (1992). The life-cycle effect is also in line with intuitive reasoning, since it is easily conceivable that relatively young sectors with a low fraction of routinised activities exhibit a greater demand for new knowledge and a greater willingness to utilise new incoming knowledge compared to mature sectors where a large fraction of activities is already following established routines that are costly to change. Furthermore, firms in the first periods of their life-cycle often do not have the capacities to maintain large-scale R&D departments themselves and therefore rely on external sources of knowledge to a larger extent than more mature firms with extensive own R&D activities.

Similar mechanisms are at work for smaller scale firms which often do not have sufficient own resources for extensive R&D activities. Link and Rees (1990) have surveyed 158 firms involved in cooperation programmes with universities. They show that such programmes have a significantly positive effect on the innovative activities of small firms. The surprising result of the survey is that the fraction of large firms taking part in such programmes is larger than the fraction of small firms. The smaller firms taking part have a lower ratio of R&D activities to total revenue, however. Apparently, smaller companies seem to make use of the programmes more efficiently, substituting own R&D by incoming knowledge spillovers. It is therefore somewhat paradoxical that large firms enter such programmes with a greater probability than small firms.

The negative effect of knowledge spillovers on the cost of innovating is also confirmed in other studies, such as Bernstein and Nadiri (1988 and 1989) and

Levin and Reiss (1988). Feldman (1994) has inquired into the influence of technological infrastructure on private sector innovations. As indicators for technological infrastructure, private sector and university R&D outlays, the embededdness into up- and downstream production and the existence of firm-related services have been used. Quite in line with the other studies mentioned here, she concludes that primarily small firms make use of external resources as additional inputs in order to compensate for a lack of own resources compared to larger firms. Other empirical studies with similar results are Acs and Audretsch (1988), Audretsch and Acs (1991) and Audretsch and Mahmood (1994). Franke (2002) reproduces these results for three German regions, relying on a survey of 1800 firms. She also shows that both intra- and interindustrial knowledge spillovers have a positive impact on the number of patents applied for by small and medium companies. The same holds for knowledge spillovers out of universities.

3.3. The importance of different types of spillovers

The evidence concerning the relative importance of different types of knowledge spillovers is somewhat more ambiguous. There are, however, empirical studies that support the hypothesis that Jacobian spillovers do matter, as well as empirical studies that show the same for MAR-spillovers. Therefore, even if the relative importance of both appears to be difficult to sort out, the statement that both types of knowledge spillovers are empirically relevant is a rather safe claim (see Forni and Paba 2001; Partridge and Rickman 1999; Henderson 1997). One of the few studies accounting for both types of spillovers is from Kelly and Hageman (1996), who attempt to show for state level data from the USA that there is a positive impact of both inter- and intraindustrial spillovers on the number of patent applications.[19] They have shown that a local transfer of knowledge has a positve effect for 11 of 12 industrial sectors under observation, while intra-industrial knowledge spillovers could be shown to have a significantly positive effect only

[19] See also Feldman and Audretsch (1999). To examine the role of specialization vs. diversity, i.e. MAR- vs. Jacobian spillovers, the authors test whether the number of innovations from an industrial sector of a certain state owes more to the city specialisation in this sector or to the precence, within the state, of other industries whose science base is related to that of the examined industrial sector. They reach the conclusion that diversity matters more than specialization and, above all, interpret this as evidence that knowledge spill overs across sectors rather than within them.

in 2 of 12 sectors. This result casts some doubt on the relative importance of MAR-spillovers, which predict knowledge spillovers to occur within a group of relatively homogeneous firms.

Some doubt on the relative dominance of Jacobian spillovers is however cast by a study of Bernstein and Nadiri (1988) who look at knowledge spillovers between US firms of producing in different sectors for the period of 1958 to 1981. They show that there are significant differences in the spreading of own knowledge as well as in the form of reception of new, externally produced knowledge between firms working in different sectors. An important result of the study is that firms in four of five surveyed sectors are sources of knowledge spillovers, but only in two sectors firms acting as recipients of such spillovers were to be found.

This hints at the existing difficulties to generalise results regarding the relative importance of both types of knowledge spillovers. Which kind of knowledge spillover is dominant (or utilised at all) depends eventually on micro-level, i.e. sectorial and firm-level conditions (Porter 1990: 131) which are not sufficiently researched thus far. There are few hints at possible criteria that allow to predict the relative importance of both types. One is the presumption that firms which tend to conduct their R&D activities in a more incremental way have a propensity to rely more on intra-industrial knowledge spillovers, while firms working on more groundbreaking innovations exhibit a larger dependence on inter-industrial externalities. Similarly, one might expect that the intensity of competition within a sector and the degree of vertical integration of production have adverse effects on the frequency of intra-industrial knowledge spillovers.

