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Knowledge markets: implications for innovation, welfare and policy design

Dissertation

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1 Introduction

The object of study in this work is the exchange of knowledge between agents of the private sector and its implications for innovation, social welfare and economic policy. The conditions and modalities of the exchange of knowledge are of great importance, in particular with respect to innovative activity. New Growth Theory for instance relies on knowledge externalities to provide the micro-foundations for their central notion of external scale economies, and Geographical Economics uses the concept of local knowledge spillovers (LKS) to explain the phenomenon of geographical clustering of economic activity. Nonetheless, as many studies in these fields point out, the exact mechanisms through which such knowledge externalities work are not well understood.

In this work it is argued that the key to understanding these phenomena lies in the special characteristics of knowledge as input and output of economic activity. From this starting point, a new methodology is developed to capture these special characteristics and based on this, a formal model of knowledge trading is built. This is then applied to topical issues in economic theory. The results turn out to be highly instructive for policy design to foster growth and social welfare and offer a meaningful alternative to existing approaches in the literature. In summary, therefore, this work is a contribution towards a better theoretical understanding of the micro-foundations of and the forces at work in knowledge economics by taking the nature of knowledge seriously.

The argument is structured into nine chapters. In chapter 2, the analysis turns to the properties of knowledge and knowledge exchanges in economic activity. Here a definition of knowledge is provided and its special characteristics and their implications are identified. These have been overshadowed by the focus of the existing literature on the notions of non-rivalry and non-excludability, and have hence largely been left unexplored. In particular, the importance of uncertainty, complementarity and cumulativeness in innovative activity and the phenomenon of pure knowledge externalities are discussed. This provides a conceptual framework for the rest of the argument and introduces a coherent system of definitions and terminology in an area which has suffered from a lack of consistency in the use of terms.

Chapter 3 then turns to the analysis of knowledge transfers between agents. The literature so far has focused on the case of non-tradability of knowledge. Accordingly, most models assume that an innovation can only be appropriated through own output (Cohen and Klepper, 1996) and is diffused through spillovers. In the first part of chapter 3 the concept of LKS is defined and its importance for the theory of geographical clustering as well as for New Growth Theory is discussed. Secondly, the theoretical and empirical literature on LKS is surveyed. In this context an analysis of possible channels for knowledge flows is undertaken, which leads to the conclusion that many of those knowledge flows which constitute genuine externalities are unlikely to be local, while some knowledge flows which are likely to be local might better be thought of as market-mediated. It is shown that even those empirical studies that claim to be supportive of the notion of LKS only ever test one of its hypotheses, i.e. for the knowledge flow to be local or for it to constitute an external-

ity, and assume the other one to hold. Consequently, the empirical evidence is also consistent with a market-based story of local knowledge flows. Finally, chapter 3 offers a new fundamental critique of the concept of LKS. In order to justify the regional boundedness of LKS, its proponents emphasise the tacit nature of the knowledge that spills. By definition, however, the transfer of tacit knowledge requires the personal participation of the sender, which gives the latter a degree of control over its transfer and makes the knowledge in question excludable. However, while being sufficient to prevent the spillover of knowledge, excludability does not suffice to ensure its tradability in a market. For this it is required that the sender can control the diffusion process of the knowledge in question after having shared it with another agent. Hence, the discussion in this chapter leads to the insight that the two parameters that determine the tradability of knowledge are its excludability for the sender and the latter´s ability to control the knowledge diffusion process.

Based on the considerations in chapters 2 and 3, the argument goes on to build a new approach to modelling knowledge in economic activity. For this purpose, in chapter 4 a new methodology is developed to capture the special characteristics of knowledge. Vector representation and basic insights from trigonometry are employed to replace the previous one-dimensional approach to modelling knowledge. This technical tool-set allows for the first time to capture the importance of complementarity and cumulativeness of knowledge and its implications for innovative activity and serves as a framework and theoretical point of reference for the arguments of the next chapters.

Building on this, chapter 5 develops a general model of knowledge production and trading. This is a new addition to the current body of theory, which is useful for at least four reasons. Firstly, the model yields necessary and sufficient conditions for knowledge trades to take place. Secondly, it identifies the drivers of knowledge exchanges which are internalised in a market as well as their impact on the knowledge production stage. Thirdly, even for types of knowledge or industries where market-mediated knowledge exchanges are of less importance, it is still useful to understand the conditions for and dynamics involved in alternatives to spillover-based exchanges. Without a model of knowledge trading, there would be no theoretical benchmark against which to evaluate such knowledge flows. Finally, it is important to understand the peculiarities, welfare implications and the requirements for the successful pursuit of knowledge trading as a basis for potential policy recommendations. This is particularly so to the extent that policy makers might be able to treat the degree to which knowledge is spilt over or exchanged in a market as a choice variable, e.g. through determining the degree of intellectual property rights protection.

Chapters 6 and 7 then go on to develop extensions and applications of the model of knowledge trading. Chapter 6 explores the consequences of a violation of two of the model assumptions. These are firstly, the consequences of a seller´s inability to commit to a post-trade market structure which prohibits appropriation through own output for the seller, and secondly, the case where a seller has no control over the diffusion process of knowledge after its sale. It is shown how in both cases knowledge exchanges might still take place via the market for mergers and ac-

quisitions (M&A) if the gains from reallocation of the knowledge concerned are large enough.

Chapter 7 then presents an extension of the model to a world with imperfect information and an application to the phenomenon of geographical clustering of economic activity. First, it is shown why firms benefit from evaluating information about other firms, both intuitively and within the model of knowledge trading developed in the previous chapters. Then, costs of evaluating information signals are introduced and argued to be rising with geographical distance between sender and receiver. Geographical clustering is then shown to be the equilibrium location structure of profit-maximising firms. Following this, the results are interpreted in the context of and shown to be consistent with the existing empirical literature on LKS and geographical clustering.

In chapter 8 the analysis turns to the welfare implications of different types of market mediated knowledge exchanges. In particular, the positive welfare effects of knowledge trading and geographical clustering are identified. The case of M&A activity, on the other hand, is found to not allow general conclusions with regard to its welfare implications but requires a case-by-case analysis instead. Based on this, excludability and control over the diffusion process of knowledge are identified as the determinants of the nature and hence welfare impact of knowledge exchanges and therefore qualify as the relevant targets for policy-makers. Furthermore, it turns out that the crucial factor for the welfare evaluation of different types of knowledge exchanges is the trade-off between static and dynamic concerns with regard to consumer and producer welfare on the one hand, and incentives for research and devel-

opment (R&D) and the diffusion of knowledge with their positive impact on growth and innovation on the other hand. Finally, the subsequent analysis of the determinants of the policy targets yields a set of implications for policy design for national and regional policy makers. To conclude, chapter 9 summarises and interprets the main results and outlines a draft for a research agenda based on the findings of this work.

2 The special properties of knowledge

2.1 Knowledge versus information

Knowledge enables its owner to do something or make decisions which he would not have been able to do or make in the same way without having this knowledge, like producing a certain product or improving quality, management or production processes. It is therefore intuitive to think of knowledge as an input into the production process. More precisely, it can be thought of as an intermediate good, as itself can be the output of organised R&D activity, i.e. of a knowledge production process.[1]

The literature usually distinguishes knowledge into "explicit" and "tacit" knowledge (e.g., Cowan and Foray, 1997; Polanyi, 1958, 1966). Tacit knowledge is defined as elusive, complex, not codifiable and embodied in people, requiring personal contact between sender and receiver for its transfer. Explicit knowledge on the other hand is codifiable, can be packaged as information and does not require personal contact or close supervision by the sender for its transfer.[2]

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[1] There is a strong argument that knowledge also is a consumption good. Depending on an agents´ utility function, acquiring and having knowledge in itself can cause pleasure. This aspect is of less relevance for the arguments to be pursued in this work, however.

[2] The degree of "tacitness" of knowledge varies across industries. In addition to this, different studies draw attention to the stage of the industry´s life-cycle as a determinant of the extent to which knowledge is codifiable.

The distinction between knowledge and information is important for the argument of this paper and has been used in other work (e.g., Audretsch, 1998; Caniëls, 2000). Information can be defined using Audretsch´s (1998, p. 21) description: "Information, such as the price of gold on the New York Stock Exchange, or the value of the yen in London, can be easily codified and has a singular meaning and interpretation." As such, it is an important prerequisite for functioning markets and can be important for strategic decisions of firms in an imperfectly competitive environment.

While knowledge can consist of a system of pieces of information which stand in a certain logical and complex relation to each other, it also comprises skills, competences and know-how acquired through training and experience. In particular, knowledge is not the same as information about knowledge. For a firm to have information about the direction and potential economic value of another firm´s new knowledge does not imply that it can make use of this new knowledge. For instance, a firm might be informed about the characteristics of other firms´ production technologies and can thereby work out its best response function as a guide for its actions. However, such information does not comprise knowledge in the sense that the firm can apply its competitors´ production technology itself. This corresponds to the spirit of the distinction between knowledge and information implicitly employed by Audretsch and Feldman (1996) and Audretsch (1998) while Dasgupta and David (1994) treat information basically as knowledge packaged for transportation thereby capturing its potential function as a vehicle for transporting knowledge from sender to receiver.

Nonetheless, information still frequently has an economic value, as discussed for instance by Arrow (1962, p. 614), "in the sense that anyone possessing the information can make greater profits than would otherwise be the case." It is a well-established principle in economics, that in general, firms will prefer to have more information to less.

2.2 Characteristics of knowledge

The characteristics of knowledge that have received most research attention and that have dominated the debate are "non-excludability" and "non-rivalry". Non-excludability means that once it is around it is not possible (at sufficiently low cost) to exclude agents from the use of knowledge. This is the basis for the spillover argument made in the context of knowledge diffusion and leads to the notion of non-appropriability of knowledge for its owner. If knowledge is not appropriable for its owner, this is problematic due to the adverse incentive effects with regard to the production of new knowledge: Investing in innovative activity is not attractive if the resulting knowledge is available to everyone and the investor cannot make a sufficient return on his investment. The result would be under-investment into R&D from a social welfare perspective. This is one of the main justifications for government funding and subsidies of R&D and other regulatory involvement for instance through the patent system.

Non-rivalry on the other hand means that the opportunity cost of a further agent using the same knowledge is zero in the sense that the amount of knowledge left for use by other agents remains unchanged regardless of the number of current

users (Arrow, 1962).[3] This is in contrast to other inputs, e.g. nails, and outputs, e.g. ice-cream, which can be used or consumed only once. The property of non-rivalry leads to the situation that abstracting from the adverse incentive effects to produce knowledge in the first place it is in the interest of social welfare to diffuse existing knowledge as widely as possible. This is even more so in the presence of pure knowledge externalities such as the "standing on the shoulders of giants" or the "cross-fertilisation" effects. The former refers to the phenomenon that knowledge is cumulative and that inventions often only become possible on the basis of what is known before. The latter refers to the notion that knowledge from one area can help spark ideas for inventions in other areas despite of current differences in content and application.

It is important, however, to draw attention to the implications of some further characteristics of knowledge which despite having been mentioned in other places in the literature (Arrow, 1962; Cohen and Levinthal, 1989; Dosi, 1988; Nelson, 1959) so far have received less attention in economic modelling. In the remainder of this work, it will be shown that these need to be taken into account when trying to capture the special properties of knowledge in economic activity.

[3] Note that this does not mean that the economic value of knowledge is independent of the number of people who are familiar with it. Exclusive possession of knowledge confers a position of market power to the knowledge owner which might allow the extraction of innovation or knowledge rents.

2.2.1 Cumulativeness

New knowledge builds on existing knowledge and often only becomes "inventable" on the basis of what was known before. This works in reverse as well: new knowledge might allow to put previously existing knowledge to other uses and thereby lead to further commercial innovation.

2.2.2 Complementarity

The economic value of knowledge to its owner is dependent on its complementarity with other knowledge already in his possession. Existing competences might help a firm to realise the contents of new knowledge at a lower cost, and the combination of new knowledge with existing knowledge might help spark new ideas and thereby enhance future R&D output and product development. Alternatively, organisational inertia might hinder effective exploitation of new knowledge because it might require new routines or a different optimal organisational structure. It follows that the same knowledge can be of different value to different agents.

Consider for instance a company specialised in the production of musical instruments which found out new knowledge about the characteristics of certain materials. The company is likely to recognise and use only those aspects of its new knowledge which fall in its area of competence and fit its organisational structure currently geared towards improving the quality, reducing the production costs and marketing of its instruments. The new knowledge might, however, contain valuable insights for completely different products, for instance in the area of sports equipment, which the musical instruments company might not even recognise or be un-

able to exploit through own production. Also, the full exploitation of the economic potential of the new knowledge might require an organisational structure which differs from the firm´s existing organisation and would be costly to adopt. As a consequence, the "potential innovative input" of the new knowledge might not be fully exploited by the musical instruments company. In what follows the term "potential innovative input" is used to refer to all aspects of new knowledge, which can be employed as an input for the production of innovative products, some of which its owner might not be able to recognise or exploit. The degree of fit of new knowledge for any particular firm will be referred to as the new knowledge´s "complementarity" with that firm´s existing knowledge (comprising competences, routines, organisational structure, etc.). Complementarity and potential innovative input of new knowledge together then determine what shall be referred to as the "effective innovative input" of new knowledge for a company. By definition therefore, the effective innovative input of new knowledge can at most be as large as the potential innovative input and will be smaller in case of less than perfect complementarity.

2.2.3 Uncertainty

This is a property which is particularly important with regard to economic activity involving the production and use of new knowledge. Even if research is conducted with an aim in mind, there is uncertainty about exactly what new knowledge will be produced until it is produced.

There are two types of uncertainty involved: firstly, about whether and how much new knowledge will be produced, and secondly, about what new knowledge

exactly will be found and how useful it will be. In the following it will be abstracted from the first type of uncertainty which has been analysed elsewhere in the literature (e.g., Arrow, 1962) [4] by assuming that the same amount of R&D expenditure will always produce an amount of new knowledge with the same potential innovative input. However, uncertainty remains about the degree of complementarity of new knowledge and hence about the effective innovative input for the inventor. This notion was touched on in earlier work by Nelson, when he points out that a "broad technological base insures that, whatever direction the path of research may take, the results are likely to be of value to the sponsoring firm" (Nelson, 1959, p. 302), but has been left unexplored since.

2.2.4 Innovation rents

To the extent that its use is exclusive, new knowledge is valuable for its owner. In the existing literature knowledge is generally viewed as an intermediate product. As such it does not lead to direct rents but works as an input into the production process of the firm instead. In so far as a particular piece of new knowledge is exclusively used by one firm, it allows this firm to differentiate itself from competitors in the output market. This affords it a more protected market position and allows the extraction of innovation rents because of decreased substitutability of competitors´ products. Note that exclusivity of the knowledge to one or a few firms is essential here and might be achieved by effective patent protection or trade secrecy. The

[4] See Sena (2004) for a survey.

method of realising rents in the output market from using new knowledge as an exclusive input will be referred to as "appropriation through own output" from now on.[5]

2.3 Knowledge externalities

The literature distinguishes between pecuniary or rent externalities on the one hand, and non-pecuniary or „pure" knowledge externalities on the other hand (Griliches, 1992; Krugman, 1991b). Pecuniary externalities result from market interactions and work through the price mechanism. Consider for example an increase in the supply of qualified workers in one location. This constitutes a positive externality for firms who seek to employ qualified workers in that location. The externality is of a pecuniary type, because it will work through the price mechanism: Due to the increased supply it will, ceteris paribus, be cheaper for a firm to find and employ its workers.

Non-pecuniary or pure knowledge externalities on the other hand are uncharged, unintended and consequently not market-mediated. They do not work through prices, but by directly affecting firms´ production technologies. It is useful

[5] The additional possibility of extracting direct rents from the sale of knowledge to other firms will also be discussed in the course of this work. The ultimate motivation of the acquirer, however, is based on the innovation rent from appropriation through own output it expects to be able to realise by using the acquired knowledge as an exclusive input for its production process, too.

to briefly review two instances of pure knowledge externalities, which are of particular importance in the context of knowledge economics.

2.3.1 Standing on the shoulders of giants

"What Des-Cartes did was a good step. You have added much several ways, & especially in taking ye colours of thin plates into philosophical consideration. If I have seen further it is by standing on ye shoulders of Giants."

(Newton, 1676)

The "standing on the shoulders of giants"-effect results from the nature of cumulativeness of knowledge. It refers to the notion that the more one knows the better one becomes at inventing new knowledge. Furthermore, many innovations only became possible on the basis of previous innovations. This can be illustrated most clearly in the case of milestone inventions like the wheel, which allowed the invention of the cart and the carriage, or like learning to generate and conduct electricity, which allowed the invention of the light bulb.

In fact, it is one important aim in the design of the patent system to exploit exactly this phenomenon: The inventor of new knowledge is granted protection and hence monopoly rents for his invention in exchange for making the new knowledge available to other agents, thereby raising the platform of knowledge in the economy in general. This will – via the giants´ shoulders effect – lead to more efficiency (e.g., through less wasteful or duplicative R&D) and productivity (e.g., through a larger input pool of existing knowledge) in R&D for everyone and increases the pace of

technical progress in the economy. This is a classical source of dynamic increasing returns to scale and of great importance for growth.

2.3.2 Cross fertilisation

Cross fertilisation is an instance of pure knowledge externalities which is closely related to the giants´ shoulders phenomenon discussed before. In the case of cross fertilisation R&D activity in one area stimulates innovative progress in a different field, for instance by providing key agents in another area with new ideas as to how to go about solving an existing problem. It helps raise new question or shows new directions, which future work might take. Cross fertilisation, therefore, is particularly relevant for the realm of ideas, visions and the application of methods from one area of activity to another seemingly unrelated one. It also refers to the case where breakthrough developments in one field stimulate progress in another field, like for instance the invention of the telegraph, which led to a host of innovations in the area of financial markets due to the increased availability and diffusion speed of information, or the invention of the internet, which revolutionised retailing and advertising.

3 Scope and limits of LKS for mediating knowledge flows

Due to the properties of cumulativeness and non-rivalry, knowledge flows are of critical importance for prosperity. Diffusing new knowledge leads to a higher overall level and a broader base of knowledge in the economy with the effect of increasing quality, decreasing production costs and facilitating further innovation. In this context, the widespread assumption of non-excludability of knowledge has led to the assumption in the main strands of the economic literature that knowledge flows are not usually internalised in a market, but spill over between agents instead.[6]

This chapter focuses on the analysis of knowledge exchanges between agents of the private sector and proceeds as follows: Firstly, the significance of the term of LKS in the economic debate is discussed. Secondly, the theoretical and conceptual shortcomings of the notion of LKS are surveyed. Based on this, an analysis of the different candidate channels for knowledge flows is conducted. Particular attention is paid to the questions of whether flows through these channels are likely to be a) local instead of boundless, and b) spillovers instead of internalised in a market. The

[6] This default assumption is particularly unsatisfactory for the case of patentable knowledge. For instance a survey by The Economist on patens and technology (Cukier, 2005) shows that growth in the number of patents and their exchange as well as in licensing is a striking phenomenon of the developments in the IT industry over the last decade. However, by definition to be patentable knowledge has to be codifiable. Non-tradability is therefore less obviously flawed with regard to tacit knowledge. It will be shown though that for tacit knowledge too a more differentiated view is called for.

result of this analysis shows that many of the candidate channels for LKS that work locally are likely to be market-mediated while those channels, which accomplish genuine knowledge externalities, are often not regionally bounded. Even for the channels that remain as candidates for genuine LKS, it emerges as likely that at least a part of the knowledge conveyed through them will be internalised in a market.

Following this, the substantial body of empirical literature is critically reviewed to check its consistency with the findings of the preceding theoretical considerations. It is shown that empirical studies so far have not managed to test whether and to what extent knowledge flows are appropriated by the inventors of new knowledge because market mediated knowledge flows are observationally equivalent to knowledge spillovers in the design of these studies.

Thirdly, the notion of tacitness of knowledge is revisited. In particular, the view of non-excludability of tacit knowledge is criticised because by definition it requires the involvement of the sender for its transfer and should therefore be treated as excludable. This amounts to a new and fundamental critique of a core concept of the LKS story. However, while excludability of tacit knowledge ensures that its owner can prevent its spillover, this is only a necessary, but not a sufficient condition for tacit knowledge to be tradable in a market. Instead, the decisive parameter enabling market exchanges of knowledge is shown to be the sender´s degree of control over the knowledge diffusion process after having shared it with another agent.

By deriving the conditions under which knowledge is tradable, this chapter shows that there are strong grounds to expect that knowledge flows are (at least par-

tially) exchanged through markets instead of spillovers. This provides the motivation and theoretical foundation to proceed to build a general model of knowledge trading as an alternative benchmark scenario to the spillover story which has not yet been explored in the literature.

3.1 LKS in the economic debate

LKS play a critical role in economic theory. The literature on geographical economics for instance relies on LKS to help explain clustering of economic and in particular innovative activity, and New Growth Theory relies on local spillovers of knowledge as a micro-foundation for its assumption of external scale economies.

3.1.1 Definition of LKS

Marshall (1890) identified the following as the main intra-industry externalities:

1. Specialised input markets: A cluster can support a greater number of more highly specialised suppliers, resulting in greater variety at lower prices and reducing inventory costs.

2. Pooled labour markets: A cluster attracts workers with special skills in larger numbers. The workers benefit from the presence of many potential employers should they loose their job, and the firms benefit from the larger and deeper pool of human capital at their disposal.

3. LKS: Geographical proximity of agents with know-how in the cluster facilitates the costless transfer of knowledge between cluster members. The main chan-

nels for these spillovers are face-to-face contacts through social and professional local networks as well as spin-offs and hiring, firing and poaching of employees through the labour market (Audretsch, 1998; Pavitt, 1987). Furthermore, the output of public R&D of local institutions, for instance universities, spill over to cluster members. LKS therefore can be considered a positive externality for the recipient of the knowledge flow which is available only in geographical proximity to the knowledge source.

Since Glaeser et al. (1992), the last category is commonly referred to as Marshall-Arrow-Romer (MAR) externalities.[7] While the first two of the above categories are externalities of a pecuniary type, i.e. they work through prices to affect the value but not the physical characteristics of agents´ property, the latter is non-pecuniary in that it affects the knowledge base and the productivity of agents´ innovative activity and creates technological and innovative opportunities. Some studies have used the term "knowledge" interchangeably with "information" in this context (e.g., Aharonson et al., 2004; Fujita et al., 2001; Henderson, 1999). This is contingent on the underlying (yet often unmentioned) assumption, that knowledge is not excludable and that it is transferred via information. However, in order to evaluate the concept of LKS it is important to distinguish carefully between knowledge and information as discussed in section 2.1.

[7] Some authors take MAR externalities to refer to all three Marshallian externalities mentioned here (e.g., Aharonson et al., 2004), but the use of the term as above corresponds more precisely with Glaeser, et al. (1992) who created it.

From the very term of LKS it is clear that the two fundamental properties that have to be met for a knowledge flow to constitute a LKS are that firstly, it has to be regionally bounded and secondly, it has to be an externality. In order to justify the local nature of such knowledge flows the concept of tacitness (see section 2.1) is employed. The argument goes that, contrary to explicit knowledge, tacit knowledge does not spread easily from one location to another because it is hard to codify and can only be learned through imitation and face-to-face contact (Nelson and Winter, 1982). Hence geographical proximity becomes important for its transfer. With regard to the externality property of knowledge flows classified under the term of LKS on the other hand, this is justified by the assumption of non-excludability of knowledge which makes a market-based exchange impossible.

It is useful at this stage to introduce a formal definition of what constitutes a knowledge spillover.[8] A knowledge spillover is defined as a situation whereby knowledge is created by one agent and used by another agent without or at least with insufficient compensation for the knowledge producer. This definition refers to the case of compensation less than the value of the knowledge. It was already shown in the previous chapter, however, that due to the importance of complementarity, the same knowledge can be of different value to different agents. What then is the compensation which is considered to properly reflect the value of the knowledge? Is it the value to the producer or the value to the prospective user which should be used

[8] The term "knowledge spillover" is defined as a knowledge flow which constitutes an externality.

as a benchmark for the externality definition? In the light of the discussion in the previous chapter, therefore, this already reveals a problem with the very concept of knowledge spillovers.

Based on this definition of the term of LKS a brief discussion of the two main areas where this concept plays a role reveals that it has become an important element in economic theory. The examples set out below are firstly, the phenomenon of clustering in Economic Geography and secondly, the micro-foundations of New Growth Theory.

3.1.2 The role of LKS in theories of geographical clustering

"A paradox has been the emergence of the importance of local proximity and geographic clusters precisely at a time when globalization seems to dominate economic activity."

(Audretsch, 1998, p. 18)

Geographical clustering is a pervasive phenomenon with regard to the geographic location of economic activity (Porter, 1998). Famous examples for this include Silicon Valley in Palo Alto (Saxenian, 1990) or Route 128 in Boston (Bathelt, 2001). Furthermore, it has been found that the propensity of innovative activity to cluster tends to be greater the more important new economic knowledge is in an industry (Audretsch and Feldman, 1996; Audretsch and Stephan, 1996; Prevenzer, 1997; Zucker et al., 1994; Zucker et al., 1998b). A large body of literature has emerged which tries to explain the forces behind clustering of economic activity.

Table 1 is a reproduction of Table 1 in Beaudry and Breschi (2003) and gives a summary of the drivers of clustering.

Table 1: Impact of clustering on firm innovation

Demand side	Supply side
Advantages	
Sophisticated users	Knowledge spillovers
User-supplier interaction	Skilled labour and specialised inputs
Informational externalities	Informational externalities
Disadvantages	
Competition in output markets	Competition in input markets
Strong relational ties	Inward orientation and lock-in

Source: Beaudry and Breschi (2003, table 1, p. 326)

Of these forces, the focus of the literature has been on supply side factors and knowledge externalities have been put forward as an important motive for clustering in particular of innovative activity (e.g., Audretsch, 2003; Audretsch and Feldman, 2003; Feldman, 1999).[9] The argument holds that given sufficient absorptive capacity (Cohen and Levinthal, 1989) and complementarity of local knowledge (see Chapter

[9] A related, comparatively younger literature initiated by the Groupe de Recherche Européen sur les Milieu Innovateurs (GREMI) emphasises the role of a strong local innovative milieu as a competitive advantage for a particular region (Aydalot, 1986; Aydalot and Keeble, 1988; Camagni, 1991; Crevoisier, 2001). These considerations are based on a non-linear understanding of the innovative process (Asheim, 1999; Lundvall, 1992), and there are recent efforts in this area which attempt to verify the theoretical literature empirically (Sievers and Maennig, 2005).

2.2) firms find it beneficial to collocate in a cluster in order to benefit from LKS (e.g., Audretsch, 1998).