3.4. Transmission channels and the speed of diffusion

The evidence regarding the speed of knowledge diffusion through spatial externalities is, fortunately, less ambiguous. Recent studies on this issue are Maurseth and Verspagen (1999), Verspagen and Schoenemakers (2000) and Mariani (2000).[20] One important result of these studies is that knowledge diffuses

[20] These studies are based upon counting the number of patent citations between pairs of regions, and then estimating a (econometric) model where these counts are related to the geographical distance between pairs of regions. Their estimates show that the number of cross-citations drops significantly as the dictance increases. In a similar manner Brouwer et al. (1999) found that

relatively faster in regions which already have a relatively higher productivity level and a larger stock of knowledge. This is clearly supporting evidence for the conjecture that knowledge is acquired in a cumulative process during which new incoming knowledge can only be utilised if necessary complementary knowledge is already in use. The diffusion between regions occurs faster, the more the source region and the receiving region resemble each other in terms of their sectoral structure. This does again support the conjecture that a diffusion of knowledge is more likely to be successful if the source and the recipient are characterised by similar histories of knowledge accumulation. It does, however, also support the presumption that between regions MAR-spillovers spread faster than Jacobs-spillovers, since heterogeneity of regions cannot be shown to facilitate a rapid diffusion of knowledge over regional boundaries in empirical studies.

A look at the transmission channels shows that particularly fast knowledge diffusion occurs within multinational companies, which is not too surprising since adverse influences on diffusion such as a competitive relationship or varying routines underlying R&D activities do generally not play a role if knowledge diffuses within the same company. However, Lutz (2000), Xu (2000) and Tybout (2000) argue that knowledge diffusion within multinational companies is often confined to countries with relatively high income levels. An intuitive explanation for this might be the fact that R&D activities relying on highly qualified labour are usually settled in highly developed economies.

Beyond this special case of intra-firm knowledge transmission, an inter-firm knowledge spillover or a spillover between firms and public sector research are probably the more important transmission mechanisms. As the literature reviewed by Feldman (1999) shows, these spillovers often occur through direct interaction on the individual level, and Schrader (1991) shows that the frequency of interaction of R&D employees from different firms has a positive impact on the frequency of innovations in these firms. In order to set up these interactions, it was shown to be of pivotal importance that the individuals expected the relationship to be reciprocal regarding the quality and quantity of knowledge that was to be exchanged. Whenever such a reciprocal relationship was not expected by an individual, he or she refused to act as a source of a knowledge spillover. Thus, this

---

firms located in agglomerated Dutch regions tend to produce a higher number of new products than firms located in more peripheral regions.

evidence can also cautiously be interpreted as supporting the hypothesis that perceived stability and reliability of given social networks between individuals support a fast diffusion of knowledge.

More direct evidence for the importance of social networks for knowledge spillovers and the frequency of innovations can be found in a pioneering study from Piore and Sabel (1984). They have analysed the determinants of innovative activities in industrial districts in northeastern Italy and have found supporting evidence for the hypothesis that stable networks between firms lead both to an increase of innovative activity and to a reduction of transaction costs. These results have been reproduced by a large number of studies concerning industrial districts in Italy, such as Lazerson (1995 and 1993) and Gottardi (1996). Despite the large number of control variables included in these studies, local and regional networks maintained an essential, significantly positive impact in all surveyed districts. In the meantime, other studies have shown that this is not solely an Italian phenomenon: Saxenian (1994) has produced evidence supporting the influence of networks in Silicon Valley and Boston, Garnsey and Connon-Brookes (1993) find the same for Cambridge (UK) and Maskell (1992), Kristensen (1992), Saglio (1992) and Ganne (1992) find similar evidence for both Denmark and France. Given the structural dissimliarities of all these countries and regions, a general importance of networks appears to be supported by the evidence.

Zucker et al. (1998) focus on cooperative transfers of knowledge in their analysis of a cooperation between biotechnology companies and renowned scientists in this field and of the impact that this cooperation had on product innovation and the size of the labour force in these companies. They show that, measured by these indicators, the existence of such cooperations has had a significantly positive effect. However, it has also been shown that the external knowledge relinquished by a cooperating scientist has been used exclusively by the company with which this scientist was involved. In other words, there have been no knowledge spillovers between firms regarding this external knowledge. The authors explain this by arguing that the knowledge surrendered by the scientists is implicit, embodied knowledge that is directly bound to the person. They find that the technical properties of the new knowledge used by the companies make further knowledge spillovers unlikely or even impossible.[21]

As the discussion in Section 2 has shown, knowledge is not necessarily embodied in persons, but can also be embodied in products. Levin et al. (1987) argue based upon US data that reverse engineering of new products from competing companies is an important source of knowledge spillovers. Harabi (1997) comes to similar conclusions as a result of surveying 358 Swiss companies for their strategies of gaining new technological knowledge. Both studies have shown that, beyond reverse engineering, frequently used strategies to acquire knowledge are licensing of technologies, surveys of (scientific) literature and communication with employees of competing businesses. For Italian data, Napolitano (1991) finds similiar results. The open recruitment of employees from competing companies and research in patent databases do, in contrast, play only a minor role.