The notion of LKS has become a stylised fact in much of the scientific and political debate on clustering despite of the fact that most studies emphasise that little is known about the exact mechanisms underlying this phenomenon. A critical re-evaluation of potential drivers of clustering on the basis of the argument developed here will be undertaken in more depth in Chapter 7.

3.1.3 The role of LKS for New Growth Theory

The neoclassical approach to growth (e.g., Solow, 1956), which dominated the literature before the advent of new or endogenous growth theory, suffered from the failure of relying on exogenous variables (like the rate of technical progress and of population growth) to explain the growth of economies.[10] Furthermore, while successful at explaining some of Kaldor´s (1963) six stylised facts of growth, its convergence prediction turned out to be at odds with empirical realities.[11]

To improve on this, New Growth Theory internalises technological progress in its models (Aghion and Howitt, 1992; Arrow, 1962; Barro, 1990; Lucas, 1988;

[10] Notably, Ramsey´s (1928) model endogenises the savings rate (Cass, 1965; Koopmans, 1965). Growth, however, is still driven by exogenous parameters in this model too, and it does not explain differences in growth rates between countries.

[11] Although the data suggests that there is convergence to some degree for certain groups of countries, as for instance OECD countries in the post Second World War period, this result does not hold for longer periods of time or broader samples of countries.

Romer, 1986, 1987, 1990). The concept of capital is widened to include knowledge. Due to the special characteristics of knowledge, these theories move away from the notion of diminishing returns to capital at the aggregate level and work on the assumption of external scale economies, i.e. increasing returns to knowledge at the aggregate level, instead. By at the same time sticking to the assumption of decreasing returns at the firm level, new growth theory achieves the trick of keeping its models soluble (hence, "external" scale economies).

The rationale for assuming increasing returns to knowledge in the economy as a whole are firstly, that knowledge can be used and re-used by many agents due to its non-rival nature and secondly, that due to learning-by-doing, cross-fertilisation and standing-on-the-shoulders-of-giants effects, these increasing returns will be dynamic in nature. Therefore, the more knowledge the economy produces, the more productively it can put to use all other factors of production and the better it will become at producing new knowledge in the future. Hence, technological progress is internalised and knowledge propels growth in the economy indefinitely. Consequently, instead of convergence the prediction is that regions and states can spiral into virtuous or vicious circles with the winners accumulating more and more knowledge and attracting more and more growth and the losers without any chance to catch-up due to the path-dependence of outcomes.

Against this background it is clear that the notion of LKS is an essential part of new growth theory in two main respects:

1. LKS are used to explain the spreading of knowledge between agents that is required in order for the increasing returns dynamic at the aggregate level to kick in.

2. LKS are used to argue that this spreading of knowledge and the increasing returns dynamics, which follow it, are regionally bounded. This is required in order to allow new growth theory to address the finding of diverging growth rates between states or regions in the first place.[12]

However, New Growth Theory has used the concept of LKS as a black-box type of term, sparing itself the hassle of building a microeconomic foundation for its arguments. Its focus on the macroeconomic side of explaining growth was a sensible first step. However, an identification and understanding of how increasing scale economies come about at the micro-level are required to put the macroeconomic story of New Growth Theory on a firm theoretical grounding. Furthermore, this is of great importance for the design of economic policy aiming to foster growth at the regional level. It is one of the contributions of this work to develop a concept of knowledge exchanges and their regional diffusion which provides a microeconomic foundation for New Growth Theory as an alternative to the LKS story.

[12] With clusters of economic growth and areas of economic stagnation dominating the landscape of economic activity even at the national level, this clearly is an essential requirement for a useful theory of growth.

3.2 A critique of the notion of LKS

3.2.1 Arguments against the LKS story

Conceptually, there are two lines of criticism of the LKS story. One is aimed at the assumption that knowledge spillovers are local. For instance, Krugman (1991a) argues that there is no reason to expect spillovers to be regionally bounded, particularly in the light of globalisation and decreased communication costs. The other criticism holds that most local knowledge exchanges turn out to be internalised in a market when examined more closely (Geroski, 1995; Griliches, 1992).

A problem with the literature so far is that very few papers have attempted to spell out the precise channels and mechanisms involved in the spillover process, leading to the criticism of LKS being a "black box" for phenomena the researcher had otherwise not been able to capture (e.g., Breschi and Lissoni, 2001a; e.g., Breschi and Lissoni, 2001b). This shortcoming will be addressed in more detail in the next section. This section therefore turns to some other problems with studies in support of the importance of LKS for clustering.

Geroski (1995, footnote 19), for instance, points out, that there is theoretical and empirical support for the view that firms must do significant R&D themselves in order to benefit from knowledge spillovers (e.g., Cohen and Levinthal, 1989). Furthermore, in most industries it is established empirically that many firms have zero or very small R&D expenditure (Cohen and Klepper, 1992). These two findings together suggest that very few firms benefit from spillovers in each industry. This

stands in contrast to the fact that overall the literature claims to find empirical support for significant knowledge spillovers.

Empirical studies supportive of the spillover story face the serious problem of measuring innovative input and output and the extent of knowledge flows. For instance, the finding that the knowledge production function works well at the aggregate level but breaks down at the level of the firm (Ács and Audretsch, 1990; Audretsch, 1995, 1998) has been used as an argument in favour of the existence of knowledge spillovers (Ács, 2002; Ács et al., 1994; Varga, 1998). These studies, however, frequently use patent counts or new product announcements as a measure for innovative output (Schankerman, 1979) and formal R&D expenditure as a measure for innovative input. It is well known though that firms may choose trade secrecy, lead time, learning curve advantages or sales and service efforts over patenting to protect their inventions and that this choice might not be independent of firm size, industry or market structure (Levin et al., 1987). Other studies use product innovation counts, which are often based on firms´ own product announcements, and can therefore be highly inaccurate with respect to the timing and substance of the actual innovation.[13] With regard to a measure of the input side using formal R&D expenditure may also introduce a size-dependent bias as smaller firms may employ people or engage in activities that are at least partially aimed at developing or applying new knowledge. However, these expenditures may not be separately accounted into a

[13] See Griliches (1979) and Scherer (1984) for a broader discussion of problems of measurement of output in R&D intensive industries.

formal R&D budget (Kleinknecht, 1987; Schmookler, 1959). Furthermore, patent citations have frequently been used as a measure for knowledge spillovers (Englander et al., 1988; Mohnen and Lepine, 1988; Mowery and Ziedonis, 2001; Scherer, 1982; Scherer, 1984). It is important to note, however, that patent citations may not actually indicate a knowledge spillover. For instance in the US, it is customary for the patent attorney or the patent examiner at the USPTO to add citations during the patent application process (Jaffe et al., 1998; Jaffe et al., 2000). Thus, the use of patent citations as a measure of knowledge flows will systematically overestimate the extent of such flows. This can lead to significant distortions when patent citations are interpreted as knowledge spillovers.

These concerns seem to be consequential due to the fact that empirical results regarding the determinants and the agents of innovation tend to be very much driven by the choice of measurement. Studies focused on R&D inputs (such as R&D expenditure and the share of labour force) or a measure of intermediate inputs in the innovative process (such as patents) usually found large firms to account for the largest share of innovative activity and output. However, when direct measures of innovative activity (such as new product or process introductions) were used, small firms turned out to be more innovative at least in some industries (Ács and Audretsch, 1987, 1988, 1990).

Further support for the black-box critique of the knowledge spillover story results from detailed empirical studies of knowledge flows in specific innovative indus-

tries and clusters, which find markets at work where for lack of a sufficiently detailed analysis previous studies suspected spillovers instead.[14] Given these empirical difficulties an important further criticism of the knowledge spillover story concerns a problem of circular causation in existing theoretical studies (Krugman, 1995; Malmberg and Maskell, 2001): While the exact spillover mechanism leading to the alleged benefits of clustering are not clearly identified, those studies turn the chain of reasoning on its head and use the observation of clustering as proof of the existence of the "black box" of knowledge spillovers.

The theoretical and empirical concerns discussed above have already led some authors to conclude that "In fact, as soon as one tries to open the black-box of LKSs, it becomes quite clear that

a. what might appear at first as 'pure' knowledge externalities are actually 'rent' (or pecuniary) externalities, which are mediated by economic (market and non-market) mechanisms, such as the labour market and firm networking;

b. what might appear as involuntary (pure or rent) knowledge externalities are actually well-regulated knowledge flows across firms, or between research institutions (or individuals therein) and firms, that are managed with deliberate appropriation purposes."

(Breschi and Lissoni, 2001b, p. 270)

[14] See, for instance, von Hippel (1988) on informal know-how trading, and the work on the role of star scientists for knowledge flows in the Californian bio-tech industry (Zucker et al., 1998a; Zucker et al., 1999; Zucker et al., 1998b).

3.2.2 Channels for knowledge flows

The lack of a detailed discussion of the channels through which knowledge actually flows has been pointed out as one of the critical shortcomings of the LKS literature (Balconi et al., 2004). In the face of the critique summarised in the previous section, it seems sensible in this section to identify the channels through which knowledge might flow and to check to what extent such flows might qualify as LKS.

1. Social networks, private and professional contacts: As set out in section 3.1.1 the LKS story of knowledge flows relies on tacit knowledge which is transferred costlessly through face-to-face contacts of individuals in the cluster. However, it follows from the definition of tacit knowledge that while local in nature, casual private or professional contacts are unlikely to accomplish a transfer of tacit (as opposed to explicit) knowledge. Instead, effort and intention are required. This is a fundamental point and will be elaborated in more detail in section 3.3 below. Accordingly, von Hippel (1988) showed for the case of engineers in competing steel mini-mill producers in the US that social, private and professional contacts often constitute a case of intentional informal know-how trading rather than knowledge externalities. In addition to this, Breschi and Lissoni (2001b) point to the importance of "epistemic communities" with a special vocabulary or "codebook" which might be hard to understand for outsiders regardless of geographic proximity.

2. Labour markets: Knowledge is supposed to flow through the labour market through hiring, firing and poaching of employees who take knowledge from

their previous to their next employer. This channel for knowledge flows is local to the extent that people prefer not to move across large distances. For the LKS story, however, the local nature of these knowledge flows is questionable in precisely those instances which are likely to involve the most significant transfers of knowledge. Highly-paid executives and researchers have a particularly high-degree of regional mobility. Furthermore, it is questionable to what extent these knowledge flows are actual externalities. If knowledge transfers take place through the labour market, then why should rational agents free to contract not internalise those flows? This should only be expected to the extent that labour market regulations restrict the parties´ options to contract. To the best knowledge of the author, no systematic evaluation of this point has been pursued so far.

3. Spin-offs: Audretsch (1995) points out that a worker with an endowment of new knowledge will make a decision about how best to appropriate the value of his new knowledge. If this worker expects to appropriate a higher return from pursuing his knowledge in a separate start-up than from pursuing it in the employ of his current company, he will pursue the more profitable strategy (Hirschman, 1970). While this effect is likely to be local, it again depends on the ability of employer and worker to write and enforce contracts whether one should expect this effect to be internalised in the labour market or to count as a genuine externality.

4. Publications: Knowledge revealed to the public via publications constitutes a genuine public good, but not a local one. Furthermore, the intention of the

sender as discussed above is obvious in these cases, but the content might require the reader to be an "insider" or a member of an "epistemic community" to be able to extract the knowledge in the publication (Breschi and Lissoni, 2001b). Anyway, this type of exchange is generally more typical for public-to-private knowledge flows or the internal communication within firms rather than for knowledge exchanges between agents of the private sector, which are the focus of this work.

5. Reverse engineering: In their survey of appropriability conditions, Levin et al. (1987, table 6, p. 806) show that reverse engineering is an important learning method, particularly about new products. It constitutes a genuine (knowledge) externality, but again not a local one as long as the product can be transported with relative ease. Typically such transportation costs of the product to be reverse engineered will be negligible compared to the value of the knowledge to be gained.

6. Patenting and licensing: The last decade has seen a huge increase in the number of patents sought and granted as well as in the revenues firms generate from licensing their patented knowledge to other players (Cukier, 2005). In addition to this, patents are more and more used by firms as currency along the following lines: If a product of firm A infringes the patent rights of another firm B, the latter might be persuaded to not enforce its patent if firm A can argue that a product of firm B infringes one of its own patents. Both, licensing of knowledge and the praxis of mutually dispensing with the right to enforce a patent claim for fear of retaliation, are market-based rather than externality

type of transactions. In addition to this, patents can be sold and purchased. Such transactions also clearly are not an externality-type of knowledge exchange. There are aspects of patenting practice, however, which come closer to constituting externalities. One example is the practice of large firms to donate patents to a patent "commons".[15] Patenting such knowledge first and making it available to the public afterwards eliminates the risk for third party or open-source developers and other companies to be sued for patent infringements and can thereby help to enhance innovative progress. This constitutes an externality, but there is no reason to expect it to be a local phenomenon. Instead, the point of a patent commons is that it is available to the public at large, regardless of where agents are located.

In summary, one can therefore conclude that many of those knowledge exchanges that constitute genuine externalities are not local, while many channels which are local are market-mediated and hence do not qualify as spillovers. Furthermore, even those channels that remain as candidates for mediating LKS are likely to at least partially serve for market-based knowledge exchanges as well (e.g., social networks, private and professional contacts).

[15] In 2004 for instance IBM pledged 500 software patents to the open-source community.

3.2.3 Evaluation of existing empirical results

In the light of the discussion so far, it seems useful to critically review the substantial body of empirical work, which is commonly cited in support of the importance of LKS, to check its consistency with the theoretical arguments above. The following categories of empirical findings are generally drawn on to support the existence and importance of LKS:

1. The failure of the knowledge production function at the level of the firm but not at larger units of observation (e.g., Audretsch, 1998).

2. The higher sensitivity of innovative performance of individual firms to external inputs which are geographically close than to external inputs which are further away (Audretsch and Feldman, 2003).

3. Empirical findings that either Jacobian-, Porter- or MAR-type of clustering enhances sectoral employment growth (Combes, 2000; Glaeser et al., 1992; Henderson et al., 1995).

4. The finding that firms located in clusters with a large number of firms or share of employment in their own industry tend to grow faster (e.g., Swann, 1998) and generate a larger number of innovations (e.g., Baptista and Swann, 1998; Beaudry, 2001) than more isolated firms or firms located in clusters which are less specialised in the innovator´s area of expertise.

5. The notion of increasing returns for new growth theories and in particular of sustained growth differentials between regions or cities (Black and Henderson, 1999; Lucas, 1988; Romer, 1986).

6. The finding of a higher propensity to cluster the more important new knowledge is in the industry (Audretsch and Feldman, 1996).

7. The finding that agents citing a patent and agents holding that patent tend to be located in the same region more often than one would expect from the pre-existing concentration of related research activity (e.g., Jaffe et al., 1993; Verspagen and Schoenmakers, 2000).

There already are several papers which critically review this empirical literature from various perspectives and question for instance empirical methods or the way certain variables are proxied and measured (Combes, 2000; Griliches, 1979, 1992; Scherer, 1982; Scherer, 1984). The objective here is not to replicate their efforts, but to argue the more fundamental point raised by Breschi and Lissoni (2001a) that the design of existing empirical studies cannot differentiate between market-mediated local knowledge exchanges and local knowledge exchanges that qualify as externalities. As a consequence, these studies do not test for the existence of LKS but estimate their size and characteristics under the assumption that they exist.

Consider the empirical points 1 and 2 first. These are results from the production function approach to testing for LKS initiated by Jaffe (1989). Many papers in this tradition focus on LKS from universities to the private sector and are therefore not relevant for the discussion here (e.g., Anselin et al., 2000). Furthermore, there

already are several papers which point to the difficulties of choosing the right proxies for innovative inputs and outputs, the units of observation (both, regional and technological) and the correct empirical techniques (Audretsch and Feldman, 2003; Feldman, 1999; Griliches, 1992; Sena, 2004).

The more fundamental point, however, is that the evidence is consistent with market-based exchanges under plausible assumptions. Consider for instance the case where a firm can buy new knowledge from another firm, either for money or in exchange for some of its own new knowledge. Then it is clear from the special characteristics of knowledge in economics discussed in chapter 2 that this will have two effects: Firstly, the new knowledge enters as an input (possibly unobserved to an outsider to the knowledge trade as the parties would presumably have an interest in secrecy vis-à-vis competitors) into the firm´s innovative activity. Secondly, the R&D efforts of the firm can be expected to become more productive because the new knowledge might spark new ideas, broaden the set of what is inventable (both due to cumulativeness) and allow a more targeted approach for future R&D efforts (due to the role of uncertainty in knowledge production). The exchange of knowledge itself, however, did not constitute a spillover, but was market-mediated, even if it gave rise to subsequent positive (pure knowledge) externalities in the firm´s knowledge production process.

That such exchanges might work locally better than with large distances can easily be explained by various transaction cost-type of factors which are well-known in the literature. Due to the problems of writing sufficiently complete contracts in the face of complex or new knowledge (Arrow, 1962; Mowery, 1983; Williamson,

1975), it is likely that the reach of market mechanisms for knowledge transfers is geographically limited (Mowery and Ziedonis, 2001). Furthermore, local proximity might facilitate monitoring of agreements and foster trust, which is required for activities such as informal knowledge trading (von Hippel, 1987). Furthermore, it might be easier to attain more complete information as a basis for subsequent knowledge trades when located closer to potential trading partners. This view is consistent with the empirical observations in so far as unobserved inputs and outputs can help explain point 1, and in so far as proximity enhances the conditions under which knowledge trades can take place, explaining point 2 above.

With regard to the empirical evidence summarised in points 3 and 4, the approaches which produced them assume rather than prove the existence of LKS. Glaeser, et al. (1992) and the work following them are concerned with testing the Jacob-, Porter- and MAR-school hypotheses (Glaeser et al., 1992; Jacobs, 1969; Porter, 1990) concerning the nature of clustering against each other. They take the existence of spillovers as given and only attempt to determine their nature as intra- versus inter-industry (MAR and Porter vs. Jacobs) and pro- or anti-competition (Porter vs. MAR). Similarly, the work regarding clustered firms´ propensity to innovate assumes the existence of spillovers and merely shows that innovative success is correlated with co-location. All of their findings are consistent with the sketch of an alternative market-based story as outlined above: Clustering facilitates growth-enhancing knowledge exchanges and is more effective at doing so the more complementary the knowledge exchanged.

Now turn to point 5 of the above empirical findings. As discussed in section 3.1.3 New Growth Theory uses LKS as a rationalisation for increasing returns dynamics, which can help explain the sustained differences in the growth of regions. It is clear, however, that due to the properties of cumulativeness and non-rivalry of knowledge discussed in the above example, it is not necessary for the existence of external scale economies that the respective knowledge flows are spilt over, i.e. not internalised in a market for knowledge. What is important to explain clustering is that such knowledge flows, even if market-mediated, are restricted to the region under scrutiny, i.e. that they are local. If this is the case, dynamic increasing returns due to the non-rivalry of knowledge will result from the stronger and faster accumulation of knowledge in local players who – standing on each others´ shoulders – will be able to invent and accumulate knowledge better than isolated competitors who find it harder to trade and complement their own knowledge with the knowledge of selected partners. As long as proximity can be shown to be a facilitator for the knowledge market, externalities are not necessary.

Similarly, the stronger clustering of more innovative activity in point 6 is reconcilable with the market-based alternative to the LKS story. Given that trust is built up and information (e.g., about trading partners) diffuses more easily locally, this favours the co-location of firms. If secondly, the ability to participate in the knowledge market is more important the more innovative the type of activity the agents are involved in, Audretsch and Feldman´s (1996) result of a higher propensity to cluster of more innovative activity is what should be expected.

With regard to point 7 concerning the localised nature of patent citations, two points have to be made. Firstly, while localised patent citations have been found to be significant, the effects were generally found to be small (Jaffe et al., 1993). Secondly and more importantly, there is a logical inconsistency in citing this empirical finding in support of the LKS story for tacit knowledge.

By definition, the knowledge published in the patent is codifiable and not tacit. Otherwise it could not have been patented. Hence, only the codifiable knowledge under the patent can spill without further assistance from the patent-holder. In this case, though, why should diffusion be local? The standard LKS argument explicitly only applies to tacit knowledge. It seems here that on the one hand search costs might play a role, which are increasing in geographical distance to the patent-holder. In other words, patent citations are local because information about the existence and content of the patent is more easily gathered locally. On the other hand, it might be that patent citations go alongside and complementary with the type of market-mediated knowledge exchanges described above (Arora, 1995; Jensen and Thursby, 2001). This logical inconsistency seems to go unnoticed in the relevant literature, for instance when Verspagen and Schoenmakers (2000, p. 17) interpret their finding of stronger patent citations with smaller distance to the patent holder as follows: "Building on the existing literature, we attribute this to the tacit nature of techno-

logical knowledge, which implies that personal contact is important in transferring spillovers." [16]

In summary, the point that emerges from this critical review of the empirical literature cited in support of LKS is that the design of these studies does not allow to differentiate between a market-based and the LKS story. Hence, they cannot rule out the hypothesis that such knowledge flows do not constitute externalities. Overall, therefore, the discussion in this section has led to the conclusion that the concept of LKS is sufficiently problematic in the light of both, theoretical arguments and empirical evidence, to justify a much more critical view of their importance. This alone provides ample motivation for the development of a theoretical alternative in the form of a model of knowledge trading. The argument put forward in the next section further strengthens this case.

3.3 Excludability and tradability

3.3.1 "Tacitness" implies excludability of knowledge

In addition to the theoretical and empirical difficulties with the concept of LKS discussed so far, there is a further fundamental critique of the LKS story due to a conceptual inconsistency regarding the role of tacitness. Breschi and Lissoni

[16] An interesting alternative interpretation of the patent system would be to view knowledge spillovers due to publication under the patent system as public-to-private rather than private-to-private knowledge flows. The government "buys" publication of the knowledge under the patent and pays the innovator with patent protection. Afterwards it intentionally diffuses the knowledge free of charge.

(2001b) criticise the notion of knowledge "tacitness" as conceptually weak on the grounds that in their view even tacit knowledge can be codified if agents decide to invest sufficient effort into designing respective "codebooks", which can be shared with a selected group of agents. The exchange and communication of tacit knowledge then happens within "epistemic communities", i.e. a group of insiders to the special vocabulary and language of the respective subject, which might be developed in networks of firms. From this point of view what is important is not geographical co-location but membership of the same epistemic community, and the reason to collocate is not to access a common knowledge pool created by spillovers but to minimise transaction costs for network firms.

Breschi and Lissoni´s suggestion amounts to a re-definition of "tacitness" and a proposition of an alternative in their view more useful conceptual framework. Here it is argued, however, that there is a further conceptual problem with the notion of "tacitness" in the LKS story, which has not yet been dealt with in the literature. Moreover, this critique is valid even when accepting the common definition of tacit knowledge as uncodifiable and exchangeable only through personal contact. This has consequential implications for the widespread assumption of non-excludability of knowledge which led previous authors to treat knowledge flows as spillovers in the first place and thereby goes to the core of the LKS argument.

The inconsistency arises in the following: The property of tacitness is used to argue that knowledge flows are regionally bounded because of the importance of a personal exchange between sender and receiver. Yet at the same time the consequences of this view with respect to the ability of the sender to control the know-

ledge transfer are ignored. The latter could, it seems, make a transfer of tacit knowledge impossible, for instance by simply not participating in the required contact. Hence, while acknowledging that tacit knowledge is in principle packagable as and hence transferable via information or personal meetings (for instance by imitation or supervised training), it follows from the very definition of tacit knowledge that its transfer can be prevented by and is hence excludable for its sender.

Tacit knowledge should therefore not be expected to spill over between firms for the same reasons which are usually brought forward to argue that it does not flow easily across large distances: The effort and time involved in transferring it are too large. This effort will not normally be made casually and requires a significant involvement and hence an intention on behalf of the sender.[17] What is "spilt over" instead via casual or informal social contacts is information about knowledge rather than knowledge itself.

The view of tacit knowledge transfers as controlled by the sender proposed here finds empirical support for instance in Collins (1974) who found that scientists

[17] With regard to knowledge exchanges initiating from the public sector, for instance from universities to companies, the intention involved in knowledge diffusion is striking. Agents of the public sector (e.g., university researchers) often have an interest in disseminating their knowledge (e.g., publication advances career development), so that the knowledge transfer happens with the intention of the sender. This is consistent with the view proposed here. Such knowledge flows were found to be significant in several studies (Ács et al., 1992, 1994; Adams, 2001; Audretsch and Stephan, 1996; Jaffe, 1989; Jaffe et al., 1993; Zucker et al., 1998a).

were unable to build a TEA laser[18] without speaking directly to a member of the original research team, even after publication of the relevant research results. While in this case it is clear that the scientists, who already affected the publication of their work had the intention of diffusing their knowledge, it is also clear that had this not been their intention, it would have been possible for them to exclude outsiders simply by refusing to answer the questions put to them. It is a particularly strong point for the connection between tacitness and excludability that the scientists had this option even after publication of the codifiable part of their knowledge.

Further support for the proposition that the transfer of tacit knowledge is not easily achieved through casual contacts and without an underlying intention is presented by Levin et al. (1987, table 6, p. 806). In their survey of high-level R&D executives they find that the category "conversations with employees of innovating firm" was rated the least effective of alternative methods of learning about new processes and products when compared with the following methods: "licensing technology", "patent disclosures", "publications or technical meetings", "hiring R&D employees from innovating firm", "reverse engineering of product" and "independent R&D".

The key result for a consistent approach to the notion of tacitness, therefore, is the high degree of the sender´s control over the knowledge flow. By requiring his

[18] "TEA laser" stands short for "Transversely Excited Atmospheric Pressure CO2 laser".

involvement for its transfer, tacit knowledge should be seen as excludable rather than non-excludable as is customary in the literature.

3.3.2 Control over knowledge diffusion: a condition for tradability

Some reflection reveals that the excludability of knowledge, which was derived in the previous section for the case of tacit knowledge, is a sufficient condition for the knowledge sender to prevent the spillover of tacit knowledge to another agent. It is, however, only a necessary and not a sufficient condition for the tradability of the knowledge in question. [19] In this section, it will be shown that the key issue for the latter is the degree of the sender´s control over the knowledge´s diffusion after he passed it on to other agents. A seller is said to be in control of the diffusion process, if he has the ability to oblige other firms to not pass the knowledge in question on to other agents or to do so only with his consent.[20]

Consider the impact of the degree of the sender´s control over the diffusion process on its ability to extract a positive price for it. If the original knowledge seller

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[19] In chapter 8 it is shown that whether a knowledge flow constitutes a spillover for the receiver and whether it is appropriable for its owner are two separate questions. Whether or not a knowledge flow constitutes a spillover, which is the question of interest in this chapter, is determined from the perspective of the knowledge receiver.