A number of studies is interested in the importance of public sector research institutions as a mechanism for regional knowledge spillovers, with Jaffe (1989) being a somewhat representative study. Jaffe has analysed knowledge spillovers by using a "Geographic Coincidence Index" which is intended to measure spatial clustering of private und university R&D spending. With data from 29 states of the USA, Jaffe analyses such geographical clustering and finds support for the conjecture that university research and private R&D are closely correlated in the spatial dimension. Several further empirical studies, such as Acs et al. (1999), Audretsch and Stephan (1996), Audretsch and Mahmood (1994) as well as Link and Rees (1990) confirm this result for the United States. For German data, Franke (2002), Edler and Schmoch (2001), Fritsch and Schwirten (1998), Sternberg (1998) and Nerlinger (1996) find a similar correlation: the more a region is

---

[21] In the same vein, Almeida and Kogut (1999) focus on the mobility patterns of individual patent-holders (engineers) in a number of industry clusters, and find them to be high and highly localized, but only in Silicon Valley, which is also the only cluster wherin such mobility affects positively the innovation rate of local firms. See also Zellner (2003), who presents evidence for embodied knowledge transfer via scientist migration. With empirical data on German scientists formerly employed by the Max Planck Society (MPS), he tested the hypothesis that a substantial proportion of the wider economic benefits to society from publicly-funded basic research is associated with scientists' migration into the commercial sector of the innovation system. Evidence for embodied knowledge transfer can also be found in Park (2004). Based on a data set of 21 OECD economies and Israel during 1971 to 1990, the study empirically explores the significance of student flows as a channel of R&D spillovers.

endowed with university research or other public sector research institutes, the more clustered are private R&D activities in this region, and the more likely is the establishment of new, R&D-intensive firms in these regions.

4. Conclusions and open questions

From the perspective of recent contributions to the theory of economic growth, the availability of knowledge (R&D investments, human capital and basic research) and the spatial range of knowledge diffusion are important foundations of endogeneous growth processes and determinants of the velocity of growth processes. The importance of space in such considerations results from the empirically well funded presumption that the diffusion of knowledge spillovers as positive externalities is spatially limited. This happens to be of special importance for complex, relatively unstructured tacit knowledge that can be transferred only through direct, personal interaction between individuals. An implication of this consideration is the fact that knowledge spillovers diffuse considerably faster in agglomerations. Another implication following from the cumulative nature of knowledge production is that regions, once they exhibit a relatively larger stock of knowledge, tend to be characterised by sustained higher growth rates. A convergence of incomes is not a necessary or even likely implication of knowledge-based theories of growth.

Despite the large number of suveyed contributions, both theoretical and empirical, there appear to be still a number of unanswered questions. The following points are of particular importance in our view:

- The empirical studies do so far not offer clear guidance regarding the question of “the role of geographical distance in the economics of knowledge transmission, which is still rather controversial” (Breschi and Lissoni 2001: 976). All best-known studies on knowledge spillovers seem to be unanimous in concluding that such spillovers are improtant and bounded in space. However, the evidence on geographical knowledge spillovers is by and large of an indirect kind, and cannot be taken as definite. Following Breschi and Lissoni (2001: 994), the major limitation of the empirical literature is that virtually no contribution has explored the ways in which knowledge is actually transferred among people located in the same geographical area. There is hardly any doubt that innovation networks are often locally confined, but the rationale for this may have less to do with the limited spatial range of knowledge spillovers but with, for example, the need to establish transaction-intensive relationships with suppliers and customers. Against this background, one could argue that the concept of geographical knowledge spillovers is still no more than a “black box”.

- Another question regards the distinction between tacit and codified knowledge which plays a central role in much of the literature on knowledge spillovers. Following Cowan et al. (2000), technical knowledge (and even more scientific knowledge) may be considered as ‘tacit’ not because it cannot be articulated (as, for example, the often citied craftsman’s knowledge) but because it is highly specific in the sense that the understanding of this knowledge (or the message that transports that knowlegde) depends on the capability of the addressees to decode the messages, which varies according to their expertise in the field. When tacitness is not only classified as an intrinsic property of knowledge, but also as a property of the communication of messages itself within a specific (epistemic) community, one is bound to recognise that the enabling conditions for benefiting from knowledge spillovers are far more complex than that of physical proximity.

- Some further research appears to be necessary regarding the mechanisms and sources of regional knowledge spillovers. In the literature, the observed correlation between knowledge (indicated, for example, by R&D output) and innovation has frequently been assumed to reflect pure technology externalities. There may, however, other economic forces at work “that are different in nature but observationally equivalent in the knowledge production function setting” (Bode 2004: 45). Other economic forces may be pecuniary externalities resulting from labor pooling, or from knowledge flows mediated by market mechanisms, or by clubs. Following Breschi and Lissoni (2001: 994ff.), there is still a need to explore the price and non-price mechanisms throught which knowledge may be traded between universities and firms, as well at between firms. Additionally, the influence of particular elements of institutional conditions, such as different access to markets for factors and goods, public funding of private research and active interventionist policies on knowledge spillovers is not sufficiently researched thus far, and only few first steps having been taken (see e.g. Feld et al. 2003).

- Finally, the normative question is not settled whether the theoretical considerations and empirical evidence produced so far warrant any economic policy measures actively encouraging knowledge spillovers and if so, how such policies ought to be designed. There are some studies displaying an uneasiness with pure laissez-faire policies (e.g. Matsuyama and Takahashi 1993), but there are no well-funded prescriptions for active interventions either. Depending on the specific economic forces mediating knowledge flows, the policy conclusions may differ considerably. Against this background, the current (and still increasing) popularity of the concept of geographical knowledge spillovers may "lead to naïve policy implications, which recall many not-so-distant and unfortunate experiences with science parks, growth poles and the likes" (Breschi and Lissoni 2001: 977).