[20] Note that it is not exclusivity of use that is required in order to have control over knowledge diffusion. It is for instance conceivable that certain knowledge is used by several agents, yet for only one of them to be able to pass it on to other agents. A possible reason for such a situation can be effective contractual obligations of all but one firm forfeiting the right to pass on the knowledge in question. If such contractual arrangements were possible and enforceable, the sender would be said to have control over the diffusion process in the definition of the phrase employed here.

cannot control the diffusion process, then each buyer of this knowledge also becomes a potential seller of it. Consequently, after the first sale, the original seller of the knowledge would find himself in Bertrand competition with the agents who already bought the knowledge of him. The classical result is that the price attainable for the seller will be equal to the marginal cost of the knowledge transfer. The immediate marginal cost of the transfer for any agent is equal to the reduction in innovation rent in the output market due to the increase in the number of agents in possession of the new knowledge in question (see section 2.2.4). To simplify the illustration of the point consider the case where this marginal cost is equal for all agents currently in possession of the knowledge in question. Furthermore, assume that the marginal benefit from acquiring this knowledge is bigger than this marginal cost for at least one agent not currently in its possession. Now, if one firm sells its knowledge to this agent, the marginal cost will occur for each of the firms in possession of the new knowledge in question, while only the seller, i.e. the firm that wins the bidding competition in the Bertrand game, will be compensated through the acquisition price. Therefore, each firm knows that (1) the trade will take place (because the marginal benefit for the buyer is larger than the marginal cost for the seller) and that hence it will incur the marginal cost of one further agent´s use of the knowledge concerned regardless of whether it wins or loses the bidding competition, and that (2) the alternative to winning the bidding competition is zero compensation. It follows from this that the marginal cost is considered a sunk cost in the price game because the seller knows it will be incurred in any case. It is consequently rational for a current knowledge holder to offer to sell his knowledge at a price below his marginal cost in order to attract at least some compensation. Therefore, the classical

result will not hold and the agents currently in possession of the knowledge in question will undercut each other in the Bertrand game until they reach a price of zero.

This result is not dependent on the assumption of identical marginal costs of all current knowledge holders. If marginal costs varied, each agent would still know that it will be incurred for sure as long as the highest marginal benefit from acquiring the knowledge concerned of all the firms not already in possession of the new knowledge is higher than the lowest marginal cost of selling it of all firms already in possession of the knowledge in question.

Accordingly, the diffusion process will continue at a price of zero until the highest marginal benefit from acquiring the knowledge concerned of all the firms not already in possession of the new knowledge is lower than the lowest marginal cost of selling it of all firms already in possession of the new knowledge in question. Note that this might not be the case for any market structure, in which a positive number of firms is excluded from the knowledge. In this case, the diffusion process will not stop until each and every firm has acquired the knowledge at a price of zero.

It follows from this discussion that if the seller cannot control the further diffusion of his knowledge, then he will not be able to sell it at a positive price. At the same time, it is clear from section 2.2.4 that sharing his knowledge with another agent will reduce the innovation rent the seller is able to realise in the output market. Consequently, he has nothing to gain but innovation rents to loose from passing on his knowledge. Therefore, the profit-maximising firm will keep its tacit knowledge to itself, if it has no control over the diffusion process. If, on the other hand, the

knowledge seller can control the diffusion of his knowledge, he can appropriate its value by acting as a profit-maximising monopolist. The resulting knowledge flow will hence not be free for its receivers. Instead the knowledge sender will be able to sell his knowledge to the number of agents and at the price of his choice, exercising monopoly power to extract potentially significant rents in the process.

The degree of control over the diffusion of knowledge in the sense introduced here therefore determines the tradability of knowledge for both, tacit and codifiable knowledge. As such, it identifies an important variation in the potential appropriation channels for different types of knowledge. Without control over the diffusion process, knowledge can only be appropriated through its owner´s output.[21] If the sender can control the diffusion of knowledge, however, this allows the additional appropriation channel of selling it to another agent.

In the case of patentable knowledge, which by definition is required to be codifiable, control over the diffusion process can theoretically be achieved through patent protection. This allows a firm to either exclude other firms from using its patented knowledge completely or to license its patented knowledge to some firms while excluding other, non-licensee firms from its use. The extent to which the patent-holder can effectively control the diffusion process, however, is largely dependent on the enforceability of his rights under the patent. In practice, various restric-

[21] Even appropriation of knowledge through own output will yield non-zero returns only to the extent that the diffusion process is not complete, i.e. that some market power is preserved for the firms in possession of the new knowledge in question.

tions limit the effective control over the diffusion process enjoyed by the patent-holder. Examples are the often large costs associated with legal efforts to enforce a patent, fear of retaliation by competitors with claims of alleged infringements of their own patent rights, and the fact that patents are only enforceable in the jurisdiction that grants them (i.e. a US American patent cannot be enforced in China). Similarly, with regard to tacit knowledge, the main determinants of the extent to which a firm can control knowledge diffusion lies in its rights with regard to writing, monitoring and enforcing contracts with employees and trading partners, albeit without the option to patent the knowledge concerned. It further relies on the type of exchange and the environment in which it is conducted. Repeated transactions, mutual trust and an ethical trading culture, for instance, can foster the innovator´s effective control over the diffusion process even in the absence of perfect monitoring and enforceability options.

3.4 Summary

This chapter undertook a detailed analysis of the dynamics involved in the exchange of knowledge between agents of the private sector, with particular attention to spillover arguments and conditions for tradability of knowledge. It was shown that the concept of LKS – while important in the economic debate – has several shortcomings both, from a theoretical and an empirical point of view. The chapter first gave an overview of existing criticisms of LKS in the literature. The analysis was then taken further with a one-by-one discussion of different candidate channels for LKS with special attention to the question of whether the respective knowledge

flows are likely to (1) be local and (2) constitute externalities. The result was that many channels fail to meet at least one of these requirements. In particular, for those channels which are local the hypothesis that knowledge exchanges are market-mediated cannot be ruled out on a theoretical basis. Next, it was shown that existing empirical studies do not prove but rather assume the importance of LKS and analyse their alleged consequences. Typically the line of argument is to establish an empirical phenomenon and then to claim that LKS are the only reasonable explanation for the respective finding. It was argued, however, that other market-based mechanisms are also consistent with the empirical observations. In particular, informal knowledge-trading, information externalities and the labour market emerged as alternatives to the LKS story in this context.

Finally, a new point was added to the list of critiques of the concept of LKS: LKS refers to tacit knowledge in order to argue for the regional boundedness of spillovers. However, due to the fact that by definition the transfer of tacit knowledge requires the participation of the knowledge sender, tacit knowledge should be treated as excludable rather than non-excludable. In fact, the degree of excludability rises with the degree of tacitness of the knowledge concerned. This is an important point because it undermines the argument that led scholars to treat tacit knowledge flows as spillovers for the receiver in the first place. Furthermore, it was shown that if the sender can control the diffusion process, the knowledge should be expected to be internalised in a market for knowledge exchanges.

The degree of the seller´s control over the diffusion process for codifiable knowledge will be determined by the effectiveness of patent protection, and for tacit

knowledge, which cannot be protected through patenting, it will be determined by the seller´s ability to write, monitor and enforce contracts with potential buyers. Therefore, the degree of control over knowledge diffusion is at least to some extent dependent on the legal and regulatory framework and will therefore be taken up in the discussion in chapter 8 on policy implications.

It follows from the arguments in this chapter that spillovers through casual contacts along the lines of the LKS story seem inappropriate for many types of knowledge that drive growth in advanced economies. Such knowledge is often complex, cumulative and highly dependent on its context and complementarity with specific other knowledge. Furthermore, it is often the output of proprietary R&D activity. Examples where this type of knowledge is important are found in industries like IT, biotechnology, arms, and high-tech industrial production.[22] Given the importance of knowledge transfers in economic theory and the empirical and theoretical problems with the LKS story, it seems imperative to further explore market-based mechanisms and to work towards more direct testing of the existence of LKS. By identifying knowledge excludability and control of the seller over the diffusion process as determinants of knowledge tradability this chapter made an important step in this direction. Based on this, the following chapters go on to develop a benchmark model of knowledge trading. This will then allow the analysis of the drivers, dynam-

[22] von Hippel (1994) also uses the term "sticky knowledge" for such "high context, uncertain knowledge".

ics and implications of exchanges of knowledge in a market as an alternative to the spillover story.

4 Vector representation of knowledge

Building a model of knowledge trading requires the ability to capture knowledge as an economic variable. Due to the special characteristics that distinguish knowledge from other economic inputs and outputs as set out in chapter 2, this cannot be accomplished in a simple one-dimensional way. In a first step towards building a model of knowledge trading, it is therefore imperative to devise a methodology that captures the special properties of knowledge in economic activity. Based on this, chapter 5 will proceed to develop a model of knowledge production and trading, which illustrates how the special characteristics of knowledge, which went unnoticed in previous attempts at modelling innovative activity, turn out to be important drivers in knowledge economics.

So far models of innovative production have failed to take the knowledge-specific properties discussed in chapter 2 into account. In particular, existing models fail to capture jointly the importance of complementarity, cumulativeness, and uncertainty. For instance, Klette and Kortum (2004) explicitly take into account the importance of uncertainty, but their model fails to capture complementarity. In their model, an invention adds the same amount to any firm´s "knowledge capital" regardless of how related it is to the firm´s current activities.[23]

[23] Cobb-Douglas type innovative production functions suffer from the same limitation (Klette, 1996).

Therefore, in this section, a new method for modelling knowledge is developed to adequately capture the special properties of knowledge and of innovative production. Building on the distinction between the potential innovative input and the effective innovative input of knowledge introduced in section 2.2.2, it is proposed to model knowledge as a vector characterised by a length, i.e. a scalar which reflects its potential innovative input, and a relative direction, i.e. an angle which reflects its complementarity with other knowledge. The potential innovative input of any new knowledge and its complementarity with the firm´s existing knowledge together then determine the effective innovative input of new knowledge for any particular firm.

This type of representation allows to deal with the conceptual problem which results from the importance of cumulativeness of knowledge. It does so by affording the ability to model the outcome of the combination of two sets of knowledge. With a one-dimensional variable this was impossible to accomplish because of the importance of complementarity. The latter means that additivity does not hold for knowledge in a one-dimensional sense. The increase in effective knowledge due to any new knowledge is dependent on its degree of complementarity with already existing knowledge.

4.1 Methodology

Let $f_t^i : \mathbb{R} \rightarrow \mathbb{R} \times \left(0^\circ, 360^\circ\right)$ be the knowledge production technology for firm i in period t such that

$$f_t^i : r_t^i \rightarrow \left\| \vec{n}_t^i \right\|, \beta\left(\vec{n}_t^i\right) \tag{1}$$

where r_t^i is a scalar denoting i´s R&D expenditure in period t. $\vec{n}_t^i$ is the vector of new knowledge, where the lower index denotes the time period in which it was produced and the upper index denotes the firm that produced it. Accordingly, $\left\| \vec{n}_t^i \right\|$ is modelled as the Euclidean norm of $\vec{n}_t^i$ and a known continuous function $g_t^i : \mathbb{R} \rightarrow \mathbb{R}$ of r_t^i,

$$\left\| \vec{n}_t^i \right\| = g_t^i(r_t^i) \tag{2}$$

with $g_t^{i'} > 0$, $g_t^{i''} < 0$. Furthermore, it is assumed that g_t^i satisfies the Inada conditions for all t and all i, which require that $g_t^i(0) = 0$, $g_t^{i'}(0) = \infty$, and $g_t^{i'}(\infty) = 0$.[24] The interpretation of the scalar $\left\| \vec{n}_t^i \right\|$ is that it denotes the length and hence the potential innovative input of $\vec{n}_t^i$.

$\beta\left(\vec{n}_t^i\right) \in (0°, 360°)$ is the basis for evaluating the relative direction and hence complementarity of $\vec{n}_t^i$. It is modelled as a random variable following a known probability distribution denoting the direction of $\vec{n}_t^i$.

[24] Primed functions indicate first derivatives.

Hence, according to f_t^i a firm can plan the amount of knowledge it produces with certainty, but it cannot know what it will discover beforehand and will therefore not be able to predict with certainty the complementarity of new knowledge with its existing knowledge. Modelling $\beta\left(\vec{n}_t^i\right)$ as a random variable with a known probability distribution allows to operationalise the notion of uncertainty in innovative activity. Furthermore, note that from the specification of the knowledge production technology it follows that there are decreasing returns to scale in the production activities of the innovative firm.

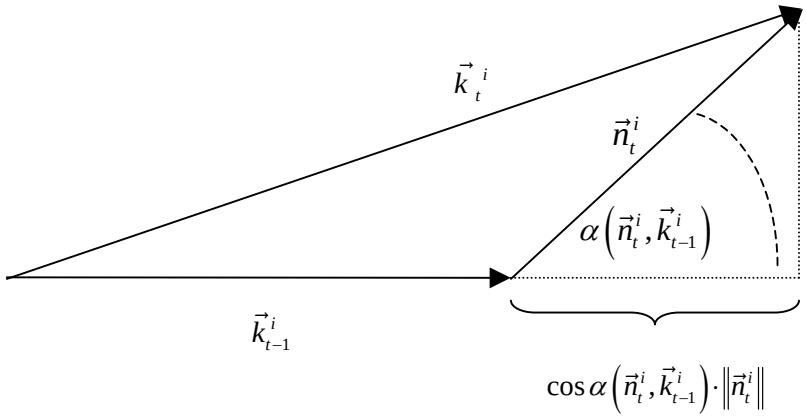
Knowledge accumulation can be captured with this methodology for instance with the help of simple vector addition:

$$\vec{k}_t^i = \vec{k}_{t-1}^i + \vec{n}_t^i \tag{3}$$

where $\vec{k}_t^i$ is the total knowledge vector of firm i in period t, which results from adding period t´s new knowledge, $\vec{n}_t^i$, to the inherited knowledge vector from the previous period, $\vec{k}_{t-1}^i$. As a measure of the difference in direction between two knowledge vectors, $\vec{v}$ and $\vec{w}$, define $\alpha\left(\vec{v},\vec{w}\right) \in \left(0°,180°\right)$ as the (smallest) difference between $\beta\left(\vec{v}\right)$ and $\beta\left(\vec{w}\right)$. As an inverse index of complementarity, $\alpha\left(\vec{n}_t^j,\vec{k}_{t-1}^i\right)$ is an important determinant of the effective innovative input of new knowledge, i.e. of how much of the knowledge´s potential innovative input a particular firm can realise.

Figure 1 illustrates an example of how vector representation can be employed to capture cumulativeness and complementarity of knowledge.

Figure 1: Cumulativeness and complementarity with vector representation



$\vec{k}_t^{\,i} = \vec{k}_{t-1}^{\,i} + \vec{n}_t^{\,i}$, and

$$\left\|\vec{k}_t^{\,i}\right\| = \sqrt{\left\|\vec{k}_{t-1}^{\,i}\right\|^2 + 2\cdot\left\|\vec{k}_{t-1}^{\,i}\right\|\cdot\left\|\vec{n}_t^{\,i}\right\|\cdot\cos\alpha(\vec{n}_t^{\,i}, \vec{k}_{t-1}^{\,i}) + \left\|\vec{n}_t^{\,i}\right\|^2} \le \left\|\vec{k}_{t-1}^{\,i}\right\| + \left\|\vec{n}_t^{\,i}\right\|.$$

Source: own design

As the defining asset of an innovative firm, one can think of $\vec{k}_{t-1}^{\,i}$ as a proxy for its inherited competences and organisation. The knowledge accumulation process above then reflects the evolution of the firm over time.

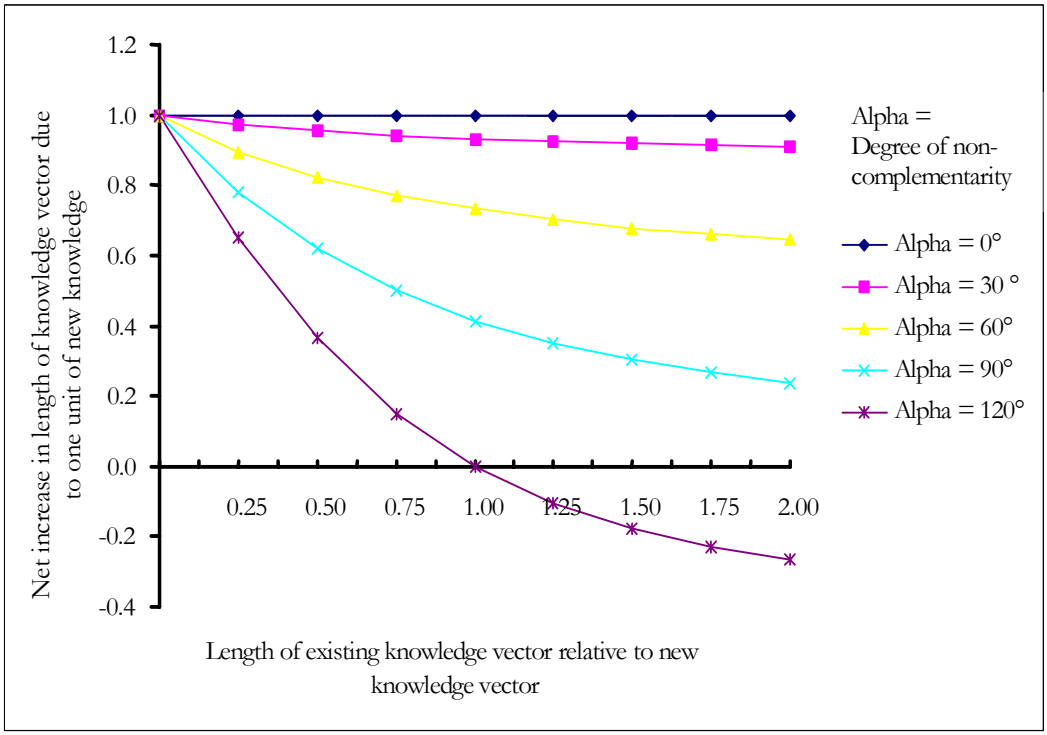
It follows from the specification of the knowledge accumulation process that the contribution of new knowledge to the growth of the stock of existing knowledge of a new firm is the full modulus of the knowledge vector.[25] It will be less than the full modulus of the new knowledge vector, however, for a firm that already has exist-

[25] If a firm is "new", the stock of existing knowledge it used in previous periods is zero by definition.

ing knowledge, if there is less than full complementarity between new and existing knowledge. This has an intuitive interpretation: The start-up firm that produces new knowledge can structure its whole activities around the economic exploitation of this knowledge. In fact, the new knowledge vector becomes the defining element for the business of the start-up. If instead an established firm comes across the same new knowledge, the situation will be different. The internal organisation as well as the marketing and sales apparatus or an established brand name are already geared towards the exploitation of the firm´s existing total knowledge. While having an impact on the direction of the established firm´s knowledge stock, the new knowledge is naturally partially forced into the firm´s existing operations and regarded in the context of its current expertise and product portfolio. Note that the new knowledge will cause a smaller change in orientation (as modelled by the change in direction of the resulting updated total knowledge vector) the larger the existing stock of knowledge of the company. Hence, complementarity becomes more important for the contribution of new knowledge to a firm´s innovative progress the more established an organisation already is in a certain field.

Accordingly, one can see from Figure 2 that the marginal product for a firm i of an extra unit of complementarity for a given vector of new knowledge is increasing in $\left\|\vec{k}_{t-1}^{\,i}\right\|$. This is the case because the larger last period´ s knowledge vector, the smaller the contribution of any new knowledge vector for a given degree of non-complementarity towards increasing the length of the firm´s total knowledge vector.

Figure 2: Impact of new knowledge as a function of complementarity and existing knowledge



Source: own design

Consider a simple numerical example for illustration: If last period´ s knowledge vector had a length of 100, the contribution of a new knowledge vector of length 2 with a degree of complementarity of $\alpha\left(\vec{n}_t^i, \vec{k}_{t-1}^i\right) = 90^0$ would be approximately 0.02. However, if last period´s knowledge vector had a length of 1000, the contribution of the new knowledge vector of length 2 would only be 0.002. Note, however, that if the new knowledge had been fully complementary, i.e. $\alpha\left(\vec{n}_t^i, \vec{k}_{t-1}^i\right) = 0^0$, its contribution would have been equal to 2 regardless of the length of the existing knowledge vector. Hence, the same degree of uncertainty is more

expensive for the larger firm. It follows that larger firms have a higher willingness to pay for complementarity and certainty than smaller firms. For any given degree of complementarity, a firm with a larger stock of existing knowledge has more to gain from a change to full complementarity. It also follows that for a given level of expected complementarity the expected future knowledge increase through new knowledge vectors is smaller the larger the existing knowledge stock of the firm. Therefore, the amount of old knowledge accumulated by a firm in previous periods is the third and final determinant of the effective innovative input of new knowledge to any particular agent, in addition to its potential innovative input and its degree of complementarity with already existing knowledge, which were discussed above.

The dynamics captured in Figure 2, and especially the idea that expected future knowledge increases through new knowledge vectors are smaller the larger the existing knowledge stock of a firm today, amount to the statement that efficiency in the exploitation of new knowledge in the current period is decreasing with the amount of knowledge used by the firm in previous periods. This phenomenon is consistent with and captures analytically some important notions, which are well established in the literature. An example is the work of Henderson (1993), who finds that new firms are more likely to commercialise radical innovations. Furthermore, it is consistent with the ideas of Imai et al. (1986) and Demsetz (1988), who show that it is difficult to "unlearn" knowledge and processes of the past, even when it is obvious that they hinder current and future success in innovation. It also captures the potential impact of growing bureaucratic inertia discussed for instance by Eliasson (1996) and the notion of "trajectory-specific lock-ins" as a consequence of previous success

and outdated experiences as discussed by David (1985) and Arthur (1989). In the remainder of this work, this phenomenon will be referred to as the "efficiency effect".

It has to be born in mind though that this efficiency effect will work independently of and alongside with "standing on the shoulders of giants", "cross-fertilisation" and learning effects which state that the productivity in new knowledge production is increasing with the amount of knowledge used in the past. This shall be called the "productivity effect" of the firm´s stock of existing knowledge.

The overall effect of the amount of old knowledge accumulated by a firm on its current and future innovative success depends on whether the efficiency or the productivity effect dominates and hence remains ambiguous. These considerations provide a theoretical framework for the empirical observation that at least in some industries small firms are responsible for a large share of innovative output. In terms of the model and terminology developed here, this is the case when the efficiency effect outweighs the productivity effect.

4.2 Significance of vector representation

From the preceding discussion it has become clear that with vector representation it is possible to capture the importance of cumulativeness, complementarity and uncertainty of knowledge without loosing any of the advantages of one-dimensional modelling with regard to tractability and the ability to operationalise via functional specification. Therefore, vector representation is a powerful analytical tool to model

knowledge more accurately and consistently, which has so far not been explored in the literature.

To employ this methodology for future research is useful for at least two reasons: The first is that the inherent properties of knowledge might be drivers of dynamics which – for lack of alternative explanations – have been interpreted as caused by other forces. An example, which will be discussed in more depth in chapter 7, is the role of knowledge spillovers as an explanation for clustering of innovative activity. The second reason is that inferences from any model involving knowledge as input or output and not taking into account its special characteristics (for instance by adopting the usual one-dimensional modelling approach) must be interpreted with caution. The potential sensitivity of results with regard to the left out properties needs to be tested. Revisiting the debate in knowledge economics with the methodology developed here therefore promises to be an interesting road to take for future work.

5 A model of knowledge production and trading

5.1 Model set-up

Building on the discussion in section 3, the analysis in this chapter is restricted to the production and transfer of knowledge for which the producer can control the diffusion process even after he has shared it with other agents. The implications of a break-down in this assumption are discussed in Chapter 6. Its welfare and policy implications are evaluated in chapter 8.

5.1.1 Market structure and innovation rents

Due to the property of non-rivalry of knowledge, a sale of a piece of knowledge to another agent will leave the knowledge in question in the possession of the seller and all buyers. The seller might decide to either not sell his knowledge to anyone and use it exclusively, to sell his knowledge to one or more agents and keep using the knowledge himself, or to sell the knowledge to one or more agents and commit to not using the knowledge himself. In other words, as part of his profit maximising choice of who to sell the knowledge to, the seller will choose the post-trade market structure for appropriation through own output.

Hence, after the sale there might be more than one agent who appropriates the value of the new knowledge in question through his own output. Therefore, with regard to the extraction of innovation rents as discussed in section 2.2.4 the market structure might change from a monopolistic to an oligopolistic one. In case of an oligopolistic market structure, innovation rents would be diminished as a conse-

quence of increased competition. The results from classical oligopoly theory, however, are not one-to-one transferable to the case under discussion here because as set out in section 2.2 and chapter 4, the same new knowledge will be of different value to different agents, whose vectors of existing knowledge differ. Hence, the ensuing competition in the output market will not be between homogeneous products. The statement that competition will decrease rents in the output market the more agents have possession of a particular piece of knowledge is nonetheless justified. The theoretical basis for this can be found in the literature on horizontal product differentiation (D´Aspremont et al., 1979; Hotelling, 1929). Sharing possession of a piece of new knowledge with another agent will decrease the degree of differentiation of the heterogeneous products of the competitors in the output market and thereby decrease the realisable price mark-up. The extent of the decrease in innovation rents appropriable through own output depends on the shape of the demand function, the number of agents in possession of the new knowledge and the type of competition in the output market.

An important consequence of these considerations is that the contract with each buyer will have to be written contingent on the number of other agents the knowledge will be used by because the size of rents realisable by the knowledge buyer depends on the degree of market power conferred upon him, which is a function of the number of agents in possession of the respective knowledge.

5.1.2 The information structure

In this chapter, the assumption of perfect information is employed to develop a benchmark version of the model. The model will be extended to the imperfect information case in chapter 7.

Note that perfect information is to be distinguished from perfect foresight. Due to uncertainty about future states of the world, agents are still required to form expectations of the future and do not know which states will be realised, which would be required under the assumption of perfect foresight. The model therefore explicitly does not assume perfect foresight. In fact, given the above exposition of the uncertainty inherently involved in the knowledge production technology, any such assumption would be inconsistent with the nature of knowledge economics. Instead, each firm i will form expectations on the basis of its available information set in the current period t, which from now on shall be denoted by Ω_t^i. The assumption of perfect information means that each firm has all available information at time t and knows the true model of the world. This entails that each firm knows the probability distribution of random variables to be realised in the future.

Firm i´s expectations of the realisation of variable x in future period k given its information set in period t shall be denoted as $E\left(x_k\right)\left|\Omega_t^i\right.$. From now on $E_t^i x_k$

will be used as a shorthand for this expression. For the case of perfect information of all agents, however, $\Omega_t^i = \Omega_t^j$ holds by definition, and hence, $E_t^i x_k = E_t^j x_k$.[26]

5.1.3 The innovative firm

An innovative firm is defined as an organisation that produces and sells innovative products. A product is "innovative" in the sense of the word employed here, if it required the input of new knowledge for its production. This is based on the Schumpeterian view of what constitutes an innovation comprising not only new goods and services but also any novel contributions to re-designing or otherwise improving existing products and processes or accessing new markets (Schumpeter, 1934). The market for innovative products is also referred to as the output market.