Literature

Acs, Z.J and D.B. Audretsch (1988): Innovation in Large and Small Firms: An Empirical Analysis, in: The American Economic Review, Vol. 78, p. 678-690.

Acs, Z.J., Audretsch, D.B. and M.P. Feldman (1991): Real Effects of Academic Research – Comment, in: The American Economic Review, Vol. 81, p. 363-367.

Acs, Z.J., FitzRoy, F.R. and I. Smith (1999): Hich Technology Employment, Wages and University R&D Spillovers: Evidence from US Cities, in: Economics of Innovation and New Technology, Vol. 8, p. 57-78.

Anselin, L. (1998): Spatial Econometrics: Methods and Models, Dordrecht.

Anselin, L. and A.K. Bera (1996): Spatial Dependence in Linear Regression Models with an Introduction to Spatial Economietrics. College of Commerce and Business Administration, University of Illinois, Working Paper No. 96-0128.

Anselin, L., Varga, A. and Z.J. Acs, (1997): Local Geographic Spillovers between University Research and High Technology Innovations, in: Journal of Urban Economics, Vol. 24, p. 422-448.

Antonelli, Ch. (2000): Collective Knowledge Communication and Innovation: The Evidence of Technological Districts, in: Regional Studies, Vol. 34, p. 535-547.

Arrow, K.J. (1962): The Economic Implications of Learning by Doing, in: Review of Economic Studies, Vol. 29, p. 155-173.

Arrow, K.J. (1985): Economic Welfare and the Allocation of Ressources for Invention, in: Production and Capital: Collected Papers of Kenneth J. Arrow, Cambridge (MA), London, p. 104-119.

Audretsch, D.B. (1998): Agglomeration and the Location of Innovative Activity, in: Oxford Review of Economic Policy, Vol. 14, p. 18-29.

Audretsch, D.B. and Z.J. Acs (1991): Innovation and Size at the Firm Level, in: Southern Economic Journal, Vol. 57, p. 739-744.

Audretsch, D.B. and M.P. Feldman (1994): R&D Spillovers and the Geography of Innovation and Production, WZB Discussion Paper FS IV 94-2, Berlin.

Audretsch, D.B. and M.P. Feldman (1996): R&D Spillovers and the Geography of Innovation and Production, in: The American Economic Review, Vol. 86, p. 630-640.

Audretsch, D.B. and M.P. Feldman (2004): Knowledge Spillovers and the Geography of Innovation. Paper prepared for the Handbook of Urban and Regional Economics, Vol. 4, forthcoming.

Audretsch, D.B. and T. Mahmood (1994): The Knowledge Production Function and R&D Spillovers. Wissenschaftszentrum Berlin für Sozialforschung. Discussion Paper, Berlin.

Audretsch, D.B. and P.E. Stephan (1996): Company-Scientist Locational Links: The Case of Biotechnology, in: American Economic Review, Vol. 86, p. 641-652.

Badinger, H. and G. Tondl (2002): Trade, Human Capital and Innovation: The Engines of European Regional Growth in the 1990s, in: Fingleton, B. (Hrsg.), European Regional Growth, Heidelberg (im Druck).

Baldwin, R.E. and Ph. Martin (2003): Agglomeration an Regional Growth. CEPR Discussion Paper No. 3960, London.

Barro, R.J. (1991): Economic Growth in a Cross-Section of Countries, in: The Quarterly Journal of Economics, Vol. 106, p. 407-443.

Baumol, W.J. and W.E. Oates (1979); Economics, Environmental Policy, and the Quality of Life, Englewood Cliffs.

Benabou, R. (1993): Workings of a City: Location, Education, and Production, in: The Quarterly Journal of Economics, Vol. 108, p. 619-652.

Bernstein, J.I. and M.I. Nadiri (1988): Interindustry R&D Spillovers, Rates of Return, and Production in High-Tech Industries, in: American Economic Review, Vol. 78, p. 429-434.

Bernstein, J.I. and M.I. Nadiri (1989): Research and Development and Intra-industry Spillovers: An Empirical Application of Dynamic Duality, in: Review of Economic Studies, Vol. 56, p. 249-269.

Black, D. and V. Henderson (1999): A Theory of Urban Growth, in: Journal of Political Economy, Vol. 107, p. 252-284.

Bode, E. (2004): The Spatial Pattern of Localized R&D Spillovers: An Empirical Investigation for Germany, in: Journal of Economic Geography, Vol. 4, p. 43-64.

Bottazzi L. and G. Peri (2003): Innovation and Spillovers in Regions: Evidence from European Patent Data, in: European Economic Review, Vol. 47, p. 687-710.

Breschi, S. and F. Lissoni (2001): Knowledge Spillovers and Local Innovation Systems: A Critical Survey, in: Industrial and Corporate Change, Vol. 10, p. 975-1005.

Brezis, E.S. and P. Krugman (1993): Technology and the Life-Cycle of Cities. NBER Working Paper No. 4561, Cambridge (MA).

Brezis, E.S., Krugman, P. and D. Tsiddon (1993): Leapfrogging in International Competition: A Theory of Cycles in National Technological Leadership, in: American Economic Review, Vol. 83, p. 1211-1219.