Knowledge is treated as "new", and hence qualifies as an input for the production of an innovative product only for the period of its invention. It is termed "old" from the period after its invention onwards. One period of time in this context is best viewed as the life cycle of an innovative product rather than one calendar year. There are two options for a firm to get hold of new knowledge in this model: It can either be produced by the firm through own R&D expenditure, which yields new knowledge according to the knowledge production technology at the firm´s disposal as specified in section 4.1, or it can be acquired from another firm.

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[26] It follows from this that the superscript on the expectations operator for the development of the perfect information scenario could be dropped. This is not done here, however, in order to improve tractability of the argument for the later extension to the imperfect information case.

5.1.4 Demand in the market for innovative products

This work is primarily interested in the dynamics of knowledge production and knowledge trading, not in the market for innovative products, which is the output market of the innovative process. Knowledge trading from this perspective has to be seen as a market for intermediates. Nonetheless, it is necessary to specify the basic properties of the output market as it indirectly determines the revenues that can be realised from the production, sale and purchase of new knowledge.

The demand for any output produced exclusively with the input of old knowledge is assumed to be zero.[27] On the other hand, the demand for any innovative product, i.e. a product which is produced with the input of both, new and old knowledge or new knowledge only, is assumed to be positive and of the usual shape with the quantity demanded a decreasing function of the price.[28]

Given that the products of different firms are produced with the input of at least partially different knowledge vectors, they cannot be treated as homogeneous. Instead, there are heterogeneous products with varying degrees of substitutability on the output market:

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[27] This assumption is primarily made to focus the analysis on innovative products. Apart from its usefulness for simplification, however, it is not necessarily unrealistic given the broad definition of what constitutes an innovative product employed here.

[28] Note that the assumption of positive demand for innovative products does not mean that it is always possible for a firm to satisfy this demand in a profitable manner. Hence, even if the demand for some exotic innovative product is non-zero, it might not be produced because a profit-maximising agent would prefer to not do so.

1. Innovative products that were produced with the exact same new knowledge vector on the exact same existing knowledge vector are perfect substitutes.

2. Innovative products that share a certain knowledge vector as an input are partial substitutes.

3. The degree of substitutability of innovative products depends on (and is rising with) the amount of knowledge they share as inputs for their production.

A functional specification of the demand function shall not be set out here because this is not necessary for the further arguments pursued in this work. Instead, as determinants of the revenue function the forces developed in the arguments of the previous chapters shall be used.[29]

5.1.5 The payoff structure

To the extent that it is exclusive (for instance, due to effective patent protection or secrecy), new knowledge can be valuable for its owner because it affords a protected or differentiated position in the output market. It is assumed that in each period it is the aim of the firm to maximise its expected lifetime profits.

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[29] Since any specification of a demand side would have to be chosen such that it would reproduce the effects of these forces, it would be an exercise in style rather than in substance to derive them indirectly from the functional specification of a demand function. Such a specification would furthermore entail two serious drawbacks: Firstly, a considerable loss of generality for the following arguments and secondly, a significant distraction from the supply side considerations relating to innovative activity which are the focus of this analysis.

The profit of the innovative firm at time t can be expressed with the help of the following general formulation of a payoff function:

$$\Pi_t^i = R_t^i - e_t^i \tag{4}$$

where R_t^i is the revenue firm i can realise by commercially exploiting its new knowledge and e_t^i is the expenditure of the firm, both in period t. e_t^i comprises the expenditures on own knowledge production (i.e. R&D), r_t^i, and its expenditure on acquiring other firms new knowledge, KA_t^i:

$$e_t^i = r_t^i + KA_t^i \tag{5}$$

The expenditure on acquiring other firms´ new knowledge, KA_t^i, can formally be captured as

$$KA_t^i = \sum_{\forall j:\vec{n}_t^j \in N_t^i \wedge j \neq i} P_t^{ij} \tag{6}$$

where P_t^{ij} denotes the non-negative price at which firm i purchases $\vec{n}_t^j$, and N_t^i is the set of all new knowledge vectors in period t, which either through own R&D or purchases from other firms are in the possession of agent i,

$$N_t^i = \left\{ \vec{n}_t^j \,\middle|\, \left(\vec{n}_t^j \,..is..in..the..possession..of\,..i \right) \right\} \tag{7}$$

The total revenue from commercial exploitation of $\vec{n}_t^j$, which is captured by R_t^i, comprises two different types of revenue, one from appropriation of new

knowledge through own output, which shall be denoted by Q_t^i, the other from the sale of the firm´s knowledge output to other firms, which shall be called KS_t^i. It can therefore be expressed with the general formulation of

$$R_t^i = Q_t^i + KS_t^i \tag{8}$$

The first term on the right hand side of equation (8) therefore captures revenues from appropriation of all new knowledge vectors in the firm´s possession:

$$Q_t^i = \sum_{\forall \vec{n}_t^j \in N_t^i} Q_t^i\left(\vec{n}_t^j\right)\Big| m_t \tag{9}$$

Accordingly, $Q_t^i\left(\vec{n}_t^j\right)\Big| m_t$ denotes firm i´s revenue in period t from appropriation through own output of a new knowledge vector produced by firm j in period t in a given post-trade market structure, m_t. The mention of "post-trade" market structure here indicates that it is the market structure after all knowledge trades are conducted, which is of relevance. In the following, $l_t\left(\vec{n}_t^j\right)$ will be used as a count variable of the number of agents in possession of the new knowledge vector $\vec{n}_t^j$. (To simplify the notation, l_t is employed instead of $l_t\left(\vec{n}_t^j\right)$ unless the latter notation is of

importance to the argument). Hence, $l_t = 1$ denotes the case of a knowledge monopoly, and market concentration is decreasing in l_t.[30]

In order to further specify $Q_t^i\left(\vec{n}_t^{\,j}\right)\middle| m_t$, it is useful based on the considerations in chapters 2 and 4 to formalise the concept of the effective innovative input value of new knowledge for firm i, denoted by $ev_{\vec{n}_t^{\,j}}^i$, as follows:

$$ev_{\vec{n}_t^{\,j}}^i = y\left[\alpha\left(\vec{n}_t^{\,j}, \vec{k}_{t-1}^{\,i}\right), \left\|\vec{n}_t^{\,j}\right\|, \left\|\vec{k}_{t-1}^{\,j}\right\|\right] \tag{10}$$

In accordance with the considerations in chapter 4, function y is monotonically decreasing in $\alpha\left(\vec{n}_t^{\,j}, \vec{k}_{t-1}^{\,i}\right)$ and $\left\|\vec{k}_{t-1}^{\,j}\right\|$ and monotonically increasing in $\left\|\vec{n}_t^{\,j}\right\|$. Furthermore, it is assumed to be continuously differentiable. $Q_t^i\left(\vec{n}_t^{\,j}\right)\middle| m_t$ can now be expressed as follows:

$$Q_t^i\left(\vec{n}_t^{\,j}\right)\middle| m_t = \max\left[h\left(ev_{\vec{n}_t^{\,j}}^i\right)\middle| m_t, 0\right] \tag{11}$$

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[30] The number of firms l_t is only one of the characteristics and hence an incomplete specification of the market structure m_t. Further characteristics are the relative size and the vectors of existing knowledge of the other players in the market. These could lead to significant differences in the revenue functions in different market structures even with the identical number of different agents in possession of the knowledge in question. Due to the fact that this distinction is not essential for the points to come, however, its inclusion in the notation is dispensed with to make the arguments more tractable.

The function h in equation (11) is assumed to be continuously differentiable and monotonically increasing in $ev^{i}_{\vec{n}_t^{\,j}}$ because it is known that the innovative firm´s revenues from appropriation through own output are increasing in the effective innovative input of its new knowledge.[31] The notation adopted in equations (10) and (11) allows the distinction between supply side effects related to the integration and use of the new knowledge vector on the side of the firm on the one hand, and the impact on revenues due to demand conditions on the other hand. Function y captures the former, while function h captures the latter.

Note in equation (11) that the revenue function will be contingent on the prevailing post-trade market structure with, ceteris paribus, lower revenues the more agents have possession of the new knowledge concerned, so that

$$Q_t^i\left(\vec{n}_t^{\,j}\right)\Big|\left(m_t : l_t = 1\right) \geq Q_t^i\left(\vec{n}_t^{\,j}\right)\Big|\left(m_t : l_t = 2\right) \geq \ldots \geq Q_t^i\left(\vec{n}_t^{\,j}\right)\Big|\left(m_t : l_t = \infty\right) \qquad (12)$$

Equation (11) does not allow for negative revenues from appropriation through own output of new knowledge. A possible interpretation of a situation of negative revenues would be, if a firm comes across new knowledge with very low degrees of complementarity with its existing knowledge (e.g., new knowledge which has very little to do with and might even obstruct the firm´s pursuit of its current core competences, brand or organisation). To restrict the analysis to non-negative

[31] Again, Inada conditions are assumed to hold as well as $h' > 0,\ h'' < 0$.

revenues is equivalent to assuming that firms have the option to forget new knowledge, if it would be detrimental for the company to pursue.

Turning to the second term in equation (8), as mentioned before KS_t^i captures appropriation through the sale of knowledge and hence denotes firm i´s revenue from the sale of its own knowledge to other agents. Importantly in this context, there is no price discrimination in this model. Hence, the same piece of knowledge costs the same for each agent, who succeeds in purchasing it, so that $P_t^{ij} = P_t^j, \forall i$.

There are two important points to make with regard to KS_t^i: Firstly, $KS_t^i \geq 0$ because otherwise the profit-maximising agent would not engage in the sale of his knowledge. Since the more competitive market structure resulting from a knowledge sale will decrease its revenues from appropriation through own output, KS_t^i has to be positive and large enough to compensate the knowledge producer for revenue forgone through lower $Q_t^i\left(\vec{n}_t^j\right)\Big|m_t$. Secondly, unlike $Q_t^i\left(\vec{n}_t^j\right)\Big|m_t$, total revenues from knowledge sales KS_t^i are not monotonically increasing or decreasing with decreasing market concentration. The reason is that the decrease in the price per sale might be more than compensated by the fact that there are revenues from a larger number of buyers.[32]

[32] The intuitive point that with a less concentrated market structure, i.e. more agents in possession of the new knowledge in question, the price per sale of the new knowledge will decrease is stated and proved formally in equation (29) in section 5.3.

It is clear at this stage, that the post-trade market structure is a choice variable for the knowledge producer and will be set such as to maximise his profits. Given the discussion of equation (8), it is not possible ex-ante to know which market structure maximises total revenues. This will be discussed in more detail below.

5.1.6 Entry and exit

There is free entry for anyone to engage in knowledge production, trade and innovative activity. As indicated by the indices in equations (1) and (2), however, knowledge production technologies differ across agents so that some firms might find it optimal to not engage in own R&D. The optimality conditions for the choice of r_t^i are discussed in greater detail in section 5.2.

There are two ways in this model in which a firm ceases to exist: Firstly, firms exit if their expected discounted life-time profits are negative. Hence, for any firm that stays in the market:

$$E_t^i \left\{ \sum_{k=t}^{\infty} \left(\frac{1}{(1+\delta)^{k-t}} \right) \Pi_k^i \right\} \geq 0 \tag{13}$$

where δ is the discount factor.[33] A second way in which a firm can cease to exist, which will be introduced in the next chapter, is if it is sold to another firm.

[33] For simplicity, δ is treated as constant over time.

5.2 Knowledge production

The knowledge producing agent chooses his expenditure on R&D, r_t^i, in order to maximise his current and discounted future profits. Note that current R&D activity has an impact on future revenues, if this period´s new knowledge vector is appropriated through own output (for instance in addition to selling it) due to the property of cumulativeness and the importance of complementarity. In this context, an efficiency effect and a productivity effect were identified in section 4.2 with an ambiguous overall impact.

The knowledge producer will solve the following maximisation problem contingent on the market structure to calculate $r_t^{i^*} \middle| m_t$ and $\Pi_T^i \left(r_t^{i^*} \right) \middle| m_t$:

$$\begin{cases} \max\limits_{r_t^i} \sum\limits_{k=t}^{\infty} \left(\dfrac{1}{(1+\delta)^{k-t}} \right) \cdot E_t^i \Pi_k^i \,\middle|\, m_t \\ \Leftrightarrow \max\limits_{r_t^i} \sum\limits_{k=t}^{\infty} \left(\dfrac{1}{(1+\delta)^{k-t}} \right) \cdot E_t^i \left(Q_k^i + KS_k^i - KA_k^i - r_k^i \right) \,\middle|\, m_t \\ \text{s. t. equations (2), (9), (11), } r_t^i \geq 0, \ \Pi_t^i \geq 0, \text{ and a probability distribution for the realisation of } \alpha\left(\vec{n}_t^i, \vec{k}_{t-1}^i \right) \end{cases} \tag{14}$$

For any given m_t, the function to be optimised is continuous by assumption and the feasible set is compact (i.e. closed and bounded). Therefore, by the Weierstrass Theorem a solution exists. Furthermore, the function to be optimised is as-

sumed to be concave so that the first-order condition is necessary and sufficient for an optimum.

That equation (14) is being solved contingent on the market structure is an important point because for any given demand function, the revenue function can be of a different form for each market structure. As discussed in section 5.1, with the decision whether to use the knowledge himself and whether and to how many agents to sell it to, the innovator effectively chooses the post-trade market structure for appropriation through own output of his knowledge. The choice of the level of optimal R&D expenditure will be made contingent on this decision such as to ensure the maximum attainable profit is realised. The profit-maximising agent will therefore solve the problem in equation (14) for each market structure, compare the maximum attainable profits and choose that market structure which is most profitable.

It is useful at this point to briefly stop to consider the meaning of the variable l_t as one of the defining elements of the market structure, m_t. From the perspective of the knowledge producer, there are two important characteristics of l_t: The first one is the number of agents that will use the new knowledge vector in the post-trade market structure. As discussed above, this will determine the revenue function in the output market faced by each of the agents using the new knowledge concerned (see also footnote 30). The second one is the question of whether the knowledge producer will appropriate his new knowledge through his own output in the post-trade market structure or not. This determines whether he will have revenues through both own output, Q_k^i, and knowledge sales, KS_t^i, or only through KS_t^i.

The solution to the problem of equation (14) is that in each market structure profit-maximising innovative agents will conduct R&D until the marginal benefit (MB) from doing so is equal to its marginal cost (MC). The calculation of the MC of one unit of R&D expenditure yields that it is equal to 1. Calculation of the MB, however, is complicated by the relevance of future periods. For any given market structure, m_t, the first-order condition for a maximum can be written as follows:

$$\left(\frac{\partial Q_t^i}{\partial r_t^i} + \frac{\partial KS_t^i}{\partial r_t^i} + \sum_{k=t+1}^{\infty} \frac{1}{(1+\delta)^{k-t}} \cdot \frac{\partial E_t^i Q_k^i}{\partial r_t^i} \right) \Bigg| m_t = 1 \tag{15}$$

The left-hand-side (lhs) of equation (15) denotes the MB and the right-hand-side (rhs) the MC of conducting R&D for firm i for a given market structure. The first term of the lhs of (15) is the marginal benefit from extra R&D appropriated through own output. From equations (9) and (11) one can write this as follows:

$$\frac{\partial Q_t^i}{\partial r_t^i} \Bigg| m_t \quad = \frac{\partial Q_t^i(\vec{n}_t^i)}{\partial r_t^i} \Bigg| m_t = \frac{\partial \max\left[h\left(ev_{\vec{n}_t^i}^i \right) \Big| m_t, 0 \right]}{\partial r_t^i} = \tag{16}$$

$$= \begin{cases} 0, if: h\left(ev_{\vec{n}_t^i}^i \right) \Big| m_t \le 0 \\ \dfrac{\partial g_t^i(r_t^i)}{\partial r_t^i} \cdot \dfrac{\partial y\left(\alpha(\vec{n}_t^i, \vec{k}_{t-1}^i), g_t^i(r_t^i), \left\| \vec{k}_{t-1}^i \right\| \right)}{\partial g_t^i(r_t^i)} \cdot \dfrac{\partial h\left(y\left(\alpha(\vec{n}_t^i, \vec{k}_{t-1}^i), \left\| \vec{n}_t^i \right\|, \left\| \vec{k}_{t-1}^i \right\| \right) \right)}{\partial y\left(\alpha(\vec{n}_t^i, \vec{k}_{t-1}^i), \left\| \vec{n}_t^i \right\|, \left\| \vec{k}_{t-1}^i \right\| \right)} \Bigg| m_t, else. \end{cases}$$

Each of the factors in the expressions in equation (16) is either zero or positive. Hence, it follows that $\frac{\partial Q_t^i}{\partial r_t^i} \Big| m_t \ge 0$.

The second term on the lhs is the marginal benefit from extra R&D appropriated through sale to other agents. If trading of knowledge was not possible or not chosen for some reason, then $KS_t^i = 0$ and $\frac{\partial KS_t^i}{\partial r_t^i} = 0$. It follows that

$$\left.\frac{\partial KS_t^i}{\partial r_t^i}\right| m_t \geq 0 . \tag{17}$$

The reason for this is that if the effective innovative input of the firm´s new knowledge vector is positive for a buyer, then – to the extent that this does not change the resulting new knowledge vector´s direction – increasing r_t^i will increase both, the potential innovative input and the effective innovative input of the new knowledge vector for the buyer. This can never lead to a decrease in the revenue from a knowledge sale. Hence, if a knowledge sale takes place, i.e. revenue from sales is larger than zero, for any given level of R&D expenditure, then an increase in R&D expenditure increases sales revenues.

The third term on the lhs of equation (15) can be either positive or negative, depending on whether the efficiency effect (pushing into the negative) or the productivity effect (pushing into the positive) is stronger, given the innovating firm´s resulting future vector of existing knowledge and the current state and expected evolution of its knowledge production function, g_t^i. The channel of influence captured by this term is that current period R&D increases the stock of existing knowledge, which in turn influences the inventor´s ability to produce and commercially exploit new knowledge in future periods.

An important point to note here is that it is not possible ex-ante or in general to tell which market structure is most conducive to innovative activity (i.e. which m_t leads to the highest R&D expenditure levels). This is dependent on the shape of the revenue function in different market structures.[34] Also, there is no reason to expect that optimising behaviour at the level of the firm will lead to the choice of post-trade market structure that involves the highest optimal R&D expenditure levels.

5.3 Knowledge trading

In addition to producing new knowledge itself, a firm can acquire new knowledge by buying it from another firm. In this case the knowledge that is bought is used by the buyer in the same way as a new knowledge vector from the buyer´s own production. It was already shown that the knowledge producer (in the following also referred to as the "seller") will choose the post-trade market structure together with his R&D expenditure in order to maximise his profits.

Once each firm has taken a decision with regard to its own R&D activities and once those firms i, that chose to invest a non-negative amount of expenditure on

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[34] It would for instance be possible for both of the following to hold: $\left.\frac{\partial Q_t^i\left(r_t^{i^*}\middle|m_t^1\right)}{\partial r_t^i}\right|_{m_t^1} < \left.\frac{\partial Q_t^i\left(r_t^{i^*}\middle|m_t^2\right)}{\partial r_t^i}\right|_{m_t^2}$ and $r_t^{i^*}\middle|m_t^1 < r_t^{i^*}\middle|m_t^2$.

An argument based on the comparison of different market structures with the help of equation (15), the concavity of the revenue function in r_t^i and the expected difference in $\frac{\partial KS_t^i}{\partial r_t^i}$ in different market structures would therefore not be valid.

research activity, r_t^i, have produced a new knowledge vector, $\vec{n}_t^i$, trading of knowledge can take place. At this stage, all knowledge vectors are taken as given, and due to the assumptions with regard to the information structure, each firm knows the length and direction of each new knowledge vector of all agents.

The analysis of knowledge trading now can be structured into two subsequent stages: Firstly, the prospective seller chooses the post-trade market structure which maximises his profits. Secondly, given the chosen market structure, there is a bidding competition to determine which firms the knowledge is actually sold to. Solving his profit maximisation problem by backward induction, the seller needs to evaluate his profit for any possible market structure as a basis for his choice in the first stage. Accordingly, in stage 2, the post-trade market structure is taken as given. The next section turns to the analysis of the second stage and considers the question of which firms will actually succeed in buying new knowledge for any given market structure.

5.3.1 The buyers´ competition for the acquisition of knowledge

In a slight variation to the use of the variable l_t so far, let l_t^* denote the number of firms a knowledge producer needs to sell his new knowledge to under a given market structure. Hence, for any given market structure l_t^*, buyers have to agree to purchase the knowledge in question at the required price. From profit maximising behaviour, it is clear that an offer price is extended by the buyer if and only if acquisition of the knowledge at this price increases his total expected discounted life-time profits as a consequence of the acquisition. The price will then be determined in a bidding process, which each firm with an interest in buying firm j´s new knowledge

vector participates in. Prices will rise until all but l_t^* firms do not wish to buy j´s knowledge at that price any more.[35] Note that the buyer has no price setting power here. While the parameters of the buyer determine an upper bound for the price, which it is willing to pay, the actual acquisition price in any given market structure depends on the parameters of the competitors for the acquisition of the new knowledge.[36]

A firm i will want to buy the new knowledge of a firm j, if the expected impact on its discounted life-time profits from this transaction is positive. It is necessary, therefore, to consider the impact of the new knowledge vector $\vec{n}_t^{\,j}$ on the current and future profits of firm i. From now on, the expression $\Delta_{\vec{n}_t^j}\Pi_k^i$ is used to denote the profit impact that commercial exploitation of $\vec{n}_t^{\,j}$ in period t has on the profit of firm i in period k, with $k \in (t,...,\infty)$. One can therefore define $\Delta_{\vec{n}_t^j}\Pi_k^i$ formally as

$$\Delta_{\vec{n}_t^j}\Pi_k^i = \Pi_k^i \left| \left(\vec{n}_t^{\,j} \in N_t^i\right) - \Pi_k^i \right| \left(\vec{n}_t^{\,j} \notin N_t^i\right) \tag{18}$$

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[35] So far the variable l_t denoted the number of firms that use the new knowledge in question in any market structure. However, the knowledge producer can choose a market structure in which he keeps using his own knowledge as well as one where he does not do so. In the former case, there will be $l_t - 1$ buyers, in the latter case, there will be l_t buyers to attain the required market structure. To avoid this technical distinction in the remainder of the argument, l_t^* is introduced here. It does not entail any loss of generality for the points to be made.

[36] The price further depends on the parameters of the seller, who sets a lower bound for the price at which the knowledge vector in question will be traded for any market structure. This will be discussed in detail below.

where $\Pi_k^i \left| \left(\vec{n}_t^{\,j} \in N_t^i \right) \right.$ denotes firm i´s profit in period k, given that it engaged in the commercial exploitation of $\vec{n}_t^{\,j}$ in period k, and $\Pi_k^i \left| \left(\vec{n}_t^{\,j} \notin N_t^i \right) \right.$ denotes firm i´s profit in period k, given that it did not engaged in the commercial exploitation of $\vec{n}_t^{\,j}$ in period k.

From the considerations above it follows that for the current period, i.e. where $k = t$, firm i´s profit impact from acquiring a new knowledge vector from firm j and appropriating it through own output is

$$\Delta_{\vec{n}_t^{\,j}} \Pi_t^i = Q_t^i \left(\vec{n}_t^{\,j} \right) - P_t^{ij} . \tag{19}$$

For future periods, i.e. $k > t$, it is further known that due to the property of cumulativeness of knowledge, the acquisition of new knowledge in this period – regardless of its source – will have an impact on future periods´ revenues from knowledge appropriation through own output as well. As discussed in the context of Figure 2, the overall effect of $\vec{n}_t^{\,j}$ on firm i´s profits in future periods could be positive or negative depending on the balance of the "efficiency effect" versus the "productivity effect".

Let $\Delta_{\vec{n}_t^{\,j}} \Pi_T^i$ denote the net present value of the total change in current and discounted future profits for firm i due to acquiring and commercially exploiting the new knowledge vector $\vec{n}_t^{\,j}$:

$$\Delta_{\vec{n}_t^{\,j}} \Pi_T^i = \sum_{k=t}^{\infty} \frac{1}{\left(1+\delta\right)^{k-t}} E_t^i \left(\Delta_{\vec{n}_t^{\,j}} \Pi_k^i \right) \tag{20}$$

For any price P_t^{ij}, the condition for firm i to want to acquire $\vec{n}_t^{\,j}$ in period t is $\Delta_{\vec{n}_t^{\,j}} \Pi_T^i \geq 0$. Using equations (19) and (20), this can be rearranged to yield the following upper bound for the price firm i would be willing to pay for $\vec{n}_t^{\,j}$:

$$P_t^{ij} \leq Q_t^i\left(\vec{n}_t^{\,j}\right) + \sum_{k=t+1}^{\infty} \frac{1}{\left(1+\delta\right)^{k-t}} E_t^i\left(\Delta_{\vec{n}_t^{\,j}} \Pi_k^i\right) \tag{21}$$

Firm i will succeed in the bidding contest for $\vec{n}_t^{\,j}$, if for any given post-trade market structure it can realise at least the l_t^*-th biggest profit increase from the acquisition of $\vec{n}_t^{\,j}$, i.e.

$$Q_t^i\left(\vec{n}_t^{\,j}\right) + \sum_{k=t+1}^{\infty} \frac{1}{\left(1+\delta\right)^{k-t}} E_t^j\left(\Delta_{\vec{n}_t^{\,j}} \Pi_k^i\right) < Q_t^p\left(\vec{n}_t^{\,j}\right) + \sum_{k=t+1}^{\infty} \frac{1}{\left(1+\delta\right)^{k-t}} E_t^p\left(\Delta_{\vec{n}_t^{\,j}} \Pi_k^p\right) \tag{22}$$

for at most $\left(l_t^* - 1\right)$ firms.[37] Otherwise, another firm will be able to outbid firm i and become a trading partner for the seller instead.

The rhs of equation (21) for the firm with the l_t^*-th highest profit increase from acquisition of the new knowledge in question will also be the upper bound for the acquisition price of $\vec{n}_t^{\,j}$, which is realisable in the given market structure. Any

[37] In case of several firms for which this is true, i.e. which have identical profits from the acquisition of $\vec{n}_t^{\,j}$, the seller is assumed to randomly choose one trading partner from those candidate buyers. In this case, each firm is chosen by the seller with equal probability.

price higher than this would be inconsistent with the market structure in question. This upper bound shall be denoted by $\overline{P_t^j}$ from now on.