Bröcker, J., Dohse, D. and R. Soltwedel (Eds.)(2003): Innovation Clusters and Interregional Competition, Heidelberg.

Brouwer, E., Nadvornikova, H.B. and A. Kleinknecht (1999): Are Urban Agglomerations a Better Breeding Place for Product Innovations?, in: Regional Studies, Vol. 33, p. 541-549.

Camagni, R. (1991): Innovations Networks: Spatial Perspectives, London and New York.

Caniëls, M.C.J. (2000): Knowledge Spillovers and Economic Growth: Regional Growth Differentials Across Europe, Cheltenham, Northhampton.

Caniëls, M.C.J. and B. Verspagen (2001): Barriers to Knowledge Spillovers and Regional Convergence in an Evolutionary Model, in: Journal of Evolutionary Economics, Vol. 11, p. 307-329.

Cappellin, R. (2001): Urban Agglomeration and Regional Development Policies in an Enlarged Europe, in: Bröcker, J. and H. Herrmann (Hrsg.), Spatial Change and Interregional Flows in the Integrating Europe: Essays in Honour of Karin Peschel, Heidelberg and New York, p. 117-129.

Carlino, G.A. (1987): Productivity in Cities: Does City Size Matter?, in: Federal Reserve Bank of Phildadelphia Business Review, November/December, p. 3-12.

Carlino, G.A. (1995): Do Education an Training Lead to Faster Growth in Cities?, in: Federal Reserve Bank of Philadelphia Business Review, January/February 1995, p. 15-22.

Cohen, W.M. and D.A. Levinthal (1989): Innovation and Learning: The Two Faces of R&D, in: The Economic Journal, Vol. 99, p. 569-596.

Cohen, W.M. and D.A. Levinthal (1990): Absorptive Capacity: A New Perspective on Learning and Innovation, in: Adminsitrative Science Quarterley, Vol. 35, p. 128-152.

Cowan, R. and N. Jonard (2004): Network Structure and the Diffusion of Knowledge, in: Journal of Economic Dynamics and Control, Vol. 28, p. 1557-1575.

Cowan, R., David, P.A. and D. Foray (2000): The Explicit Economics of Knowledge Codification and Tacitness, in: Industrial and Corporate Change, Vol. 9, p. 211-254.

Dohse, D. (1996): The Transmission of Knowledge Spillovers and its Impact on Regional Economic Growth, Kiel Working Paper No. 774, Kiel.

Dohse, D. (2001): Knowledge Creation, Knowledge Diffusion and Regional Growth, in: Bröcker, J. and H. Herrmann (Hrsg.), Spatial Change and Interregional Flows in the Integrating Europe: Essays in Honour of Karin Peschel, Heidelberg and New York.

Dosi, G. (1988): Sources, Procedures, and Microeconomic Effects of Innovation, in: Journal of Economic Literature, Vol. 26, p. 1120-1171.

Edler, J. and U. Schmoch (2001): Wissens- und Technologietransfer in öffentlichen Forschungseinrichtungen, in: ifo Schnelldienst, Nr. 4/2001, p. 18-30.

Fagerberg, J. (1996): Convergence or Divergence? The Impact of Technology on „why Growth Rates Differ“, in: Dopfer, Kurt (Hrsg.), The Global Dimension of Economic Evolution: Knowledge Variety and Diffusion in Economic Growth and Develop-ment, Heidelberg, p. 89-104.

Feld, L.P., Zimmermann, H. and T. Döring (2003): Fiscal Federalism and Regional Growth. Philipps-University Marburg, Public Finance Group, Discussion Paper Series „Fiscal Federalism and national Growth“, No. 1-2003, Marburg.

Feldman, M.P. (1994): The Geography of Innovation, Dordrecht.

Feldman, M.P. (1999): The New Economics of Innovation, Spillovers and Agglomeration: A Review of Empirical Studies, in: Economics of Innovation and New Technology, Vol. 8, p. 5-25.

Feldman, M.P. and D.B. Audretsch (1996): Location, Location, Location: The Geography of Innovation and Knowledge Spillovers, WZB Discussion Paper FS IV 96-28, Berlin.

Feldman, M.P. and D.B. Audretsch (1999): Innovation in Cities: Science-based Diversity, Specialisation and Localised Competition, in: European Economic Review, Vol. 43, p. 409-429.

Fingleton, B. (2000): Spatial Econometrics, Economic Geography, Dynamics and Equilibrium: A ‘Third Way’?, in: Environment and Planning, Vol. 32, p. 1481-1498.

Fingleton, B. (2001): Equilibrium and Economic Growth: Spatial Econometric models and Simulations, in: Journal of Regional Science, Vol. 41, p. 117-147.

Forni, M. and S. Paba (2001): Knowledge Spillovers and the Growth of Local Industries, CEPR Discussion Papers No. 58, London.

Franke, G. (2002): Regionale Wissens-Spillover und Innovationserfolge industrieller Unternehmen, Frankfurt am Main et al.

Fraunhofer-Institut für Systemtechnik und Innovationsforschung (2000): Regionale Verteilung von Innovations- und Technologiepotentialen in Deutschland und Europa, Karlsruhe.