Furthermore, it is possible with the help of equation (21) to derive a lower bound for the price at which $\vec{n}_t^j$ will trade. This will be equal to the rhs of equation (21) of the firm with the $\left(l_t^* + 1\right)$-th highest profit increase from acquisition and subsequent commercial exploitation of the new knowledge in question. This is the last firm to unsuccessfully drop out of the bidding contest and which has to be outbid by the eventually successful candidates to acquire $\vec{n}_t^j$. Any price lower than this would again be inconsistent with the given market structure. This lower price bound shall be denoted by $\underline{P_t^j}$ from now on.

The above analysis made it possible to derive a price corridor from the perspective of potential buyers for the price at which the new knowledge in question will trade and to set-up conditions for which firms will succeed in the competition to acquire $\vec{n}_t^j$. In summary, it can be said that for any given post-trade market structure trading will take place such that:

$$\underline{P_t^j} \leq P_t^j \leq \overline{P_t^j} \tag{23}$$

5.3.2 The seller´s choice of market structure

Now turn to stage 1 of the seller´s profit maximisation problem. In this stage, the knowledge seller will choose the market structure which maximises his profits, given his knowledge of the other firms´ behaviour in the second stage as analysed

above. The decision about the profit-maximising market structure includes the decision of whether or not to engage in knowledge trading at all. The seller has the alternative option of appropriating the value of his new knowledge vector as a knowledge monopolist instead, and he will choose to do so if this earns him a higher overall profit than any market structure which involves knowledge trading.

From this profit maximising behaviour of the seller, it is possible to derive the condition for the knowledge seller to engage in knowledge trading. The seller will only engage in trading, if it does not decrease his profits relative to the knowledge monopoly case. This requires that the price is set such that seller j´s total revenues from the sale of his new knowledge vector, KS_t^j, compensate him for his current period´s revenues forgone plus his expected discounted future profits foregone due to engaging in trade of $\vec{n}_t^j$.[38]

To be able to use the case of a knowledge monopoly as a benchmark, it is helpful to define the following concepts in order to derive a condition for the knowledge seller to engage in trading. Let $\Delta_{m_t} Q_t^j\left(\vec{n}_t^j\right)$ denote the difference between revenues from appropriation of $\vec{n}_t^j$ through own output in case of a knowledge mo-

[38] For the current period it is revenues rather than profits forgone, because at this stage, i.e. after the production of all knowledge vectors, R&D expenditure was already incurred regardless of whether the firm engages in knowledge sales and/or appropriation through own output.

nopoly for the seller, denoted by $m_t^{j,mon}$, on the one hand and in case of the given market structure m_t on the other hand:

$$\Delta_{m_t} Q_t^j\left(\vec{n}_t^{\,j}\right) = Q_t^j\left(\vec{n}_t^{\,j}\right)\Big|m_t^{j,mon} - Q_t^j\left(\vec{n}_t^{\,j}\right)\Big|m_t \tag{24}$$

Furthermore, let $\Delta_{m_t}\Pi_k^j$ denote the difference between the seller´s profits in future periods k in case of $m_t^{j,mon}$ and in case of m_t as the prevailing market structure in period t respectively:

$$\Delta_{m_t}\Pi_k^j = \Pi_k^j\Big|m_t^{j,mon} - \Pi_k^j\Big|m_t \tag{25}$$

Using these concepts the condition for a profit maximising seller j to engage in trading which leads to a post-trade market structure m_t is the following:

$$KS_t^j \geq \Delta_{m_t} Q_t^j\left(\vec{n}_t^{\,j}\right) + \sum_{k=t+1}^{\infty} \frac{1}{\left(1+\delta\right)^{k-t}} E_t^j\left(\Delta_{m_t}\Pi_k^j\right) \tag{26}$$

Due to the fact that $KS_t^j = l_t^* * P_t^j$ equation (26) defines a second lower bound, $\underline{\underline{P_t^j}}$ for the price of $\vec{n}_t^{\,j}$ for any given post-trade market structure m_t, which follows directly from the profit maximising behaviour of the seller. This second lower price bound is determined by the parameters of the seller only and holds for any post-trade market structure for $\vec{n}_t^{\,j}$. That the following holds for at least one market structure therefore is a necessary condition for trading of $\vec{n}_t^{\,j}$ to take place

$$P_t^j \geq \underline{\underline{P_t^j}} \tag{27}$$

5.3.3 Price determination

Overall then, provided that equation (26) is satisfied, equations (23) and (27) allow the following conclusion with regard to the determination of the price at which firms will engage in trading of $\vec{n}_t^j$ in any given market structure:

$$P_t^j = max\left(\underline{P_t^j}, \underline{\underline{P_t^j}}\right) \tag{28}$$

i.e. within the price range defined in equation (23), the price at which firm i succeeds in taking over $\vec{n}_t^j$ is the higher of the following: the maximum price which the firm with the $\left(l_t^* + 1\right)$-th highest profit from the acquisition of $\vec{n}_t^j$ would be willing to pay, or the lowest price at which firm j would be willing to sell. Hence, on the one hand, the exact price of any particular piece of new knowledge depends on the distribution of maximum prices potential buyers are willing to pay as defined in equation (21). These will shape the parameters of the bidding process.[39] On the other hand, it will depend on the alternative opportunities with regard to the commercial exploitation of $\vec{n}_t^j$ for the seller.

[39] Note that there is no price discrimination in this model. Each buyer of a new knowledge vector pays the same price for its acquisition. Allowing price discrimination would simplify the analysis because the price for all firms that do buy the knowledge in question would then be such that equation (21) holds with equality. Given perfect information, the seller would get all the surplus from any trade.

The fact that the maximum price the firm with the $\left(l_t^* + 1\right)$-th highest profit from the acquisition of $\vec{n}_t^j$ would be willing to pay determines the actual price of the trade in a given market structure (as long as this is higher than the seller´s lower price bound), allows to prove formally the intuitive point that the purchase price will decrease with increasing l_t^*, i.e. with a less concentrated market structure. It follows from equation (21) that the firm with the $\left(l_t^* + 1\right)$-th highest benefit from the acquisition of $\vec{n}_t^j$ as defined by the rhs of equation (21) has a lower willingness to pay for $\vec{n}_t^j$ than the firm with the $\left(l_t^* + 2\right)$-th highest benefit from the acquisition of $\vec{n}_t^j$. Given that the former determines the price at which the seller has to find l_t^* buyers, and the latter determines the price for which the seller has to find $\left(l_t^* + 1\right)$ buyers for the new knowledge vector in question, it follows that

$$P_t^j \left| \{m_t : l_t = 1\} \geq P_t^j \right| \{m_t : l_t = 2\} \geq \ldots \geq P_t^j \left| \{m_t : l_t = \infty\} \right., \text{ q.e.d.} \tag{29}$$

5.3.4 Drivers of knowledge trading

It is possible to derive a necessary and sufficient condition for knowledge trading to take place from equations (23) and (27):

$$\overline{P_t^j} \geq \underline{\underline{P_t^j}} \text{ for at least one } m_t \neq m_t^{j,mon} \tag{30}$$

If this is true for one post-trade market structure $m_t \neq m_t^{j,mon}$, then this market structure will be chosen by the profit maximising seller. If it is true for more than

one post-trade market structure $m_t \neq m_t^{j,mon}$, then the seller will evaluate each of these and choose the one that yields the highest total discounted life-time profit. Note, however, that while equation (30) is a necessary and sufficient condition for knowledge trading to take place, it is not a sufficient condition for any particular firm to succeed in the acquisition of a new knowledge vector, or for any particular post-trade market structure to obtain. With regard to the former, this is so because another firm might have an interest in buying the same new knowledge too and be able to outbid it as argued in the context of equation (22) above. With regard to the latter, the reason is that there might be a different market structure, which is more profitable for and hence chosen by the profit-maximising seller.

In order to identify the drivers of knowledge trading, it is useful to analyse the circumstances under which equation (30) holds. The first factor that affects both sides of the inequality is the effective innovative input of the new knowledge vector respectively for buyer and seller. Given the new knowledge´s potential innovative input, its effective innovative input is determined firstly by its degree of complementarity with the stock of existing knowledge and secondly by the size of the existing knowledge vector of seller and buyer. From the discussion in the context of equation (10) it follows with regard to the degree of complementarity that if, ceteris paribus, the new knowledge is more complementary to the stock of existing knowledge of the buyer than it is to that of the seller, this tends to lead to a higher $\overline{P_t^j}$ relatively to $\underline{\underline{P_t^j}}$. With regard to the effect of the vector of existing knowledge, it follows that if, ceteris paribus, the vector of existing knowledge of the knowledge seller is larger

than that of the buyer, this also tends to lead to a higher $\overline{P_t^j}$ relatively to $\underline{\underline{P_t^j}}$. Both would therefore be conducive for knowledge trading to take place.

The further effects, which are relevant for the evaluation of the relative size of the two sides of equation (30), are due to the increase in future periods´ stock of existing knowledge through the current period´s new knowledge and its impact on the ability of the firm to exploit (efficiency effect) and produce (productivity effect) new knowledge in the future. To evaluate the relative size of these terms for seller and buyer, turn first to some further consideration of the efficiency effect. It was already shown in section 4.2 how bureaucratic inertia and lock-in effects are the drivers of this phenomenon and that its impact for a given vector of new knowledge will be larger the smaller the firm´s vector of existing knowledge in the current period. Intuitively, if a firm is already well-established in a certain direction, then the same new knowledge will change the overall orientation of the firm´s activities by less than it would for a less established firm.[40] Thus, relatively speaking, the more established firm looses less flexibility due to the new knowledge then the more flexible firm does. With regard to the evaluation of equation (30), this means that if the

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[40] Technically, this can be shown by reference to Figure 1. Let γ denote the angle between $\vec{k}_{t-1}^{\,i}$ and $\vec{k}_t^{\,i}$, so that

$$\gamma = \tan^{-1}\left(\frac{\sin\alpha\left(\vec{n}_t^{\,i}, \vec{k}_{t-1}^{\,i}\right)\cdot\left\|\vec{n}_t^{\,i}\right\|}{\left\|\vec{k}_{t-1}^{\,i}\right\| + \cos\alpha\left(\vec{n}_t^{\,i}, \vec{k}_{t-1}^{\,i}\right)\cdot\left\|\vec{n}_t^{\,i}\right\|}\right)$$

From this it follows that γ is decreasing in $\left\|\vec{k}_{t-1}^{\,i}\right\|$, q.e.d.

buyer has a larger stock of existing knowledge in the current period than the seller, this tends to push the relative size of $\overline{P_t^j}$ and $\underline{\underline{P_t^j}}$ in the direction required by equation (30).

Now turn to the productivity effect which plays a role in determining the relative size of both sides of equation (30) by influencing the ability of the firm to produce new knowledge in the future. New knowledge might improve future periods´ knowledge production technology, g_t^i, due to learning effects and similar dynamics as were already discussed in the context of the "standing on the shoulders of giants" and the "cross-fertilisation" arguments. However, there are no firm theoretical grounds to establish the relative size of this positive effect on different firms. Intuitively, it seems likely that it will be stronger the smaller the firm´s existing knowledge stock which might favour a higher willingness or ability to learn and because any given amount of new knowledge raises the height of the "giant´s shoulder" by a larger percentage. However, to a large extent this will be dependent on the culture of the firm and the type of knowledge concerned, so that it does not lend itself easily to economic modelling and is more suitable for case study type of analysis. It shall therefore suffice at this stage to have identified qualitatively its potential role.

5.4 Summary

This chapter built a formal model of knowledge trading. For this purpose first the assumptions were outlined which define the model framework. Next, the importance of knowledge trading on the knowledge production decisions of forward-

looking agents was discussed. Finally, it was possible to derive necessary and sufficient conditions for knowledge trading to take place and to show how these conditions are affected by the knowledge specific characteristics highlighted in chapter 2. Selling new knowledge to other firms in exchange for a price that compensates the seller for the resulting decrease in his innovation rents in the output market can be a profitable opportunity.

The significance of the model of knowledge trading developed here lies in the fact that those properties, which uni-dimensional approaches to the modelling of knowledge in economic activity were unable to capture and which have therefore gone unnoticed in the existing literature, were shown to be crucial drivers of knowledge trading. The derivation of the properties of knowledge from first principles in the previous chapters and the novel vector-based methodology developed to capture these made it possible to show that the drivers of knowledge trading are rooted in the very nature of knowledge and innovative activity.

To conclude the discussion, it is useful to translate the technical approach chosen for the formalisation of the argument in this chapter back into the business context which motivated the analysis. Consider a start-up firm which has come across new knowledge in period one. This company will then gear its organisation towards exploiting the value of this new knowledge. Now consider the next period. The company has inherited an organisational structure, human capital, a sales apparatus, client relationships and a brand from last period. These were geared towards exploiting last period´s new knowledge, which by now has been fully appropriated. The aim of the innovative firm in period 2 is again to find and exploit new knowledge. Its

existing organisation, routines, skills and assets from the last period, however, now act as a constraint on its current period pursuits if the new knowledge it comes across is less than perfectly complementary to last period´s activities. In this case, its organisational inheritance will make it more difficult for the firm to exploit the full economic potential of the new knowledge. Hence, to the extent that existing knowledge from previous periods is a proxy for the amount of a company´s past activities and its organisation, it will be more difficult for the company to extract the full potential from new knowledge the more old knowledge it has. Merging this idea with the inherent lack of predictability in R&D output and hence control in knowledge production over the complementarity of new knowledge with existing knowledge, there might be scope for increasing efficiency through the reallocation of new knowledge from its inventor to firms with more complementary existing knowledge. Profit-maximising firms will move to exploit such profitable opportunities by engaging in knowledge trading.

6 M&A as a special form of knowledge trading

This and the following chapter develop extensions of the benchmark model of knowledge production and trading by considering violations of its underlying assumptions. These extensions allow to address two highly topical debates in the economic literature for applications of the model: the market for M&A, which is the subject of this chapter, and the phenomenon of geographical clustering of innovative activity, which shall be discussed in chapter 7.

The M&A market is a special market for the internalisation of knowledge flows. An active M&A market and the strategy of "picking winners" are well-known phenomena, whereby established firms buy small firms with promising new ideas or technologies. This illustrates that one candidate channel for the reallocation of new knowledge might be M&A activity. This idea is consistent with studies by Grandstrand, Bohlin, Oskarsson and Sjoberg (1992), Link (1988), and MacDonald (1985) who suggest that M&A is an important element in the technology acquisition strategy of companies, particularly in R&D intensive sectors.[41]

The way in which a firm acquires new knowledge is by acquiring the firm that owns it. In this case, the firm that is bought (the "acquiree") is assumed to be integrated into the firm that buys (the "acquirer") as follows: the acquiree´s new know-

[41] While studies like de Jong (1976) and Chakrabarti and Burton (1983) suggest that technology is not or only moderately important as a motive for M&A activity.

ledge vector is integrated into the acquirer in the same way as a new knowledge vector from the acquirer´s own research would be. The stock of existing knowledge of the acquiree, on the other hand, which is a proxy for the acquiree´s institutional lock-in, lapses.[42]

The key variable for understanding the drivers of M&A activity is the impact of market structure on firms´ profits. In the previous chapter, it was assumed that the producer of new knowledge can

1. commit to not using the new knowledge in question himself and

2. control the diffusion of knowledge (i.e. commit his trading partners to not sell or otherwise pass on without his consent the piece of knowledge he sold to them).

Under these assumptions, it was possible for knowledge to be traded at a non-zero price and to attain every possible market structure through the design of a contract that determined which other agents the knowledge would be passed on to and whether the seller would use his new knowledge himself or not. Hence, if any particular market structure with regard to the new knowledge was sufficiently profitable for any one agent, he could ensure this market structure simply by offering a suffi-

[42] This is a simplification to focus the attention on and isolate the effects of the special characteristics of knowledge and innovative activity. In the real world, there will often be a transition, in which the acquirer tries – with varying degrees of success – to impose its culture and organisation on the acquiree. Costs, that might arise out of this often friction-laden process, involve for instance staff layoffs and brain-drain effects as the acquiree´s top staff leave in frustration.

ciently high purchase price to make the seller accept his terms. In the following it will be shown that a violation of each of these two assumptions provides a motive for M&A activity.[43]

6.1 M&A activity due to the seller´s inability to commit

First, turn to the case where assumption 1 above fails as a potential scenario in which M&A can play a role. Given the non-rivalry of knowledge and problems of monitoring and enforceability, this is a useful extension. The consequence of this change in the model set-up is that any post-trade market structure in which the knowledge producer does not use the new knowledge he produced for appropriation through own output (for instance, as would be the case in a monopolistic post-trade market structure for the buyer) is not attainable any more through conventional knowledge trading, even if this was the most profitable scenario for the seller.

Therefore, the advantage of taking-over (through M&A) the producer of a piece of new knowledge instead of simply buying the piece of knowledge through conventional trading lies in the fact that a market structure in which the producer is excluded from the use of his knowledge can be achieved. Revenues from appropriation through own output will therefore be higher than had the company acquired the knowledge from the seller via conventional knowledge trading. Clearly, however, this

[43] Apart from these and unless stated otherwise, this section is based on the same assumptions as introduced in the previous chapter.

advantage comes at a cost. In order to consent to being taken-over, the acquiree needs to be compensated for all his current and discounted future profits forgone, whereas in case of a standard knowledge trade as discussed in the previous chapter only the current and discounted future profit impact of the traded new knowledge vector are of relevance for the seller. The purchase price can therefore be expected to be larger than in the case of the acquisition of the new knowledge vector only.

Given the knowledge producer´s constraint of not being able to commit himself to not using his new knowledge for appropriation through own output, an M&A transaction will therefore only take place if the following holds: The acquirer finds his desired market structure so much more profitable than the one the seller would have chosen that he can afford to compensate the latter for all his profits forgone and still make a larger profit than had he acted under the seller´s optimal market structure. The advantage of acquisition of the knowledge producing firm instead of merely its new knowledge therefore lies in the ability to manipulate the post-trade market structure. The function of M&A identified here differs from the well-known notion in the literature which views M&A as a tool for the acquirer to gain control over an uncertain environment, necessitated for instance by a dependence on certain supplier or client relationships, as discussed in Link (1988), MacDonald (1985), Pfeffer (1972), Sutton (1980) and Williamson (1996).[44]

[44] There are many other potential drivers of M&A activity discussed for instance in the literature on theory of institutions (e.g., Grossman and Hart, 1986). Their merits and drawbacks are not the subject of this work and shall not be further discussed. The purpose here is to provide an additional perspective from the point of view of knowledge economics.

The drivers of M&A activity in this view again are rooted in the very nature of knowledge in economic activity: Problems of contract design due to knowledge non-rivalry as well as scope for gains through knowledge reallocation due to uncertainty in knowledge production and the importance of complementarity and cumulative-ness in innovative activity.

Analogously to section 5.3, it is possible to derive upper and lower bounds for an acquisition price and to derive from these the conditions for M&A to take place. From this exercise, it will be possible to identify the drivers of knowledge exchanges through M&A activity due to a violation of assumption 1.

The upper bound of the price range at which an M&A deal can take place is set by the acquiring firm. Note that a take-over of the firm that produced $\vec{n}_t^j$ does not mean that there will not be subsequent trading in $\vec{n}_t^j$. In the order of play in the model so far, the M&A stage can be thought of as after the knowledge production and before the knowledge trading stage. The point of acquiring a firm in this stage is to gain control of the subsequent market structure in the knowledge trading and appropriation stage.

The post-trade market structure that is profit-maximising for the acquirer (and hence chosen in case of a take-over) is denoted by $m_t^{i^*}$, and the post-trade market structure that is profit-maximising for the knowledge producer (and hence chosen in case of no take-over) is denoted by $m_t^{j^*}$. Let $P(a)_t^{ij}$ be the acquisition price at which firm i purchases firm j. In order for the acquirer i to be willing to buy firm j in

period t, the upper bound for $P(a)_t^{ij}$ is such that the change in the acquirer´s current and discounted future profits is positive:

$$\left[\Delta_{\vec{n}_t^j}\Pi_T^i \middle| m_t^{i^*}\right] - \left[\Delta_{\vec{n}_t^j}\Pi_T^i \middle| m_t^{j^*}\right] \geq 0 \tag{31}$$

with

$$\Delta_{\vec{n}_t^j}\Pi_T^i \middle| m_t^{i^*} = \left\{ Q_t^i\left(\vec{n}_t^{\,j}\right) + KS_t^i\left(\vec{n}_t^{\,j}\right) + \sum_{k=t+1}^{\infty} \frac{1}{(1+\delta)^{k-t}} \cdot E_t^i\left(\Delta_{\vec{n}_t^j}\Pi_k^i\right) \right\} \middle| m_t^{i^*} - P(a)_t^{ij} \tag{32}$$

$$\Delta_{\vec{n}_t^j}\Pi_T^i \middle| m_t^{j^*} = \left\{ Q_t^i\left(\vec{n}_t^{\,j}\right) + \sum_{k=t+1}^{\infty} \frac{1}{(1+\delta)^{k-t}} \cdot E_t^i\left(\Delta_{\vec{n}_t^j}\Pi_k^i\right) \right\} \middle| m_t^{j^*} - P_t^{ij} \middle| m_t^{j^*} . \tag{33}$$

The difference between these two terms, therefore, derives from the following: the impact of the different choice of market structure on current and future revenues, the fact that in case of an acquisition the acquirer might have additional revenues from conventional knowledge trading, $KS_t^i\left(\vec{n}_t^{\,j}\right)$, and the difference between the price that would have to be paid for acquisition of the new knowledge vector in conventional knowledge trading compared to the price for the acquisition of the knowledge producer.

As there can only be one acquirer, equality of equation (31) for that firm i with the largest realisable profit increase from the acquisition of firm j determines an upper bound for the acquisition price $P(a)_t^{ij}$. Let the upper bound be denoted by $\overline{P(a)_t^j}$, such that

$$P(a)_t^{ij} \leq \left\{ Q_t^i\left(\vec{n}_t^{\,j}\right) + KS_t^i\left(\vec{n}_t^{\,j}\right) + \sum_{k=t+1}^{\infty} \frac{1}{(1+\delta)^{k-t}} \cdot E_t^i\left(\Delta_{\vec{n}_t^{\,j}} \Pi_k^i\right) \right\} \Bigg| m_t^{i^*}$$
$$- \left\{ Q_t^i\left(\vec{n}_t^{\,j}\right) + \sum_{k=t+1}^{\infty} \frac{1}{(1+\delta)^{k-t}} \cdot E_t^i\left(\Delta_{\vec{n}_t^{\,j}} \Pi_k^i\right) \right\} \Bigg| m_t^{j^*} + P_t^{ij} \Big| m_t^{j^*} = \overline{P(a)_t^{\,j}} \qquad (34)$$

In addition to this, equation (31) also determines the first lower price bound $\underline{P(a)_t^{\,j}}$ for the acquisition price for firm j. This results from equality of equation (31) for the firm with the second largest realisable profit from acquisition of firm j.

With regard to the second lower bound $\underline{\underline{P(a)_t^{\,j}}}$ for the acquisition price this will again be determined by the parameters of the seller, or in the case of M&A, the acquiree. An offer price $P(a)_t^{ij}$ is accepted by the acquiree, if and only if it is at least as large as the sum of the revenue forgone in this period and the discounted profits of all future periods if the acquiree continued its business.[45]

$$P(a)_t^{ij} \geq \left(R_t^j + \sum_{k=t+1}^{\infty} \left(\frac{1}{(1+\delta)^{k-t}} \right) \cdot E_t^j \, \Pi_k^j \Big| \left(\vec{n}_t^{\,j} \in N_t^j \right) \right) \Bigg| m_t^{j^*} = \underline{\underline{P(a)_t^{\,j}}} \qquad (35)$$

Analogously to section 5.3, the actual acquisition price will be such that

$$P(a)_t^{ij} = \max\left[\underline{P(a)_t^{\,j}}, \underline{\underline{P(a)_t^{\,j}}} \right] \qquad (36)$$

[45] It is the current period´s revenues rather than profits foregone because all costs occurred at the beginning of the period when the new knowledge was produced and are therefore considered sunk with regard to their relevance for a potential M&A deal.

i.e. the take-over price will be equal to the larger of the following: the minimum price at which firm j would be willing to accept a take-over offer according to equation (35) and the maximum price that the firm with the second largest profit increase from the take-over of firm j can afford to offer according to equation (34).

Furthermore, it follows that the possible range for the purchase price as well as the necessary and sufficient conditions for an M&A transaction to take place are given by

$$\overline{P(a)_t^j} \geq P(a)_t^{ij} \geq \underline{\underline{P(a)_t^j}} \tag{37}$$

6.2 M&A activity due to the seller´s inability to control the diffusion process

Consider now the case where the knowledge seller has no control over the diffusion process, i.e. that assumption 2 above fails. It was shown in section 3.3.2 how this leads to non-tradability of knowledge in the conventional fashion. The reason was that each knowledge buyer knows that after purchasing the new knowledge concerned from the knowledge producer, it will diffuse at a price of zero. This is so because due to non-rivalry a sale will leave the new knowledge in the possession of both, producer and the first buyer, and hence lead to a Bertrand-type price competition with a price floor of zero. The diffusion will continue until the highest marginal benefit of the firms excluded from the knowledge is lower than the lowest marginal cost of all firms in possession of the knowledge. Hence, it might be that the knowledge diffuses to all firms, making it impossible to realise non-zero innovation rents

even through appropriation through own output. Therefore, without control over the diffusion process the knowledge producer might not be able to find a buyer willing to pay a non-zero price in the first place.

In this scenario, acquisition of the knowledge producer in question is a possibility to achieve a reallocation of new knowledge circumventing the vicious circle that kicks in once more than one firm is in its possession. The post-trade scenario in case of knowledge reallocation through M&A leaves only one firm in possession of the knowledge concerned, allowing the acquirer to appropriate the value of the new knowledge through his own output.

With regard to the upper and lower bounds for a price for an M&A transaction to take place, it is important to note that the post-trade market structures, under which the potential acquirer and the knowledge producer evaluate their respective profits from a transaction, are narrowed down to only two alternatives: a knowledge monopoly with regard to $\vec{n}_t^{\,j}$ of the potential acquirer i (this market structure is denoted by $m_t^{i^*}$) or a knowledge monopoly of the knowledge producer j (referred to in the following as $m_t^{j^*}$). This is due to the non-tradability of new knowledge other than through M&A discussed above. Hence, there will be no market structure other then $m_t^{i^*}$ such that $\vec{n}_t^{\,j} \in N_t^i$.

Therefore, condition (31) for the acquirer i to be willing to engage in buying the target company j, and hence the upper bound for an acquisition price, simplifies to

$$\left[\Delta_{\vec{n}_t^j}\Pi_T^i \middle| m_t^{i^*}\right] \geq 0 \tag{38}$$

Using equation (32) and the fact that there will be no subsequent knowledge trading, i.e. $KS_t^i\left(\vec{n}_t^j\right)=0$, this can be rearranged to yield the following:

$$P(a)_t^{ij} \leq \left\{ Q_t^i\left(\vec{n}_t^j\right) + \sum_{k=t+1}^{\infty} \frac{1}{(1+\delta)^{k-t}} \cdot E_t^i \Delta_{\vec{n}_t^j} \Pi_k^i \right\} \middle| m_t^{i^*}. \tag{39}$$

The rhs of equation (39) for that firm i with the largest realisable profit increase from the acquisition of firm j will then determine the upper price bound, $\overline{P(a)_t^j}$, and the rhs of equation (39) for the firm with the second largest realisable profit increase from the acquisition of firm j will determine the first lower price bound, $\underline{P(a)_t^j}$.

With regard to the second lower bound, $\underline{\underline{P(a)_t^j}}$, which is again determined by the acquiree, equation (35) simplifies to

$$P(a)_t^{ij} \geq \left(Q_t^j\left(\vec{n}_t^j\right) + \sum_{k=t+1}^{\infty} \left(\frac{1}{(1+\delta)^{k-t}} \right) \cdot E_t^j \Pi_k^j \middle| \left(\vec{n}_t^j \in N_t^j\right) \right) \middle| m_t^{j^*} = \underline{\underline{P(a)_t^j}} \tag{40}$$

Analogously to before, price determination, price range and necessary and sufficient condition for M&A activity are then the same as in equations (36) and (37) above.

In summary, this chapter analysed the consequences of a violation of two of the assumptions, which were used in the previous chapter to develop a formal model of knowledge trading. These are firstly, the ability of the knowledge seller to commit to not use the knowledge he sells in a post-trade market structure, and secondly, the ability of the seller to control the diffusion process of knowledge after a sale. It was shown how M&A activity emerges as an alternative channel for the reallocation of new knowledge in case of a break-down in these assumptions.[46] Furthermore, it was possible to identify necessary and sufficient conditions for M&A activity to take place as well as the basic parameters that determine the conditions for knowledge reallocation through M&A by deriving the price corridor which would be acceptable to acquirer and acquiree respectively.

The analysis identified two motives for M&A activity, which result from the knowledge specific characteristics in economic activity that are the focus of this work. These are firstly, to gain control over the market structure in order to secure (higher) innovation rents and secondly, the lack of alternative channels for knowledge reallocation. Hence, M&A activity, like knowledge trading, can result from the scope for realising gains in the commercial exploitation of new knowledge through reallocation due to cumulativeness, complementarity and uncertainty in innovative activity. It has its root in the problems of contracting over knowledge due to the

[46] Note that the exploration of the case of a violation of assumption 1 above is contingent on assumption 2 to still hold. The considerations of a violation of assumption 2, on the other hand, are independent of assumption 1 and hold even in case of the additional violation of assumption 1.

difficulties of monitoring and enforceability, which lead to the break-down of the assumptions considered here in the first place.

7 Imperfect information and geographical clustering of economic activity

In order to explain the phenomenon of clustering of innovative activity, it is necessary to extend the model of chapter 5 with information imperfections and the importance of expectations. For this purpose, the assumption of free availability of all information signals will be kept, but it is assumed that there are costs of searching, processing and evaluating information signals about other firms´ knowledge vectors and that these are increasing in geographical distance between source and receiver of the signal. The existence of costs of information processing internal to the firm is firmly rooted in the Theory of Institutions literature (Coase, 1937; Garicano, 2000; Williamson, 1985; Williamson, 1975). The rationale for them to be increasing in distance, on the other hand, are firms´ familiarity with their neighbourhood and the social and professional contacts of a firm as well as its employees. These are predominantly local and thereby allow close to costless collection and evaluation of information about firms near by. Also, local media make it easier to evaluate and process information signals of nearby firms.

In this set-up clustering emerges as the optimal strategy for each firm´s location choice. All equilibrium location structures are shown to consist of one or several clusters at different points in space. Hence, to the extent that it improves the information structure for the reallocation of new knowledge, clustering is the dominant strategy for profit-maximising firms. Furthermore, costs from the evaluation of information are minimised and information benefits are maximised, if a maximum

number of senders and receivers of information are at a minimum distance to each other. Location of all firms in one cluster therefore maximises total location profits of all firms in this model.

Building on the discussion in section 2.1, one can distinguish between the length and the direction of a firm´s knowledge vector and information about these two parameters. To extend the model from a world of perfect information, it is assumed that each firm learns the complementarity and length of its own new knowledge vector upon production but learns the information about other firms´ new knowledge vector only after evaluating their information signals. s_t^{ji} is used to denote the information about firm j in period t, which is assumed to be freely available to each firm i.

As before, the length and direction of all other firms´ total knowledge vectors of the previous period (i.e. all information concerning old knowledge) are public and hence known by each firm. The additional private information needed to fully characterise a firm in each period, therefore, is the length and direction of its new knowledge vector of that period, both of which are assumed to be transferred through evaluation of s_t^{ji}. Furthermore, firms know the true probability distributions of random variables, which serve as the basis for expectations formation. Apart from this and unless stated otherwise, the set-up of the model here is identical to the model of knowledge trading developed in chapter 5. Hence, a firm can be fully described as follows:

Figure 3: Characterisation of the innovative firm

	Characteristic	Information status
Firm j at time t	Length and complementarity of the new knowledge vector of j, $\vec{n}_t^j$	Can be learned in period t through evaluation of information signal, s_t^{ji}
	Length and direction of the existing knowledge vector of j, $\vec{k}_{t-1}^j$	Public knowledge in period t

Source: own design

In principle, all information signals are available to all firms regardless of their geographical location. Hence, s_t^{ji} is treated as the information signal of firm j available to every firm i regardless of its location for all other firms. The question is only whether or not firm i chooses to evaluate the information signal of firm j. Accordingly, the information set of firm i is defined as comprising the information about all other firms´ new knowledge whose information signal s_t^{ji} firm i has evaluated:

$$\Omega_t^i = \left\{ j \in A \middle| \, firm..i..evaluated..s_t^{ji}..in..period..t \right\} \tag{41}$$

where A is the set of all firms. [47]

7.1 Benefits from information

There are several reasons why information about other firms´ knowledge might be beneficial for the innovative firm. Apart from facilitating strategic decisions with regard for instance to product portfolio and pricing, it has been pointed out in the literature that information about the state-of-the-art in its own or related fields might help a firm to better direct its own R&D activities, thereby mitigating the risks of producing knowledge of little value for instance due to missing important industry trends like the emergence of technological standards, etc. (Feldman, 1994a).[48]

There are, however, two other sources of benefits from information gathering: Firstly, to the extent that information signals are transmitters of explicit knowledge, which is non-rival and non-excludable, a firm evaluating and processing such information signals also learns the explicit knowledge they transport. Secondly, there is

[47] As mentioned above, the information set of each firm will also contain the information of all firms´ old knowledge vectors and the probability distributions of random variables. Because these components of the information set are identical for each firm and for simplicity of notation, this is not included in the formalisation of Ω_t^i.

[48] There is for instance ample anecdotal evidence of situations where location decisions are driven by the intention to get more information. In particular in new high-tech industries, it is important to keep track of what´s going on because here industry developments are particularly rapid and consequential.

another type of information externality at work here. As pointed out in chapters 2 and 4, innovative activity involves uncertainty in terms of how well new knowledge will fit with the innovator´s stock of existing knowledge and his existing organisation. Due to the fact that this fit determines the effective innovative input of a new knowledge vector for its user, perfect information is required for knowledge trading to ensure ex-post efficient outcomes.[49] Only then firms can use the knowledge market to increase their actual profits with certainty.

With imperfect information, on the other hand, the profit-maximising firm trades with firms, whose information signal it has not evaluated, on the basis of its expectations of the length and direction of the respective firms´ new knowledge vector. In this case, there is a positive likelihood for the buyer of knowledge of engaging in ex-post unprofitable trades or of missing out on ex-post profitable ones with firms whose information signal he chose to not evaluate.[50] The elimination of the positive likelihood of suffering the losses from such mistakes for any particular firm through the evaluation of its information signal, therefore, is the expected marginal benefit of evaluating that firm´s information signal. Notably, this benefit will be invariant to (or possibly decreasing in) distance. In summary, therefore, the evaluation

[49] "Ex-post" refers to the time when the agent learns the actual realisation of the random variable in question.

[50] An intuitive alternative option would be that the firm decides to not engage in knowledge trading with firms whose information signal it has not evaluated. For the consistency of this behaviour with profit-maximising behaviour, however, the assumption of extremely high risk aversion on behalf of the firm would be required. In this case too, however, there is the cost of missing out on profitable deals because the firm did not find out about them.

of information can prevent allocative inefficiencies and therefore – as would be expected – a profit maximising firm prefers more information to less. [51]

In terms of the model of knowledge production and trading, the decision of whether or not to engage in knowledge trading can be captured with the help of expectations operators. For simplicity and to focus the discussion on the role of information assume risk neutrality on behalf of the profit-maximising firms. From the assumptions on the information structure it is clear for all $E_t^i\left[\left\|\vec{n}_l^{\,j}\right\|,\alpha\left(\vec{n}_l^{\,j},\vec{k}_{l-1}^{\,i}\right)\right]$ that the following holds once all new knowledge vectors in period t are produced:

$$E_t^i\left[\left\|\vec{n}_t^{\,j}\right\|,\alpha\left(\vec{n}_t^{\,j},\vec{k}_{t-1}^{\,i}\right)\right]=\left\|\vec{n}_t^{\,j}\right\|,\alpha\left(\vec{n}_t^{\,j},\vec{k}_{t-1}^{\,i}\right),if:\left(j\in\Omega_t^i\right),\text{ and} \tag{42}$$

$$E_t^i\left[\left\|\vec{n}_l^{\,i}\right\|,\alpha\left(\vec{n}_l^{\,i},\vec{k}_{l-1}^{\,i}\right)\right]=\left\|\vec{n}_l^{\,i}\right\|,\alpha\left(\vec{n}_l^{\,i},\vec{k}_{l-1}^{\,i}\right),if:\left(l\le t\right). \tag{43}$$

For all other l and j, however, firm i does not have information about the actual realisation of the new knowledge vector and therefore has to make decisions

[51] The term "information externality" is not new to the literature. Beaudry and Breschi (2003, p. 327) for instance discuss the different but qualitatively similar phenomenon of proximity facilitating "the assessment of competitors´ economic and innovative performance". By also subsumising "emulation" and "imitation" of competitors under their term of informational externality, however, they blur the distinction between knowledge spillovers, constituted by the latter and information externalities. Feldman (1994b) puts forward the argument that the exchange of information in local networks helps reduce uncertainty inherent in the innovative process. This differs from the notion of information externalities employed here in that in her story the information exchange affects the knowledge production function of the individual firm and thereby constitutes a knowledge externality.

on the basis of its expectations $E_t^i\left[\left\|\vec{n}_l^{\,j}\right\|,\alpha\left(\vec{n}_l^{\,j},\vec{k}_{l-1}^{\,i}\right)\right]$ instead of the actual realisations $\left\|\vec{n}_l^{\,j}\right\|,\alpha\left(\vec{n}_l^{\,j},\vec{k}_{l-1}^{\,i}\right)$.

Adapting equations (21) and (26) to the imperfect information case, for the buyer yields

$$P_{t,\Omega_t^i}^{ij} \le Q_t^i\left(E_t^i\vec{n}_t^{\,j}\right)+\sum_{k=t+1}^{\infty}\frac{1}{\left(1+\delta\right)^{k-t}}E_t^i\left(\Delta_{E_t^i\vec{n}_t^{\,j}}\Pi_k^i\right) \tag{44}$$

as condition for the acquisition of firm j´s new knowledge by firm i in case that $j\notin\Omega_t^i$, where $P_{t,\Omega_t^i}^{ij}$ denotes the price in the imperfect information scenario.

For the seller the condition for firm j´s consent to the acquisition of its new knowledge by firm i in case that $j\notin\Omega_t^i$ is the following:

$$KS_{t,\Omega_t^i}^{\,j} \ge \Delta_{m_t}Q_t^j\left(\vec{n}_t^{\,j}\right)+\sum_{k=t+1}^{\infty}\frac{1}{\left(1+\delta\right)^{k-t}}E_t^{\,j}\left(\Delta_{m_t}\Pi_k^j\right) \tag{45}$$

which due to $KS_{t,\Omega_t^i}^{\,j}=l_t^*\cdot P_{t,\Omega_t^i}^{\,j}$ determines a lower bound for the acquisition price from the profit maximising behaviour of the seller. For all $j\in\Omega_t^i$ on the other hand, it is still equations (21) and (26) that are relevant for the trading decisions.

Given that each firm is potentially active as both, buyer and seller, it is useful to evaluate inequalities (21) and (44), which are relevant to the buyer, and inequalities (26) and (45), which are relevant to the seller, in turn. Consider the perspective of the firm as a knowledge buyer first. To the extent that the actual realisation of $\vec{n}_t^{\,j}$ devi-

ates from $E_t^i \vec{n}_t^j$, for instance in the degree of complementarity with the buyer´s vector of existing knowledge, the following scenarios can arise for any firm j such that $j \notin \Omega_t^i$:

- Equation (44) holds but equation (21) does not. Firm i incurs a loss due to the acquisition of j´s new knowledge vector at the price $P_{t,\Omega_t^i}^{ij}$ in the imperfect information scenario. It would not have undertaken the transaction (and hence not incurred the loss), had it evaluated firm j´s information signal.

- Equation (44) does not hold but equation (21) does. Firm i does not engage in the acquisition of firm j´s new knowledge vector, thereby missing a profitable opportunity, which it would have exploited had it evaluated firm j´s information signal.

- Both equations (44) and (21) hold. The knowledge trade takes place whether or not firm j´s information signal is evaluated by firm i. The prices at which the transactions take place in the respective information structures, P_t^j and $P_{t,\Omega_t^i}^j$ might differ, but there is no reason to expect the buyer to be systematically better or worse off.

- Both equations (44) and (21) do not hold. No knowledge trading takes place in either information structure and hence profits from knowledge trading are zero regardless of whether firm i evaluated firm j´s information signal.

Therefore, from the perspective of the buyer one can conclude that the expected marginal benefit from evaluating the information signal of another firm is positive.

Now consider the perspective of the firm as the knowledge seller. The only way equation (45) differs from (26) is through the trading price, P_t^j and $P_{t,\Omega_t^i}^j$ (due to $KS_{t,\Omega_t^i}^j = l_t^* \cdot P_{t,\Omega_t^i}^j$). As pointed out in section 5.3, the influence of the seller on the determination of the price works solely through setting a floor below which no trading will take place and the knowledge producer would commercially exploit his new knowledge as a knowledge monopolist instead. However, it follows from equations (45) and (26) that this lower price ceiling is identical in both, the perfect and imperfect information case. The important point here is that the marginal effect of evaluating an extra information signal for the seller of new knowledge is zero. The impact of the information structure on the expected profits of the seller works solely through changing the information set at the disposal of potential buyers rather than of the seller of new knowledge.

Abstracting for the moment from the costs of information evaluation, which are the subject of the next section, one can summarise the argument above more formally as follows: The expected marginal benefit for any firm active as both, potential buyer and seller of knowledge, of evaluating an extra information signal is positive:

$$\frac{\Delta\left[E_t^i \sum_{\forall \vec{n}_t^j \in N_t^i} \Delta_{\vec{n}_t^j} \Pi_T^i(\vec{n}_t^j)\right]}{\Delta\left|\Omega_t^i\right|} = b \geq 0 \text{ [52]} \tag{46}$$

7.2 Costs of information gathering

Even if – as proclaimed by the "death of distance"[53] – transmission costs for information have become negligibly small and invariant to distance, and even if the sender cannot contain and hence not charge for information about himself, like for instance the characteristics of his production technology or the level of his R&D expenditure, it will still be costly to gather, evaluate and process information about other firms.[54]

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[52] See equation (7) for a definition of N_t^i. Also note that here the fact is used that a firm has identical expectations about the properties of new knowledge vectors of firms whose information signal it has not yet evaluated because it does not have a basis for differentiating between them. Otherwise instead of b in equation (46) it would have to be b^j, where j is an index for the firm whose information signal firm i expands its information set with. This would for instance be the case if the firms in question used different knowledge production techniques (e.g., with different probability distributions for the realisations of the new knowledge vector´s direction).

[53] The "death of distance" is argued to be a consequence of globalisation and rapid advances in telecommunications technology which dissociates information transmission and geographical space (Cairncross, 1995).

[54] von Hippel (1994) already makes the point that information is costly to transfer and gives a survey of the development of this view in the literature. His point is different to the one made here to the extent that von Hippel does not treat this cost as a function of distance and he does not distinguish between "knowledge" and "information". His concept of "information" includes both, "knowledge" and "information", in the terminology of this work.

On the one hand, decreasing costs of information transmission from one location to another have worked to decrease costs of information gathering. The resulting acceleration of the availability of information, on the other hand, has led to information overflow and has made selecting and evaluating relevant pieces of information more costly. The overall effect on costs of information gathering for individual firms therefore remains unclear. It is argued, however, that one can treat as certain that costs of acquiring and using information do exist, simply due to the time and effort that go into these activities (Simon, 1955, 1959).

In particular, the costs of selecting and evaluating relevant information should be expected to be increasing in the distance between sender and receiver, especially so in the face of information overflow. The rationale for this lies in the familiarity of firms´ employees with their neighbourhood through their leisure time activities and their social and professional contacts and networks, which are predominantly local. These allow close to costless collection and verification of information about firms close by. Also, local media make it easier to evaluate and process information signals of nearby firms. From this point of view and with the definitions of knowledge vs. information in mind, face-to-face contacts and social networks actually serve to allow for easier processing and evaluation of information instead of providing for the local spillover of tacit knowledge.

In the terms of the model one can formalise c^{ij} to denote the cost for firm i of evaluating the information signal of firm j. Let d_{ij} denote the smallest Euclidean

distance between sender i and receiver j of an information signal. This introduces the notion of geographical space into the model. c^{ij} can then be defined as follows:

$$c^{ij} = f\left(d^{ij}\right) \tag{47}$$

where f is a continuously differentiable function with $\lim_{d_{ij}\to 0} c_t^{ij} = 0$, $\lim_{d_{ij}\to\infty} c_t^{ij} = \infty$, and $f' > 0$, i.e. the receiver´s cost of evaluating the information signal of another firm is monotonically increasing in distance to the sender of the information signal.

One can then define the total search costs for firm i as follows

$$C_t^{\,i} = \sum_{j\in\Omega_t^i} c_t^{ij} \tag{48}$$

This view of costly information-gathering shall be used in the way proposed by Simon (1959, p. 269) "by treating information-gathering as one of the processes of production, so to speak, and applying to it the usual rules of marginal analysis." Accordingly, given the costs of evaluating information, innovative firms will only attempt to learn about their environment as long as the expected benefit from an extra information signal exceeds the marginal cost of gathering it. The profit-maximising firm, therefore, might choose to act in an environment of imperfect information.

In summary, therefore, it was established at this stage that

1. there are benefits from gathering and evaluating information signals, which are invariant to or decreasing with geographical distance,[55] and

2. there are costs of processing and evaluating information signals from other firms, which are increasing in distance.

7.3 Geographical clustering as the equilibrium outcome of profit-maximising firms´ location choices

This section analyses the location choices of profit-maximising firms under the assumptions derived above. Let there be an exogenously given large but finite number $|A|$ of firms. Each firm is assumed to use up one unit of space (i.e. it is not infinitely small) of quadratical form wherever it locates. Hence, each firm has at its disposal the $(|A|-1)$ information signals of all other firms. To learn the information contained in the information signal of firm j, however, firm i has to choose to evaluate it at the cost c^{ij} as specified in equation (47). Furthermore, as discussed above assume that learning the information about another firm holds a benefit for the receiver of b, which is invariant to distance between sender and receiver and for simplicity assumed to be the same for all firms.

[55] The point with regard to the sensitivity of the benefits from information gathering with regard to geographical distance between sender and receiver is that the latter did not play a role in the derivation of this benefit. If it did vary with distance, however, one would expect it to be decreasing, but certainly not increasing in distance.

It is the objective of each firm to maximise its "location payoff" $\Pi^i\left(L^i\right)$, given the location of all other firms, with

$$\Pi^i\left(L^i\right)=\sum_{\forall j\in\Omega^i}\left(b-c^{ij}\right). \tag{49}$$

Now consider the following non-repeated, non-cooperative two-stage game: In the first step firms choose their location on an infinite homogenous plane taking the choice of all other firms as given.[56] In a second step firms choose their individual information set Ω^i by choosing which information signals to evaluate and which not in order to maximise their location profit.

In order to be able to analyse the game, it is useful to introduce some terminology first: Let the term cluster be defined formally as a geographical concentration of neighbouring firms. The number of firms located in one cluster will be called the "size" of the cluster. Furthermore, a cluster is called "compact" when there is no location in the cluster which is not occupied by a firm. In other words, in a compact cluster the only firms that are not surrounded by neighbours in every direction are located on the cluster boundary. Furthermore, as a basis for the following analysis note that in order to tell with certainty that a location l_2 is preferred to a different

[56] Where clusters emerge is not the object of study here. Instead, the analysis aims at finding equilibrium location structures, i.e. how firms locate relatively to each other. Hence, the assumption of a homogenous and infinite plane is inconsequential for the results of the analysis.

location l_1 without imposing any further restrictions on b or f one of the following criteria needs to be met:

1. At l_2 more firms are located at at least one distance $d^{ij} \leq d^{ij^*}$ than at l_1 and there is no distance $d^{ij} \leq d^{ij^*}$ at which less firms are located at l_2 than at l_1, or

2. at l_2 for any firm located less at a distance $d^{ij} \leq d^{ij^*}$ there is at least one firm more at a smaller distance than at l_1.

Solving the game backwards it is clear that in stage 2 each firm will evaluate the signals of all those firms for which the marginal benefit of learning their information exceeds the marginal cost, i.e. for which $b \geq c^{ij}$. From this one can conclude that for each firm i there will be a critical distance d^{ij^*} such that firm i does not expect it to be profitable to evaluate j´s signal if j is further away than d^{ij^*}, i.e. $\exists d^{ij^*}, s^j \in \Omega^i \Leftrightarrow d^{ij} \leq d^{ij^*}$. Note that d^{ij^*} is the same for all firms in this model because b and f were assumed to be identical for all firms.

Now turn to the analysis of stage 1 to find the equilibria of the location game. The important specification of the game that has been left open as of yet is whether firms make their location choices in this stage sequentially or simultaneously.[57] The

[57] The results of the analysis of stage 2 are not affected by this. It is therefore legitimate to apply them to the analysis of each of the variants of the game in stage 1.

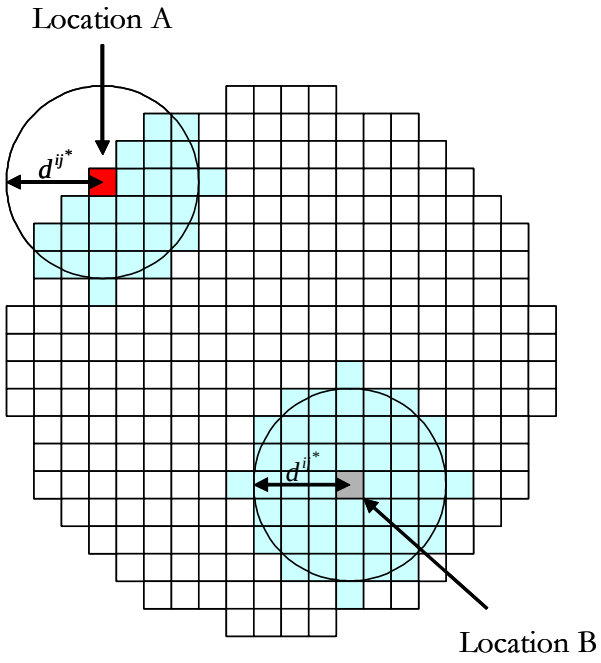
argument to treat location as a sequential choice holds that, when coming into existence, firms make location decisions for the long run and in the face of an existing location structure. This, therefore, seems to be a useful set-up when approaching the problem from an evolutionary perspective. It might be argued, however, that while a sequential move-order is most suitable for the location choice of start-up companies, the majority of firms at any point in time are already in existence. While these are already located somewhere, each firm has the option to change its location at any time, if it chose to. Firms will not make use of this option, only if their current location is optimal in terms of maximising their location profit, given the location of all other firms. The problem at hand would therefore be better modelled as a game with simultaneous location decisions in stage 1, and the only stable location structure would be the Nash equilibria (in the following referred to as "NE") of this game. In the following both of these settings, simultaneous and sequential move-order, shall be analysed.

Turning to the case of simultaneous move-order in stage 1 first, one can draw the following conclusions for the properties of possible NE:

Conclusion I: It is a necessary condition for any cluster in a location structure which constitutes a NE that the cluster is compact. If a cluster was not compact, a firm on the boundary of the cluster would find it profitable to change its location towards a more central location within the cluster and away from the boundary. This could therefore not be a NE of the location game. Figure 4 illustrates this case. If a cluster was not compact and a location space such as B was not occupied, then a

peripheral firm such as the one marked in red at location A would prefer to move to location B.

Figure 4: Peripheral firms prefer to move towards cluster centre



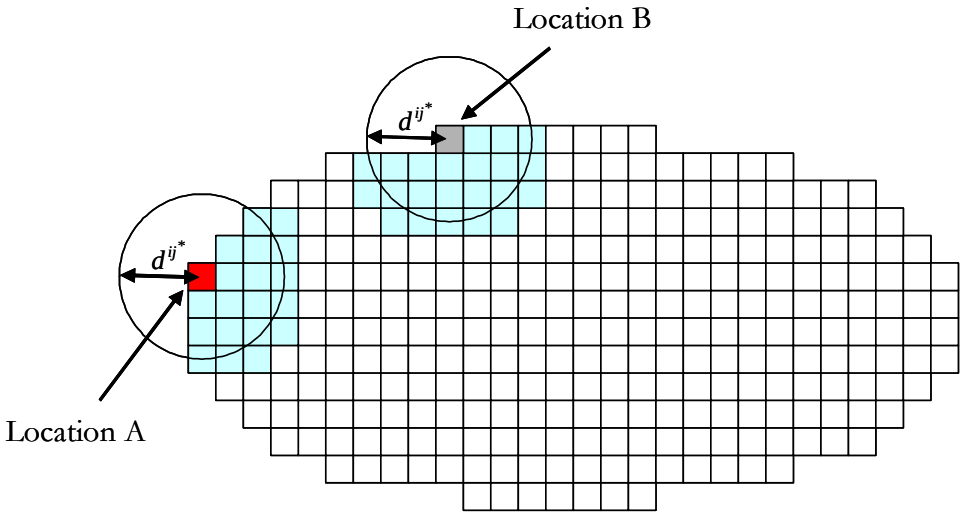
Source: own design

Conclusion II: It is a necessary condition for any cluster in a location structure which constitutes a NE that in its geographical extension the cluster approximates the shape of a circle.[58] In any other geographical extension it would be profitable for firms on the boundary located near the "edges" of the geographical shape of

[58] The expression of "approximating" a circle is used because the location space of firms is not infinitely small. Therefore, the boundary of the cluster will be "bumpy" and deviate from the shape of a perfect circle. When the cluster is large in comparison to the space occupied by one firm, deviation of its shape from a perfect circle is small.

the cluster to move towards its flatter side, thereby increasing the number of firms within its critical distance d^{ij^*}. Figure 5 illustrates this. At location A towards the "edge" of the cluster shape, there are fewer firms at each distance within the firms search radius d^{ij^*} than at location B. This is due to the stronger curvature of the cluster boundary in the neighbourhood of A. In any geographical extension other than one approximating a circle, a pair of locations on the cluster boundary such as A and B can be found such that one is preferred to the other. This cannot be a NE. With the geographical extension of a circle this is not possible because the curvature of the boundary is equal at any point.