Fritsch, M. and Ch. Schwirten (1998): Öffentliche Forschungseinrichtungen im regionalen Innovationssystem: Ergebnisse einer Untersuchung in drei deutschen Regionen, in: Raumforschung und Raumordnung, Jg. 56, p. 253-263.

Fritsch, M. and R. Lukas (1998): Innovation, Cooperation, and the Region, Universität Freiberg, Working Papers, Freiberg.

Fritsch, M. and G. Franke (2000): Innovation, Regional Knowledge Spillovers and R&D Cooperation, Universität Freiberg, Working Paper, Freiberg.

Fujita, M., Krugman, P. and A.J. Venables (2000): The Spatial Economy, Cambridge (MA) and London.

Fujita, M. and J.-F. Thisse (2002): Does Geographical Agglomeration Foster Economic Growth? And Who Gains and Looses From It?, CEPR Discussion Paper No. 3135, London.

Funke, M. and A. Niebuhr (2000): Spatial R&D Spillovers and Economic Growth – Evidence from West Germany, HWWA Discussion Paper Nr. 98, Hamburg.

Ganne, B. (1992): Industrial Development and Local Industrial Systems in Postwar France, in: Storper, M. and A.J. Scott (Hrsg.), Pathways to Industrialization and Regional Development, London, p. 216-229.

Garnsey, E.W. and A. Cannon-Brookes (1993): The ‚Cambridge Phenomenon‘ Revisited: Aggregate Change Among Cambridge-High-Technology Companies Since 1985, in: Entrepreneurship & Regional Development, Vol. 5, p. 179-207.

Glaeser, E.L., Kallal, H.D., Scheinkman, J.A. and A. Shleifer (1992): Growth in Cities, in: Journal of Political Economy, Vol. 100, p. 1126-1152.

Gottardi, G. (1996): Technology Strategies, Innovation Without R&D and the Creation of Knowledge Within Industrial Districts, in: Journal of Industry Studies, Vol. 3, p. 119-134.

Greif, S. (1998): Patentatlas Deutschland, München.

Griliches, Z. (1979): Issues in Assessing the Contribution of Research and Development to Productivity Growth, in: Bell Journal of Economics, Vol. 10, p. 92-116.

Griliches, Z. (1990): Patent Statistics as Economic Indicators: A Survey, in: Journal of Economic Literature, Vol. 28, p. 1661-1707.

Griliches, Z. (1992): The Search for R&D Spillovers, in: Scandinavian Journal of Economics, Vol. 94, p. 29-47.

Grossman, G.M. and E. Helpman (1991): Innovation and Growth in the Global Economy, Cambrdige (MA).

Hägerstrand, T. (1967): Innovation Diffusion as a Spatial Process, Chicago and London.

Harabi, N. (1997): Channels of R&D Spillovers: An Empirical Investigation, in: Technovation – International Journal of Technological Innovation, Entrepreneurship and Technology Management, Vol. 17, p. 627-635.

Hayek, F.A.v. (1945): The Use of Knowledge in Society, in: The American Economic Review, Vol. 35, p. 519-530.

Henderson, V. (1997): Externalities and Industrial Development, in: Journal of Urban Economics, Vol. 24, p. 449-470.

Henderson, V., Kuncoro, A. and M. Turner (1995): Industrial Development in Cities, in: Journal of Political Economy, Vol. 103, p. 1067-1090.

Hippel, E.v. (1994): „Sticky Information“ and the Locus of Problem Solving: Implications for Innovation, in: Managment Science, Vol. 40, p. 429-439.

Jacobs, J. (1970): The Economy of Cities, New York and Toronto.

Jacobs, J. (1986): Cities and the Wealth of Nations, Harmondsworth.

Jaffe, A.B. (1989): Real Effects of Acadamic Research, in: American Economic Review, Vol. 79, p. 984-1001.

Jaffe, A.B. (1998): Patents, Patent Citations, and the Dynamics of Technological Change, in: NBER Reporter, Summer 1998, p. 8-11.

Jaffe, A.B., Trajtenberg, M. and R. Henderson (1993): Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations, in: The Quarterly Journal of Economics, Vol. 108, p. 577-598.

Jones, Ch.I. (2002): Introduction to Economic Growth, 2nd edition, New York and London.

Kaldor, N. (1970): The Case for Regional Policies, in: Scottish Journal of Political Economy, Vol. 17, p. 337-348.

Kahnert, R. (1998): Wirtschaftsentwicklung, Sub- und Desuburbanisierung, in: Informationen zur Raumentwicklung, Jg. 24, p. 509-520.

Kaiser, U. (2002): Measering Knowledge Spillovers in Manufacturing and Services: An Empirical Assessment of Alternative Approaches, in: Research Policy, Vol. 31, p. 125-144.

Keeble, D. (2000): Collective Learning Processes in European High-Technology Milieux, in: Keeble, D. and F. Wilkinson (Hrsg.): Nigh-Technology Clusters, Networking, and Collective Learning in Europe, Aldershot et al., p. 199-229.

Keilbach, M. (1998): Marshallian Externalities and the Dynamics of Agglomeration and Regional Growth, Technische Universität Berlin, Diskussionspapier 1998/19, Berlin.