Figure 5: Firms prefer parts of cluster boundary with flatter curvature



Source: own design

Conclusion III: Clustering of all firms in one compact circle-shaped cluster is a NE of the location game. Or more precisely: For any given central location, there is a finite number of NE (due to the fact that there is a finite number of firms) each

consisting of a compact circle-shaped cluster of all firms.[59] This is the case because no firm can improve its profit from re-location given the location of all other firms.

Conclusion IV: Clustering of all firms in several compact circle-shaped clusters can be a NE provided that a number of necessary conditions (NC) hold:

- NC 1: Each cluster is compact and approximates the shape of a circle. The reasons are the same as set out in Conclusions I and II above.

- NC 2: Each cluster in a multi-cluster NE exceeds a minimum size. To see why this is a necessary condition consider the case where the clusters were small enough for all their members to fall within d^{ij^*} of even the firms on the cluster boundary. Then there will be a marginal firm on the boundary of one of the clusters of equal size that can increase its profit by changing to the other cluster as this would increase the number of firms within its reach d^{ij^*}. The minimum radius of each cluster in a multi-cluster NE therefore has to exceed $\frac{1}{2} \cdot d^{ij^*}$.[60]

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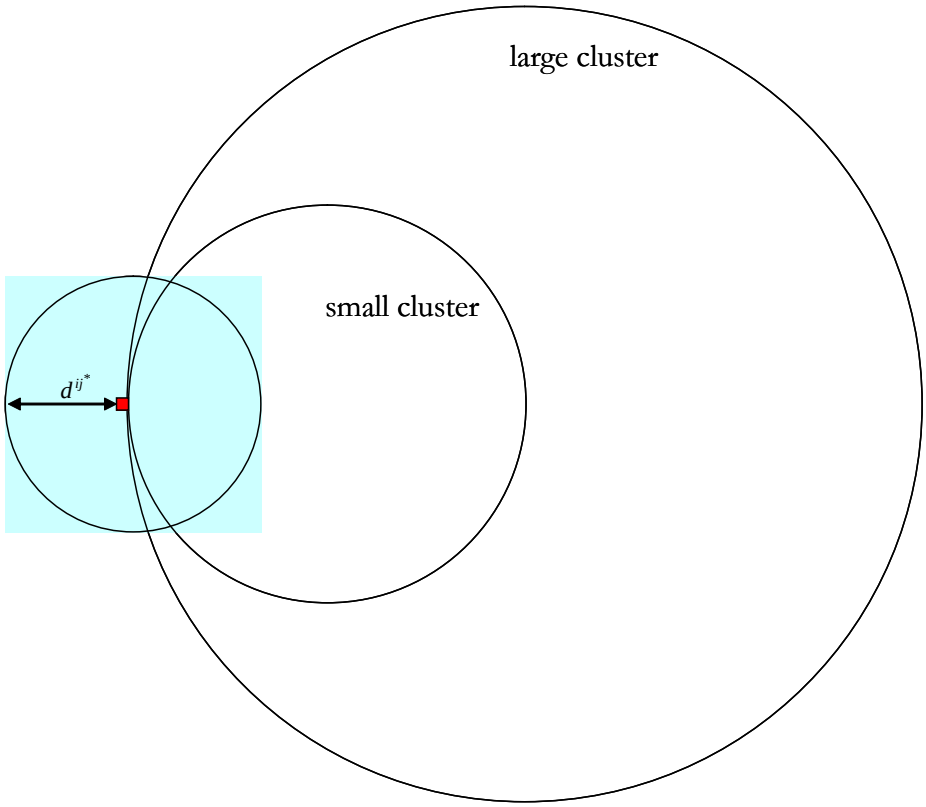
[59] Overall, there is an infinity of such NE because there is an infinity of possible cluster centres on the homogenous plane.

[60] Note that $\pi \cdot \left(\frac{1}{2} d^{ij^*}\right)^2$, i.e. the area of the circle with a radius of $\frac{1}{2} d^{ij^*}$, is the maximum cluster size at which each cluster member finds it profitable to evaluate the information signal of each other cluster member. Hence, provided that $|A| > \pi \cdot \left(\frac{1}{2} d^{ij^*}\right)^2$, there will be at least one firm with an incomplete information set.

- NC 3: The clusters do not differ substantially in size. This is a necessary condition because when a firm moves from the boundary of a smaller cluster to the boundary of a larger cluster, it can generally increase the number of firms within its reach d^{ij^*}. This gain will be larger the larger the difference in size of the compact clusters.

Figure 6: Peripheral firms prefer larger to smaller clusters



Source: own design

Figure 6 illustrates this point. Due to the smaller curvature of the boundary of a larger cluster the shared area of the circle defined by the firm´s search radius d^{ij^*} and the larger cluster is bigger than its shared area with the smaller

cluster. Therefore, there are additional location spaces within the reach of a firm located on the boundary of a large cluster (provided that the size difference of the two clusters is large enough).

A further reason why small size differences might be possible arises from the possibility that there are free locations on the cluster boundary which yield an identical location profit. Then the marginal firm will be indifferent as to whether to locate on the marginally smaller cluster or the remaining free spots of identical location profit of the marginally larger cluster.

- NC 4: The minimum distance between two firms in separate clusters in the multi-cluster NE needs to exceed d^{ij^*} or be countered by a strong premium from close proximity of neighbouring firms. To see that this is a further necessary condition, consider the case where the minimum distance between any of the multiple clusters falls short of d^{ij^*}. Now some firms on the boundary of the cluster have firms of another cluster within their reach of d^{ij^*} and others do not. Firms on the cluster boundary but outside the reach of another cluster then might want to relocate on the boundary such that neighbouring clusters´ firms come within a distance of d^{ij^*}. Location on the cluster boundary outside the reach of the other cluster can only dominate a move to such a location, if there are less firms at lower Euclidean distances at the new location than at the previous one. Then a sufficiently large premium from proximity (depending on the functional form of f) can counter the advantage of a larger number of

firms at a greater distance within d^{ij^*} to some extent. As a result a (slightly) smaller distance between two clusters might be sustainable.

Conclusion V: Any distribution of firms across space other than in compact circle-shaped clusters cannot constitute a NE of the location game because the peripheral firms in any such structure would find it profitable to relocate towards an unoccupied more central location. There is for instance no NE such that some firms are located within one or several clusters and some firms are not. The only way in which firms located outside of a cluster might prefer to not change location is, if they can benefit from being close to more than one cluster, i.e. if they are located at a distance $d^{ij} \leq d^{ij^*}$ to more than one cluster. However, then either there is no strong premium from proximity and firms on the boundary of one of these clusters but outside the reach of the firms located outside of clusters will want to relocate towards including the outsider firms in their reach, or there is a strong premium from proximity in which case the firms in isolation will want to relocate to the boundary of one of the clusters.

In summary, all NE of the game with simultaneous choices in stage 1 involve location of all firms in compact clusters of a geographical shape approximating a circle. A minimum cluster-size, and hence a minimum number of firms, as well as a minimum distance between clusters is required for the existence of several clusters to become a possible NE.

Now turn to the analysis of the game with sequential move order[61] in stage 1: The only equilibrium location structure of this game involves location of all firms in one compact cluster which in its spatial extension approximates the shape of a circle. More precisely, there is an infinity of equilibrium location structures each consisting of location of all firms in one compact, circle-shaped cluster due to the fact that there is an infinity of possible centres. After location of the first firm, which is indifferent as to where to locate on the homogeneous plane, the second firm will want to locate immediately next to the first firm as this yields the highest location profit. The third firm then wants to locate in the immediate neighbourhood of the previous two firms, and so on. As long as the cluster is small enough that each firm can locate such as to include all other firms in its search radius (and hence in its information set), it is the preference for firms close by that ensures compactness and the circle-shape of the cluster. Once the cluster has become so large that no remaining free location allows to capture all occupied location spaces within its search radius, the profit maximising rule according to which each firm makes its location choice is to include as many firms within its search radius as possible, again with a preference for firms close by compared to firms further away.

The main difference between simultaneous and sequential location choices in stage 1 lies in the possibility of multi-cluster equilibrium location structures in case of

[61] With sequential location choice, firms that make their location decision after other firms are assumed to have full knowledge about the location choices of the firms that got to choose before them.

the former. In the sequential version of the game, this is only possible when, for instance by historical accident, there already are several agglomeration, which are equally large, exceed a critical size and have a sufficiently large distance between each other, to start with.[62] To see why the initial agglomerations need to be equally large and exceed a critical size, which will be equal to the critical size identified for the multi-cluster equilibrium in the simultaneous choice version of the game above, consider two separate clusters of equal size with a radius smaller than $\frac{1}{2} \cdot d^{ij^*}$, which are far away from each other. The next firm to choose a location is indifferent between the two clusters and will choose to locate on the boundary of one of them. The firm after that, however, will choose to locate on the same cluster as the previous firm, as this increases the total number of firms within its search radius. Therefore, once one cluster is larger than the other one, all following firms will choose to locate on it. As long as the critical distance is not reached, this is because the firm can increase the number of firms within its search radius. Afterwards, this is due to the dynamics discussed in the context of Figure 6 regarding the smaller curvature and hence larger area within the search radius of firms on the boundary on a larger cluster. The result of an initial size difference would therefore be that one cluster remains in its initial state, while the other one grows until all firms are located in it. If the initial agglom-

[62] If the initial locations were not sufficiently far away from each other, initially separate agglomerations would grow to become one large cluster. A well-known real-world example of the latter case is the so-called "Bosnywash" agglomeration at the East Coast of the USA consisting of the cities Boston, New York and Washington.

erations are of the same, larger than required critical size, however, it is possible that they both grow in parallel to each other.

As it was shown that, under certain conditions, single and multiple cluster location structure are possible equilibria, the question arises which of these are preferable from a social planner´s point of view. It can be shown that co-location of all firms in one cluster is optimal in terms of maximising the overall location profit received by all firms. To prove this, one can write the total location profit of all firms in any location structure L as follows:

$$\Pi_{Total}\left(L\right)=\sum_{\forall i\in A}\sum_{\forall j\in\Omega^{i}}\left(b-c^{ij}\right) \tag{50}$$

It is clear that all firms at a location at which the smallest Euclidean distance to a firm on the boundary of their cluster exceeds d^{ij^*} have an identical location profit of

$$\Pi\ \left(L^{i}\right)=\left[\pi\cdot\left(d^{ij^*}\right)^{2}-1\right]\cdot b-\sum_{\forall j\in\Omega^{i}}c^{ij} \tag{51}$$

which is the maximum possible location profit for any firm. The proof that the overall location profit for all firms is maximised with location in one large cluster proceeds as follows:

1. For any firm with a smallest Euclidean distance to the cluster boundary equal or smaller than d^{ij^*}, the location profit increases with larger distance to the boundary of its cluster.

This follows from the observation that for a given cluster size and a given search radius d^{ij^*}, moving the firm´s location further away from the cluster boundary towards the centre of the cluster increases the number of firms within the search radius of the firm at some distances without decreasing the number of firms at other distances. This unambiguously raises the firm´s location profit.

2. For any distance to the cluster boundary smaller than d^{ij^*}, the location profit of the firm cannot be larger if it is located in a cluster of smaller size (and it will be smaller if the size difference is large enough).

This follows from the observation illustrated in Figure 6 that for any distance to the cluster boundary smaller than d^{ij^*}, the shared area of the cluster and the circle defined by the firm´s search radius increases with larger cluster size due to the smaller curvature of the boundary of a larger cluster.

3. With all firms in one cluster there are fewer firms at any smallest Euclidean distance to the cluster boundary equal or smaller than d^{ij^*} and more firms at a smallest Euclidean distance larger than d^{ij^*} to the cluster boundary than in a location structure with more than one cluster.

The number of firms is given with $|A|$, and it is known that clusters are compact and circle-shaped and that each firm uses up one unit of space for its location. Therefore, using the general formula for the area of a circle:

$$|A| = \pi \cdot r_l^2 = \pi \cdot r_1^2 + \pi \cdot r_2^2 \tag{52}$$

where r_l is the cluster radius in the location structure with only one cluster, and r_1 and r_2 are the radius of cluster 1 and cluster 2 respectively in a location structure with two clusters. It follows from equation (52) that

$$r_l = \sqrt{r_1^2 + r_2^2} < \sqrt{r_1^2 + r_2^2 + 2 \cdot r_1 \cdot r_2} = r_1 + r_2 \tag{53}$$

so that the overall circumference F in a location structure of one large cluster is smaller than the combined circumference of clusters 1 and 2 in the location structure of two clusters.[63] Therefore, fewer firms can locate at each distance to the cluster boundary smaller than or equal to d^{ij^*}, and consequently more firms are located at a distance greater than d^{ij^*} in case of a location structure consisting of all firms in one cluster than in case of a location structure consisting of all firms in two clusters. This argument can easily be extended to the case of a comparison of a location structure of one cluster with a location structure consisting of three or more clusters.[64] This proves that with all firms in one cluster, there are fewer firms at any smallest Euclidean distance to the cluster boundary equal or smaller than d^{ij^*}. As a

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[63] The general formula for the circumference of a circle is $F = 2 \cdot \pi \cdot r$, so that from equation (53) it follows that $F_l = 2 \cdot \pi \cdot r_l < 2 \cdot \pi \cdot r_1 + 2 \cdot \pi \cdot r_2 = F_2$.

[64] Take the example of a location structure of three clusters. In analogy to equations (52) and (53): $|A| = \pi \cdot r_l^2 = \pi \cdot r_1^2 + \pi \cdot r_2^2 + \pi \cdot r_3^2$ and $r_l = \sqrt{r_1^2 + r_2^2 + r_3^2} < \sqrt{r_1^2 + r_2^2 + r_3^2 + 2r_1 r_2 + 2r_1 r_3 + 2r_2 r_3} = r_1 + r_2 + r_3$. The key is that the cross terms, which need to be added to get the sum of the radii of the clusters in the multi-cluster location structure, are always positive.

consequence, in a location structure with one cluster more firms are located at a smallest Euclidean distance to the cluster boundary larger than d^{ij^*} than in any location structure with more than one cluster.

From points 1 to 3 it follows that for a given number of firms the overall location profit of all firms is maximised with location of all firms in one cluster. Q.e.d.

Overall, the discussion in this section aimed to identify equilibrium location structures, and it was shown that any equilibrium structure involves the location of all firms in compact, circle-shaped clusters. The analysis was not interested in the equilibrium location of individual firms. For this, it would have been necessary to discuss equilibrium selection and to specify how firms co-ordinate.[65] This shall not be pursued at this point, and the next section will continue with an interpretation of the discussion so far in the context of the existing theoretical and empirical literature on LKS and clustering.

[65] Firms´ location choices affect each other because firstly, the space chosen by one firm is blocked for all others and secondly, each firm imposes a positive externality on its neighbours. Furthermore, location rivalry arises out of the fact that locations near the cluster periphery yield lower profits than those towards the centre. In order to analyse the equilibrium location of individual firms, the set-up of a repeated game would be useful. This would also allow an analysis of how firms could achieve the one-cluster location structure, which was shown to be optimal in terms of maximising overall location profits. For the analysis of co-ordination mechanisms it would further be interesting to introduce land ownership and the co-ordinating role of land prices into the model.

7.4 Local spillovers of explicit knowledge – an alternative to the LKS story

The discussion in this chapter draws attention to local spillovers of explicit rather than tacit knowledge as a driver of clustering. In chapter 3, it was shown that LKS might not be a useful concept for the analysis of at least some flows of tacit knowledge between agents of the private sector. This is due to the inconsistency involved in using the property of tacitness to argue that knowledge flows are local yet ignoring its implications for the sender´s power to prevent them. Local tacit knowledge flows might therefore not constitute an externality. Explicit knowledge flows, on the other hand, are widely acknowledged in the literature to constitute a case of externalities (except for the case of patented explicit knowledge). However, it is generally argued that these are not local but global because they are carried by disembodied information signals which are assumed to be transferred close to costlessly regardless of geographical distance. The argument in this chapter, however, shows that there is a case for explicit knowledge spillovers to be local rather than global because of costs of information gathering and evaluation, which are rising in geographical distance, and that this might lead to geographical clustering as the equilibrium location structure of profit-maximising firms.

The view of local spillovers of explicit knowledge as drivers of clustering is consistent with the well-known empirical phenomenon that agents citing a patent and agents holding that patent are found to be located in the same region more often than one would expect from the pre-existing concentration of related research activity (e.g., Jaffe et al., 1993; Verspagen and Schoenmakers, 2000). As discussed in the

context of point 7 in section 3.2.3, it seems inconsistent to explain this finding with local spillovers of tacit knowledge because by definition the knowledge revealed in the patent´s documentation is explicit and codifiable. Hence, for an explanation with tacit knowledge flows one would have to resort to assuming the existence of unobserved complementary local flows of tacit knowledge for which patent citations are a suitable proxy measure. While this is not implausible, it amounts to a "proof by assumption", which is not uncommon in the LKS literature: One assumes the existence of local flows of tacit knowledge and then interprets the observation of local flows of explicit knowledge as a suitable empirical proxy and confirmation of the original assumption. This is questionable because an explanation with the help of local spillovers of explicit knowledge is much more straight forward. In this view, the localisation of patent-citing and patent-holding agents is due to the fact that information about the existence and context of patents diffuses more easily in the proximity of its holder.

Secondly, the model of location choice of the previous section points to pecuniary externalities of co-location as an alternative or additional explanation for the empirical findings usually cited in support of LKS. These have received far less attention in the literature.[66] In fact, pecuniary information externalities are consistent with and offer a more elegant explanation for some of the empirical findings, like for

[66] Note that these motives for clustering are independent of the potential role of forward and backward linkages (Fujita et al., 2001) or the presence of Marshallian intra- or Jacobian inter-industry externalities (Glaeser et al., 1992; Jacobs, 1969; Marshall, 1890).

instance the phenomenon that innovative performance of individual firms seems to be more sensitive to external inputs, which are geographically close, than to external inputs, which are further away (e.g., Audretsch and Feldman, 2003). This phenomenon was already discussed in detail in the context of point 2 of section 3.2.3. In the model developed here, the phenomenon is not surprising because better availability of information will provide for a more efficient allocation for commercialisation of tacit knowledge through market-mechanisms. Hence, to the extent that external inputs have a positive effect on external outputs, and external outputs increase supply in the local knowledge market, this should be expected to be particularly beneficial for innovative firms located in the cluster.

Also, empirical work finds that either Jacobian-, Porter- or MAR-type clustering enhances sectoral employment growth (Combes, 2000; Glaeser et al., 1992; Henderson et al., 1995) and that firms located in clusters with a large number of firms or employment in their own industry tend to grow faster (e.g., Swann, 1998) and generate a larger number of innovations (e.g., Baptista and Swann, 1998; Beaudry, 2001) than more isolated firms or firms in less specialised clusters. As discussed in section 3.2.3 in the context of points 3 and 4, these findings too are consistent with the purely pecuniary information externality view. The key is that pecuniary information externalities will allow for faster and more efficient knowledge accumulation of cluster members because they have access to a more efficient knowledge market. Dynamic increasing returns due to the non-rivalry and cumulativeness of knowledge will result from this stronger and faster accumulation of knowledge in cluster members who – standing on each others´ shoulders – will be able to invent and commer-

cialise knowledge better than isolated competitors. The latter will find it comparatively harder to trade and complement their own knowledge with the knowledge of their trading partners. Note that this also addresses a further important motivation for the popularity of the notion of LKS, namely New Growth theory´s need to find sources of external scale economies in order to account for sustained growth differentials between cities or regions (Black and Henderson, 1999; Lucas, 1988; Romer, 1986), previously discussed in point 5 of section 3.2.3.

Next, the observation of industry-specific agglomeration and the fact that specialised clusters seem to be particularly strong stimuli of innovative performance (e.g., Aharonson et al., 2004) are easily reconciled with the presence of pecuniary information externalities because presumably benefits from knowledge exchanges with firms in the own industry are larger than with firms in other industries. A more efficient knowledge market will then be more important and hence so will clustering of the related players to exploit the informational advantages brought about by locating in close proximity.

Finally, the finding of a higher propensity to cluster the more important new knowledge is in the industry (Audretsch and Feldman, 1996) has been used as evidence for the importance of tacit LKS. In the LKS approach, the greater importance of tacit and elusive knowledge, that characterises complex, innovative or young and immature industries (e.g., Audretsch, 1998), has been used to rationalise this phenomenon. Consequently, the LKS explanation only works for tacit knowledge but not for spillovers of explicit knowledge. Again, as discussed in the context of point 6 in section 3.2.3, an alternative explanation for this phenomenon lies in the presence

of pecuniary information externalities because benefits from information in an innovative and hence fast-changing environment are larger than from information in less fast-paced industries. Consequently, more innovative activity would be expected to cluster more strongly than less innovative activity. Furthermore, due to uncertainty in innovative activity it is reasonable to expect firms´ benefits from information about other firms to be positively correlated with the importance of new knowledge in the respective industry. In this case, adjusting the assumptions with regard to the information structure as proposed in this work can account for this empirical phenomenon even without recourse to knowledge externalities, thereby further weakening the case for tacit LKS.

7.5 Summary

The argument of this chapter can be summarised as follows: Firstly, firms benefit from having information about other firms and these benefits are invariant to (or decreasing in) distance. Pecuniary information externalities as well as local spillovers of explicit knowledge are identified as sources for such benefits: Local pecuniary information externalities arise from access to a more efficient market for tacit knowledge due to better availability of information. The notion of stronger local spillovers of explicit knowledge arises from the view that costs of the transmission of information, which is the medium of transport for explicit knowledge, are increasing in geographical distance. Secondly, the costs of information transmission are rising in distance despite the "death of distance" on the supply side of information. The reason for this is that gathering, evaluating and processing information is more

costly the further away from each other sender and receiver are. Finally, under these conditions clustering emerges as the equilibrium location choice of firms. Spillovers of explicit knowledge then work alongside pecuniary information externalities discussed above as a driver of clustering, which should be stronger (1) the more prevalent informational imperfections, (2) the larger the benefits from eliminating them, and (3) the stronger costs of gathering, evaluating and processing information are rising with distance between sender and receiver. Due to the special characteristics of knowledge in economics, these properties tend to be stronger the more innovative (i.e. the more important new knowledge is in) the industry. To the extent that co-location can mitigate informational imperfections, which in turn leads to efficiency-improvements in the market for tacit knowledge, agents located in clusters are able to accumulate knowledge more quickly and commercially more efficiently than agents located in isolation. Due to non-rivalry of knowledge and its cumulative nature, this is a source of external scale economies and enables clustered players to be more innovative and to grow faster than agents outside of clusters. Previously it was argued that it is necessary to rely on dynamic local spillovers of tacit knowledge to explain such effects.

The approach here departs from the existing literature dealing with innovative activity in the following main ways: Firstly, with regard to the information structure the current literature treats information as well as explicit knowledge as easily codifiable messages, which are available costlessly or at low cost invariant to distance. Here it is argued that due to search and processing costs of gathering and evaluating information for the receiver, it is useful to analyse information imperfections. This is

particularly relevant in a situation of information overload, in which the receiver has to find, verify and interpret information that is relevant for him. Furthermore, the costs of information gathering and processing are increasing in distance between sender and receiver.

Secondly, in the view proposed here, clustering helps eliminate informational imperfections, thereby eliminating a source of market failure and providing an incentive for innovative firms to cluster. With regard to pecuniary information externalities, the drivers of clustering differ fundamentally from the view based on LKS: In the latter, clustering involves the costless transfer of an asset as an externality and therefore qualifies as a source of market failure. In the former, clustering helps to provide the basis for efficient market outcomes by mitigating a source of market failure. This point differs subtly but significantly from previous contributions in the literature, which introduced the idea that clusters help mitigate the risks – or what Dosi (1988) called "uncertainty"[67] – inherent in innovative activity (Feldman, 1994a; 1994b). Their claim is equivalent to a claim that clustering somehow changes the knowledge production technology, for instance by skewing the probability distribution of the realisation of new knowledge´s complementarity with the firm´s existing knowledge in a favourable way. Such an assumption is not necessary here.

Thirdly, the argument for clustering developed in this chapter addresses the problem of circular causation in existing theoretical studies on LKS (Krugman, 1995;

[67] The first of Dosi´s (1988) so called "stylised facts" of "contemporary innovation".

Malmberg and Maskell, 2001), which was discussed in chapter 3. While the exact spillover mechanisms leading to the alleged benefits of clustering are not clearly identified, many studies turn the chain of reasoning on its head and use the observation of clustering as proof of the existence of the "black box" of knowledge spillovers. Contrary to this, a model of how knowledge is transferred between profit-maximising firms is developed first, and it is shown how a cluster emerges contingent on assumptions on the information structure as a consequence of profit-maximising firms´ behaviour afterwards. This avoids the fallacy of reverse causality.

8 Welfare and policy implications

The model developed in this work provides a basis for the systematic evaluation of welfare implications of knowledge trading, M&A activity and geographical clustering. In particular, the micro-foundations of and the dynamics involved in knowledge exchanges, which were derived from first principles in the previous chapters, allow the analysis of which conditions are most conducive to economic welfare and growth. It then follows naturally to analyse how they might be affected by policy parameters. This provides a firm theoretical basis as a guide for economic policy aimed at constructing the most favourable environment for innovative activity and growth.

The next section starts with an analysis of the welfare implications of knowledge trading, M&A activity and clustering. Based on this the conditions which are most conducive for economic growth and social welfare are identified. Then the analysis turns to the policy parameters that can help to achieve these favourable conditions and how they depend on the nature of the knowledge in question.