Keilbach, M. (2000): Spatial Knowledge Spillovers and the Dynamics of Agglomeration and Regional Growth, Heidelberg, New York.

Keller, W. (2001a): Knowledge Spillovers at the World's Technology Frontier, CEPR Discussion Paper No. 2815, London.

Keller, W. (2001b): International Technology Diffusion, NBER Working Paper 8573, Cambridge (MA).

Kelly, M. and A. Hageman (1996): Marshallian Externalities in Innovation and Growth. Centre for Economic Research, Department of Economics, University College Dublin, Working Paper 96/8, Dublin.

Klatt, S. (1994): Agglomeration, in: Vahlens Großes Wirtschaftslexikon, Bd. 1, 2. Auflage, München, p. 34-35.

Kosfeld, R. and J. Lauridson (2004): Dynamic Spatial Modelling of Regional Convergence Processes, HWWA Discussion Paper, No. 261, Hamburg.

Kristensen, P.H. (1992): Industrial Districts in West Jutland, in: Pyke, F. and W. Sengenberger (Hrsg.), Industrial Districts and Local Economic Regeneration, Geneva, p. 122-173.

Krugman, P. (1991): Increasing Returns and Economic Geography, in: Journal of Political Economy, Vol. 99, p. 483-499.

Krugman, P. (1998a): What's New About New Economic Geography?, in: Oxford Review of Economic Policy, Vol. 14, p. 7-17.

Krugman, P. (1998b): Space: The Final Frontier, in: Journal of Economic Perspectives, Vol. 12, p. 161-174.

Landes, D. (1998): The Wealth and Poverty of Nations, New York.

Lazerson, M. (1993): Factory or Putting-out? Knitting Networks in Modena, in: Grabher, G. (Hrsg.), The Embedded Firm: On the Socioeconomics of Industrial Networks, London and New York, p. 203-226.

Lazerson, M. (1995): A new phoenix? – Modern putting-out in the Modena knitwear industry, in: Administrative Science Quarterly, Vol. 40, p. 34-95.

Levin, R.C., Klevorick, A.K., Nelson, R.R. and S.G. Winter (1987): Appropriating the Returns from Industrial Research and Development, in: Brookings Papers on Economic Activities, Vol. 2, p. 783-831.

Levin, R.C. and P.C. Reiss (1988): Cost-reducing and Demand-creating R&D with Spillovers, in: Rand Journal of Economics, Vol. 19, p. 538-556.

Link, A.N. and J. Rees (1990): Firm Size, University Based Research, and the Returns of R&D, in: Small Business Economics, Vol. 2, p. 25-31.

Lucas, R.E. (1988): On the Mechanics of Economic Development, in: Journal of Monetary Economics, Vol. 26, p. 3-42.

Maskell, P. (1992): Learning in the Village Economy of Denmark: The Role of Institutions and Policy in Sustaining Competitivness, in: Braczyk, H.-J., Cooke, P. and M. Heidenreich (Hrsg.), Regional Innovation Systems: The Role of Governance in a Globalized World, London, p. 190-213.

Malecki, E. J. and P. Varaiya (1986): Innovation and Changes in Regional Structure, in: Handbook of Regional and Urban Economics, Bd. I, Amsterdam, p. 629-642.

Mariani, M. (2000): Networks of Inventors in the Chemical Industry, Urbino.

Marshall, A. (1966): Principles of Economics, London et al. 1966.

Matsuyama, K. and T. Takahashi (1993): Self-defeating Regional Concentration, NBER Working Paper No. 4484, Cambridge (MA).

Matusik, Sh.F. and Ch.W.L. Hill (1998): The Utilization of Contingent Work, Knowledge Creation, and Competitive Advantage, in: Academy of Management Review, Nr. 4, p. 680-697.

Maurseth, P.B. and B. Verspagen (1999): Knowledge-Spillovers in Europe, Maastricht.

Meagher, K. and M. Rogers (2004): Network density and R&D Spillovers, in: Journal of Economic Beahvior and Organization, Vol. 53, pp. 237-260.

Metcalfe, J.S. (2002): Knowledge of growth and the growth of knowledge, in: Journal of Evolutionary Economics, Vol. 12, p. 3-15.

Myrdal, G. (1964): Economic theory and under-developed regions, reprint, London.

Napolitano, G. (1991): Industrial Research and Sources of Innovation, in: Research Policy, Vol. 20, p. 171-178.

Nelson, R.R. (1982): The Role of Knowledge in R&D Efficiency, in: The Quarterly Journal of Economics, Vol. 97, p. 453-470.

Nerlinger, E. (1996): Firm Formation in High-Tech Industries. Empirical Results for Germany, Zentrum für europäische Wirtschaftsforschung (ZEW), Discussion Paper No. 96-07, Mannheim.

Niebuhr, A. (2000): Räumliche Wachstumszusammenhänge – empirische Befunde für Deutschland, HWWA Discussion Paper Nr. 84, Hamburg.

Ottaviano, G. and J.-F. Thisse (2003): Agglomeration and Economic Geography. CEPR Discussion Paper No. 3838, London.

Paci, R. and F. Pigliaru (2001): Technological Diffusion, Spatial Spillovers, And Regional Convergence in Europe, University of Cagliari and CRENoS, Nota di lavoro 36.2001, Cagliari.

Park, J. (2004): International Student Flows and R&D Spillovers, in: Economic Letters, Vol. 82, p. 315-320.

Partridge, M.D. and D.S. Rickman (1999): Static and Dynamic Externalities, Industry Composition, and State Labour Productivity: A Panel Study of States, in: Southern Economic Journal, Vol. 65, p. 319-335.

Peri G. (2003): Knowledge Flows, R&D Spillovers and Innovation, ZEW Discussion Paper 03-40, Mannheim.

Polanyi, M. (1985): Implicite Knowledge, Frankfurt/Main.

Popper, K.R. (1972): Objective Knowledge. An Evolutionary Approach. Oxford.

Porter, M.E. (1990): The Competitive Advantage of Nations, London.

Richardson, H.W. (1973): Regional Growth Theory, London et al.

Romer, P.M. (1986): Increasing Returns and Long-Run Growth, in: Journal of Political Economy, Vol. 94, p. 1002-1037.

Romer, P.M. (1990): Are Nonconvexities Important for Understanding Growth?, in: American Economic Review. Papers and Proceedings, Vol. 80, p. 97-103.

Rosenberg, N. (1963): Technological Change in the Machine Tool Industry, 1840-1910, in: The Journal of Economic History, Vol. 23, p. 414-443.

Rosenthal, S.S. and W.C. Strange (2004): Evidence on the Nature and Sources of Agglomeration Economies. Paper prepared for the Handbook of Urban and Regional Economic, Vol. 4, forthcoming.

Saglio, J. (1992): Localized Industrial Systems in France: A Particular Type of Industrial System, in: Storper, M. and A.J. Scott (Hrsg.), Pathways to Industrialization and Regional Development, London, p. 230-253.

Saxenian, A.L. (1994): Regional Advantage, Culture and Competition in Silicon Valley and Route 128, Cambridge (MA) and London.

Schmitz, H. and B. Musyck (1994): Industrial Districts in Europe: Policy Lessons for Developing Countries?, in: World Development, Vol. 22, p. 889-910.

Schmutzler, A. (1999): The New Economic Geography, in: Journal of Economic Surveys, Vol. 13, p. 355-379.

Schnellenbach, J. (2004): Learning from Decentralised Policy: The Demand Side. Paper presented at the Royal Economic Society annual conference at Swansea, April 4-7, 2004.

Schrader, S. (1991): Informal Technology Transfers between Firms: Cooperation through Information Trading, in: Research Policy, Vol. 20, p. 153-170.

Scitovski, T. (1952): Two Concepts of External Economies, in: Journal of Political Economy, Vol. 60, p. 143-151.

Smolny, W. (2000): Endogenous Innovations and Knowledge Spillovers, Heidelberg and New York.

Staber, U.H. (1996): Networks and Regional Development: Perspectives and Unresolved Issues, in: Staber, U.H., Schaefer, N.V. and B. Sharma (Hrsg.), Business Networks: Prospects for Regional Development, Berlin and New York, p. 1-23.

Sternberg, R. (1998): Innovierende Industrieunternehmen und ihre Einbindung in intraregionale versus interregionale Netzwerke, in: Raumforschung und Raumordnung, Jg. 56, p. 288-298.

Tallman, E. and P. Wang (1994): Human Capital and Endogenous Growth. Evidence from Taiwan, in: Journal of Monetary Economics, Vol. 34, p. 101-124.

Tybout, J. (2000): Manufactoring Firms in Developing Countries: How Well Do They Do, And Why?, in: Journal of Economic Literature, Vol. 38, p. 11-44.

Varga, A. (1998): Local Academic Knowledge Spillovers and the Concentration of Economic Activity, Regional Research Institute, West Virginia University, Research Paper No. 9803, Morgantown.

Verspagen, P. and W. Schoenmakers (2000): The Spatial Dimention of Knowledge Spillovers in Europe, Paper presented on the AEA Conference on IP Econometrics.

Wilkinson, F. and B. Moore (2000): Concluding Reflections: Some Policy Implications, in: Keeble, D. and F. Wilkonson (Hrsg.), High-Technology Clusters, Networking, and Collective Learning in Europe, Hampshire, p. 230-259.

Xu, B. (2000): Multinational Enterprises, Technology Diffusion, And Host Country Productivity Growth, in: Journal of Development Economics, Vol. 62, p. 477-493.

Zellner, Ch. (2003): The Economic Effects of Basis Research: Evidence for Embodied Knowledge transfer via Scientists' Migration, in: Research Policy, Vol. 32, p. 1881-1895.

Zucker, L.G., Darby, M.R. and J. Armstrong (1998): Geographically Localized Knowledge: Spillovers or Markets?, in: Economic Inquiry, Vol. 36, p. 65-86.

All our publications can be accessed, free of charge, on our website **www.dbresearch.com**
You can also register there to receive our publications regularly by e-mail.

Ordering address for the print version:

Deutsche Bank Research

Marketing
60262 Frankfurt am Main
Fax: +49 69 910-31877
E-mail: marketing.dbr@db.com

ISSN Print: 1610-1502 / ISSN Internet: 1610-1499 / ISSN E-mail: 1610-1480