8.1 Welfare impact of different types of knowledge exchanges and geographical clustering

8.1.1 Knowledge trading

As a benchmark scenario to evaluate the impact of knowledge trading the case of exploitation of new knowledge by its producer as a knowledge monopolist shall be used. Knowledge trading affects social welfare in the following main ways: Firstly,

it achieves the allocation of knowledge to the agents which are most efficient at commercially exploiting it. This follows directly from the discussion in section 5.3. In particular, the conditions for knowledge trading to take place require that the knowledge seller is fully compensated for profits forgone[68], and the price mechanism ensures that the new knowledge in question is allocated to the firms that can realise the highest economic benefit from it. Therefore, it follows unambiguously from the conditions for knowledge trading to take place that the overall producer surplus in the economy rises. If this was not the case, it would be impossible for the knowledge buyer to compensate the seller for his profits forgone while still making a profit from acquiring the new knowledge concerned.

Secondly, consider the effect of knowledge trading on consumer surplus. This also is positive, even if the static first best result of no market power for the knowledge producer and universal knowledge diffusion at its marginal cost of zero are not attainable. In case of a monopoly position in the commercial exploitation of new knowledge in the output market, the producer has stronger market power due to the lower degree of substitutability of his output compared to the output of those firms which would otherwise have acquired the knowledge in question. Ceteris paribus, trading therefore results in lower prices, larger quantities and more variety for the consumer, all unambiguously increasing consumer surplus.

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[68] Intuitively, the seller keeps the option of acting as a knowledge monopolist and will only engage in trading if this increases his profits from new knowledge. Relaxing the restrictions of an optimisation problem cannot decrease the attainable extremum. This argument is inspired by Le Chatelier´s principle (Le Chatelier, 1884).

Next, knowledge trading leads to wider and faster diffusion of knowledge in the economy than would be possible in the case of monopoly exploitation of new knowledge by its producer. Due to non-rivalry of knowledge and the knowledge externalities discussed in section 2.3, this will tend to increase the overall pace of progress in the economy, thereby raising innovativeness, the growth rate and the quality of products. All of these effects unambiguously raise social welfare.

With regard to the effect of knowledge trading on the preceding stage of the production of new knowledge and the individual firm´s decision how much to invest in R&D, however, it was shown in section 5.2 that one cannot tell in general which market structure is most conducive to R&D expenditure. Given the analysis of the model presented in this work, it is theoretically possible for instance that a market structure of monopolistic exploitation of knowledge involves a higher investment in R&D of the respective firm than would be conducted in case of knowledge trading. Working on the assumption of lower marginal private than marginal social benefits of and hence underinvestment in R&D activity, to allow knowledge trading would entail a negative effect on social welfare. However, there is a strong case that the impact of enabling firms to trade their knowledge on R&D expenditure is in fact positive. Non-rivalry of knowledge means that the output of each unit of R&D is commercially exploitable by more than one agent. The extent to which the innovator can recoup this increased marginal social benefit for high levels of R&D expenditure by engaging in its sale might be countered by decreased innovation rents and a less favourable revenue function in the resulting market structure. Given the overall increase in the innovating firm´s profits in case it engages in knowledge trading, how-

ever, it would require quite special circumstances for its R&D expenditure to decrease compared to the monopolistic situation.[69] However, it is not possible to show technically and in a general manner which of the effects outlined above dominates.

With regard to LKS the welfare implications differ from those of knowledge trading in important respects. The latter holds the advantage from a stationary point of view of eliminating all market power and providing the knowledge in question at its marginal cost of zero with beneficial consequences for social welfare. With knowledge trading, on the other hand, some degree of market power remains. Furthermore, the potentially wider diffusion (at least among local agents) of knowledge in the spillover case is advantageous for social welfare due to its effect of raising the overall level of knowledge in the (local) economy. With knowledge trading comparatively more firms might remain excluded from the knowledge in question. From a dynamic perspective, however, LKS robs the knowledge producer of his incentives to engage in knowledge production in the first place. This leads to low R&D activity. Knowledge trading, on the other hand, gives the knowledge producer the ability to appropriate the value of his new knowledge and thereby provides him with incentives to engage in R&D activity and knowledge production. This is a point of crucial importance for the policy debate.

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[69] These circumstances include that for the revenue function of the post-trade market structure the marginal revenue from R&D expenditure starts from a higher level (for low R&D expenditure) and then decreases more strongly than for the revenue function in case of monopolistic exploitation of the knowledge concerned.

In summary, one can state that from a static perspective enabling firms to engage in knowledge trading has unambiguously positive effects on consumer and producer surplus compared to the alternative of a monopolistic market structure. From a dynamic perspective it leads to stronger knowledge diffusion which is also unambiguously welfare enhancing. Its impact on the overall amount of R&D expenditure cannot be assessed with certainty as this does not vary systematically with market structure. Consequently, its expected effect in this regard is neither positive nor negative, but should be taken into account as a possible reservation when applied to specific cases.

8.1.2 Knowledge reallocation through M&A activity

It was shown in chapter 6 that M&A is a special form for the reallocation of new knowledge which arises in case of a violation of the necessary assumptions for standard knowledge tradability. The welfare considerations with regard to the effect of M&A in comparison to the alternative that would ensue in the absence of M&A activity differ depending on which of the assumptions actually fails.

Consider first the case discussed in section 6.1 of a break-down in the assumption that the seller is able to commit to not using his own knowledge in the post-trade market structure. In this case the buyer is motivated by the fact that the only way he can achieve a market structure that excludes the knowledge producer from the knowledge´s use is by staging a take-over. An acquisition will then take place, if the profit the buyer would make in his preferred post-trade market structure is so much larger than the profit he would have made in the market structure chosen by

the seller in case of no acquisition that the buyer can afford to fully compensate the seller for his discounted life-time profits forgone and still make a profit.

For the evaluation of M&A´s welfare impact in this case consider the effect on producer surplus first: While seller as well as buyer are both unambiguously better off with the ability to engage in the M&A deal under the given circumstances, the effect on the remaining producers who might have an interest in buying the knowledge in question is not clear. There is no way ex-ante to tell whether the effect on producer surplus is positive or negative. Turning to the evaluation of the effect on consumer surplus next, this also yields an ambiguous result. The point here is that the comparison needs to be made between the post-trade market structure that would ensue under the buyer after the acquisition and the one that would be chosen by the knowledge producer in the absence of an acquisition. In both cases, there will be market power for a limited number of firms in possession of the new knowledge in question which limits consumers´ welfare. Which scenario is preferable cannot be told ex-ante.

Now turn to the case discussed in section 6.2 of a break-down in the assumption that the seller of knowledge is able to control its further diffusion after its sale. This was shown to lead to a situation where the post-trade market structure will be a knowledge monopoly with and without M&A activity. The impact on producer surplus will therefore be unambiguously positive as a transaction can only take place if the buyer can afford to fully compensate the seller for his life-time profits forgone and still make a profit from the transaction. However, the impact on consumer wel-

fare is ambiguous. It cannot be said ex-ante whether the result of the potential buyer or the seller acting as a knowledge monopolist will be better for consumers.

In summary, if the individual decision-maker is solely motivated by profit-maximisation, then there is nothing in the decision process of whether or not to engage in M&A activity that ensures the maximisation of social welfare. There is no reason in this approach, however, why in principle it should be harmful to social welfare either.[70] Market power is associated with a decrease in consumer welfare through lower quantities, higher prices, and lower variety.[71] Therefore, the motivation of the buyer to engage in a take-over, namely to gain control of the post-trade market structure to increase his innovation rents, seems suspicious at first. It is not clear, however, whether the acquisition of a firm will necessarily bring about a more concentrated market structure. Importantly, the resulting post-trade market structure has to be compared with the one that would have been chosen by the take-over target or another acquirer, rather than with the case of no market power at all. The question of M&A activities´ effect on social welfare therefore cannot be answered

[70] It is worth to note that in this model M&A activity, whenever it occurs, will be beneficial for the acquirer as well as for the acquiree. This goes contrary to the connotation the phrase "take-over" carries in everyday language for the take-over target. It is the share-holders´ perspective rather than that of the management or the workforce, however, which is considered here.

[71] Importantly, note that this discussion is in reference to the dynamics in the output market that are due to the restricted diffusion of new knowledge, with its consequence of market power due to decreased substitutability of the resulting produce. Dynamics related to the traditional arguments against market power due to control in the output markets over quantities or prices of homogeneous products are not discussed here. These are dealt with at length in the existing literature. Such effects work independently of and in parallel to the dynamics due to the properties of new knowledge and innovative activity which are the focus in this work.

on a general level. This is particularly the case because even if a take-over entailed losses for consumer welfare, it might still be overall desirable from the perspective of a social planner if a gain on the producers´ side outweighed the consumers´ losses.

It follows from these considerations that no general policy rule can be devised for whether M&A activity due to the motives rooted in knowledge economics as discussed above is welfare enhancing or not. This can be interpreted as constituting additional justification for the existing practice of case-by-case evaluation of M&A deals as a suitable policy design.

8.1.3 Geographical clustering

Chapter 7 showed how clustering of economic and in particular innovative activity is the equilibrium result of profit-maximising firms´ individual location decisions. This result is based on the presence of costs of processing and evaluating information which are increasing in geographical distance, as well as on the existence of benefits from the evaluation of extra information signals as the basis for the decision as to whether and at what conditions to engage in knowledge trading.

Clustering is unambiguously beneficial from a welfare perspective for two reasons: Firstly, search and information evaluation costs are minimised in this location structure. Secondly, with co-location firms evaluate more information about their environment as this is less costly at the margin. As a result, they will be better in-

formed and be more likely to achieve ex-post efficient allocations of new knowledge.[72]

It is important for evaluation of the welfare impact of clustering, however, to realise the importance of the type of knowledge exchange that one assumes it to facilitate. At the heart of the above analysis is the focus on knowledge trading rather than LKS. To the extent that clustering facilitates or is brought about by LKS, as is argued in much of the economic geography literature, this will have adverse incentive effects as discussed in section 8.1.1 with negative effects on welfare from a dynamic point of view and will also lead to very different policy implications, as will be shown below.

8.2 Policy implications

8.2.1 Excludability and control over knowledge diffusion as policy targets

It was shown in the previous section that excludability and control over the diffusion process of knowledge determine whether and how knowledge will be exchanged between agents of the private sector, and that this in turn has significant

[72] A further advantage of clustering arises when firms are risk averse, a possibility which was explicitly abstracted from in the analysis so far. Then if firms collocate in a cluster, they will have certainty about the realisation of a larger number of knowledge vectors, so that they have to make decisions under uncertainty and hence assume risk for a smaller number of potential trading partners. This is a reason why clustering is advantageous from the perspective of the social planner in itself, because decreasing the risk agents are forced to take increases welfare for risk averse agents. Furthermore, it might lead to a greater number of ex-post efficient transactions.

implications for social welfare. The role for government intervention now arises out of the fact that both of these parameters, excludability and control over the diffusion process, can be regarded as at least partially under the control of the policy maker. The government can exert significant influence on excludability and tradability of both explicit and tacit knowledge, for instance through the design of the patent system or through determining contracting, monitoring and enforceability options at the hands of knowledge producers. Therefore, the model developed in this work has important implications for policy design.

With regard to the most favourable conditions for social welfare and economic growth, it is useful to consider the following three scenarios (Table 2):

Scenario I: Non-excludability and no control over the diffusion process. Knowledge spills over. Statically, this is beneficial for social welfare as it leads to diffusion of knowledge to all firms and through competition in the output market to delivery of its benefits to all consumers at its marginal cost of zero. Also, the resulting local diffusion of knowledge is conducive to growth. However, due to their inability to appropriate the value of their knowledge output private agents lack the incentive to pursue R&D: private marginal benefit from R&D in the spillover case is zero. Subsidies and public provision of R&D on a large scale are necessary.

Scenario II: Excludability and control over the diffusion process. Knowledge exchanges are internalised in a market. The resulting knowledge diffusion has a positive impact on growth. Furthermore, increased appropriability of knowledge leads to a partial solution of the incentive problem with regard to private R&D activity. Still

private marginal benefit is lower than social marginal benefit from R&D so that underinvestment results if left to the private sector alone. Diffusion of knowledge is less than universal and externalities are likely to still exist. Therefore, a case for government involvement remains, albeit on a smaller scale and with smaller information and co-ordination requirements on the public sector than in scenario I.

Scenario III: Excludability but no control over the diffusion process. Agents are able to keep knowledge to themselves for appropriation through own output, but there will be no diffusion of knowledge. As discussed in chapter 6, producers know that if they passed on their knowledge to other agents it would diffuse for free, eliminating any innovation rents. The private marginal benefit, which is much lower than the social marginal benefit, determines the amount of R&D activity. This leads to severe under-provision of R&D in addition to a high degree of duplicative and wasteful efforts. Furthermore, by preventing knowledge diffusion, this scenario does not allow for the increasing returns dynamics to kick in at the aggregate level with adverse consequences for economic growth.[73]

[73] Note that for knowledge which is not excludable it follows that its diffusion process cannot be controlled either. A scenario IV consisting of a set-up of non-excludability and control over the diffusion process therefore cannot exist.

Table 2: Welfare impact and policy challenges of different settings of excludability and control over the diffusion process

excludability	knowledge diffusion control	consequences			policy challenge[74]
		consumer and producer welfare	*incentives for R&D*	*knowledge diffusion*	
I. No	**No**	First-best statically due to universal provision of knowledge at MC of zero; problematic dynamically due to adverse consequences on new knowledge production	No incentive for R&D in private sector due to impossibility to appropriate the value of knowledge output	(L)KS, universal local diffusion of knowledge; positive impact on growth is countered by lack of incentives to engage in private R&D	Knowledge production becomes responsibility of public sector: R&D subsidies, public R&D in universities, etc. Problems include coordination and market-orientation of R&D thus provided; large information and management requirements on public sector
II. Yes	**Yes**	First-best for producer surplus; consumer surplus rises compared to monopolistic knowledge exploitation (lower prices, increased quality, more variety); statically consumer surplus smaller than first-best due to possibility of remaining positive mark-ups	Incentive problem addressed through market mechanism, appropriation of knowledge value; R&D pursued by private agents, possibly underinvestment because pure and pecuniary externalities keep private below social MB	(Limited) knowledge diffusion through trading with positive dynamic effects for growth; universal diffusion possible but unlikely	Enforcement of excludability and control over diffusion (via patents and licensing for explicit and via contracting and monitoring for tacit knowledge); still case for R&D subsidies due to pecuniary and pure knowledge externalities at the aggregate, but much less than with LKS
III. Yes	**No**	Monopolistic knowledge appropriation through own output for knowledge producers, i.e. lower than in trading case; consumer welfare minimised with monopoly exploitation of knowledge	Private sector has incentive, but private benefit much lower than social benefit, i.e. severe underinvestment in R&D by private agents; high degree of duplicative & wasteful R&D	No exchange of knowledge, i.e. no diffusion and hence no increasing returns dynamic; Worst case diffusion scenario for growth	Public provision of knowledge for sharing in the economy to make up for lack of growth impetus from private R&D activity; co-ordination of private R&D to avoid duplication and waste; large information and management requirements for public sector

Source: own design

[74] A policy challenge which arises in all of the scenarios discussed here is the potential role for government regulation of private firms´ choice of a market structure with low optimal R&D levels (section 5.2). This requires a case-by-case evaluation and would require a policy with regard to knowledge diffusion similar to antitrust policy applied to M&A activity.

The two main conclusions from this analysis are the following: Firstly, due to the trade-off between the static advantages from full diffusion at a price of zero and the need to provide incentives for R&D activity in the private sector, the first best outcome both, from a static and a dynamic perspective, is not attainable. Secondly, judging from the perspective of how well the private sector would do without government intervention in each scenario, a setting of excludability and control over the diffusion process (scenario II) produces the best results for social welfare. It allows for a balance of static and dynamic concerns of consumer and producer welfare on the one hand and growth on the other hand. With the aim in mind to minimise the need for government intervention, this is therefore the most desirable scenario.[75] This is followed by a setting of non-excludability and no control over knowledge diffusion (scenario I) as the next best case for social welfare. Scenario III, on the other hand, is the worst case from a welfare point of view.

From this it is possible to derive a set of policy objectives: For those types of knowledge where it is achievable, the policy maker should aim to design a legal environment that enables knowledge trading to take place by providing for and enforcing excludability and control over the diffusion process (scenario II). In those instances where this is not attainable, it is preferable to ensure non-excludability of knowledge

[75] The aim to minimise the need for corrective intervention on behalf of the government is adopted as the principle of choice for the most desirable scenario here. This can be justified by a sceptical view of a central planner´s ability to collect and evaluate the information and to implement and coordinate corresponding measures, which would be necessary for a centralised intervention to ensure first-best outcomes.

(scenario I) to avoid the possibility of a situation of excludability of knowledge without control over its diffusion process for the sender (scenario III). The remainder of this chapter is devoted to exploring how this might be done and what instruments at the policy maker´s disposal to influence these parameters.

Looking at the analysis summarised in Table 2, it is clear that the largest welfare increase can be achieved by making sure that the diffusion process of excludable knowledge is controllable for the seller. In the terms of Table 2, this allows a move from scenario III to the dynamics outlined in scenario II.

8.2.2 Determinants of control over the diffusion process

As already discussed in the context of section 3.3, in order to have control over knowledge diffusion it is necessary for the knowledge producer to either be given an easily enforceable patent (explicit knowledge) or to be able to write a contract with or otherwise commit his trading partners to not engage in any knowledge trading which is not contractually agreed upon with the knowledge producer (tacit knowledge). Effective control over the diffusion process is further complicated by the difficulty of monitoring potential violations of such agreements.

As a consequence, the legal and judicial environment plays a pivotal role for innovators´ control over knowledge diffusion. Policy makers provide agents with such control by strengthening and facilitating the monitoring and enforcing of contracts relating to knowledge transfers. Examples for such policy measures include the provision of support with regard to monitoring the diffusion of particular knowledge. This, for instance, could be a service provided by a government agency or a

research institute.[76] Further measures include cheap and swift pursuit of claims of knowledge sellers against suspected perpetrators with effective penalties, if found guilty, as well as subsidised legal advice in such matters, in particular for smaller innovative companies.

Given the international mobility of companies, people and ideas, it is an important point that control over the diffusion process might not be achievable through legislation and regulation at the national level alone. Instead, international cooperation might be required to enable effective diffusion control for the knowledge producer. This is particularly so for countries and regions with lively trade and for knowledge which can be used in types of products which are not tied to a particular location for instance due to input requirements, transport costs or trade restrictions.

8.2.3 Determinants of excludability

The patent system is the mechanism through which an innovator can achieve excludability for (some types of) his codifiable knowledge.[77] Hence, the regulations, standards and practices of the respective patent office determine the degree of excludability of any particular piece of explicit knowledge by deciding whether it quali-

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[76] For patented knowledge this is done for instance by patent attorneys in the USA, who complete filings with missing citations.

[77] Software for instance was unpatentable in the USA until 1981, and only since 1998 is it possible to patent "business methods". The latter is still not patentable in Europe, where the former also is handled with close scrutiny. (Cukier, 2005, p. 6)

fies for patenting and by determining the length and breadth of patent protection.[78] As discussed above, costs of registering, monitoring and enforcing patents also play a critical role. Other ways of achieving excludability for explicit knowledge involve arrangements regarding the protection of documents and files and restricted access to sensitive information (incl. for instance clearance hierarchies, etc.) which can be very costly to design and implement.

With regard to excludability of tacit knowledge it was established in section 3.3 that one of the defining characteristics of tacit knowledge is that it is embodied in people. Consequently, excludability follows from the definition of tacit knowledge as requiring the participation of the sender for its transfer. The following section shows, however, that it is fruitful to explore this notion in more detail for a more differentiated understanding of implications for policy design.

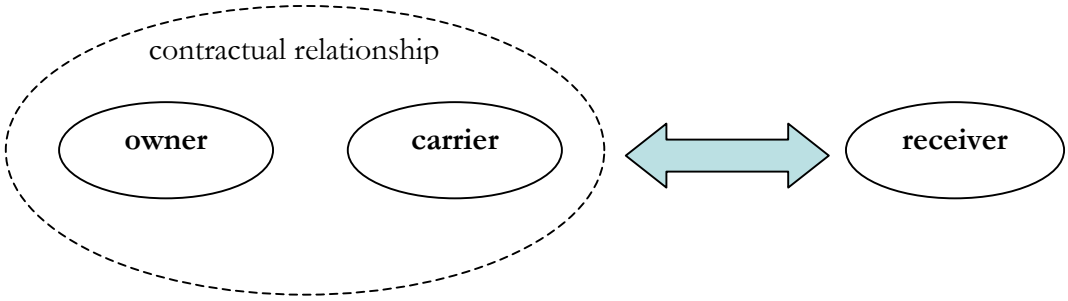
8.2.3.1 Owner, carrier and receiver of knowledge

It is useful at this point to introduce a distinction of what was so far referred to collectively as the "knowledge sender" into "knowledge owner" and "knowledge carrier". These agents might not be identical. For instance, a legal entity like a firm often is the owner and an employee the carrier of a particular piece of knowledge.

[78] An analysis of the question of the optimal design of the patent system is not within the scope of this work. There is an extensive literature on issues such as optimal length and breadth of patents which the interested reader is referred to. (Gallini, 1992; Gilbert and Shapiro, 1990; Hopenhayn and Mitchell, 2001; Klemperer, 1990; Lampe and Niblett, 2003; O´Donoghue et al., 1998; Wright, 1999)

When this is the case, it is quite conceivable that the owner cannot control the knowledge flow because he has insufficient control over the carrier, for instance due to his inability to write a sufficiently complete contract. The problem of incomplete contracts in the context of new or complex knowledge is particularly severe because it is rarely possible ex ante to specify all contingencies and to codify all relevant knowledge subject to the contract (Arrow, 1962; Mowery, 1983; Williamson, 1975).

Figure 7: Owner, carrier and receiver of knowledge



Source: own design

The existing literature does not make this distinction into owner and carrier. In those instances where owner and carrier are the same person or where the owner can effectively control the behaviour of the carrier, this is not problematic. The problem arises once one allows for the possibility that the carrier pursues his own interests and that these differ from those of the owner. Hence, to the extent that the carrier acts as an independent maximising agent (e.g., an employee), whose actions might differ from the actions that the owner of the knowledge (e.g., a firm) would have wanted him to undertake, the carrier´s best response function becomes a constraint on the owner´s maximisation problem.

This distinction is most relevant for the case of tacit knowledge as it is embodied in the carrier. Consequently, a trade-off arises between the owner´s intellectual property rights on the one hand and the basic right to freedom of the carrier (e.g., the right to free job choice) on the other hand. For explicit knowledge, this trade-off does not arise in this form, as it can be held by the owner independently of the carrier.

It is important to recognise that in those instances where owner and carrier of tacit knowledge are not the same agent, ultimate control over the knowledge flow lies with the carrier. In this instance, the tacit knowledge in question will be excludable for the knowledge carrier for the reasons set out in chapter 3.3. It might not be excludable though for the knowledge owner. In this case, two separate questions arise:

1. Is the tacit knowledge concerned appropriable for its owner?

2. Is it a spillover from the perspective of the receiver?

The distinction between these two questions is a new contribution to the analysis of knowledge flows. The existing literature treats these two as one and the same question. Some reflection reveals that this is incorrect. For instance, the knowledge carrier (the employee) might transfer tacit knowledge against the interests of and without compensation for the knowledge owner (the firm) by changing into the employ of another company. As discussed above, the options of the owner to appropriate such a knowledge flow might be limited by the inability ex ante to write and enforce a contract. The carrier, on the other hand, might still extract a payment

for the transfer of his knowledge from the receiver. In the example of the poached employee this could be through a higher salary or a higher sign-on or end-of-year bonus. As a consequence, the knowledge concerned would at the same time be non-appropriable for its owner and not a spillover for the receiver. Instead, the carrier appropriated the owner´s rent. The separate consideration of the two questions is of importance because it enables the researcher to ask the right question in the first place and to isolate the analysis from irrelevant dynamics that concern one but not the other of the two questions above.

Furthermore, the distinction between owner and carrier is of importance for the question of economic policy because as shown above excludability of knowledge is a necessary condition to ensure knowledge appropriability for its owner. This is required to provide the latter with sufficient incentives for the conduct of R&D in the first place. The first of the two questions above, therefore, takes centre stage with regard to policy evaluation in the current context.

8.2.3.2 Policy tools and targets

Given excludability of knowledge for its carrier, it follows from the considerations above that it is the interaction between knowledge owner and knowledge carrier as independent maximising agents that determine the extent of excludability of tacit knowledge for the knowledge owner. This relationship is highly sensitive to the legal environment and its enforceability. Consider for instance the type of activities that can lead to the owner being cheated for the returns of his knowledge by the carrier, such as poaching of employees and spin-outs, in particular involving tacit-

knowledge-intensive employees such as company researchers in case, for instance, of pharmaceuticals or high-tech companies or relationship networks in case of investment bankers or consultants. The policy maker can influence such interactions for instance with the help of labour market regulations, intellectual property rights protection and employer vs. employee rights.[79]

The policy recommendations that emerge from this analysis, however, differ depending on the policy makers ability to ensure the control over the diffusion process after the sale of knowledge discussed in the previous section: For those types of knowledge for which the policy maker has the power to enable the sender to control the diffusion process of excludable knowledge after its sale, policy tools should be used to allow for the highest possible degree of knowledge excludability for the knowledge owner. This ensures that the dynamics discussed in scenario II will kick in, avoiding the alternative of scenario I. In practice this means, for instance with regard to the labour market, that strict rules are required to balance the employees basic right of freedom to move between employers or to set up their own business with the need to protect the intellectual property of their former employers. At least from the perspective of knowledge diffusion, R&D activity and growth, a company-

[79] An example from German labour law is an employer´s option to agree with his employee on a so called "Karenzentschädigung". This has to be agreed on in writing and in advance. The "Karenzentschädigung" involves a payment of at least 50% of the employee´s wage, which obliges the latter to not engage in competition with his former employer even after leaving the company ("nachvertragliches Wettbewerbsverbot" following §§ 74 ff. HGB). It can be agreed upon for a maximum of 2 years.

friendly legislation and strict enforcement of such rules with effective penalties for breaking them are the optimal policy design for this type of knowledge.

Importantly, however, for those types of knowledge for which the policy maker is not able to ensure that the post-trade diffusion process is controllable for the sender, the policy aim must be to ensure non-excludability of knowledge, aiming to achieve scenario I in Table 2 and to avoid the alternative of worst-case scenario III, which would otherwise obtain. In practice this means therefore, that it is one of the main tasks for policy makers to categorise knowledge as to whether it can be subject to binding contracts with regard to its post-trade diffusion and whether it is possible to ensure its excludability for its owner. On the basis of this classification then, the right policy mix can be applied according to the rules as set out above.

These policy conclusions are particularly interesting as they stand in partial contrast to the LKS view, which has gained ground in particular with regional policy makers in recent years. It is important to understand that while local authorities are welcome to act as facilitators for the flow of information and even such knowledge for which the seller cannot control its post-trade diffusion, the tendency to encourage the costless diffusion of the type of tacit knowledge discussed here, for instance through facilitating poaching within the cluster, is counter-productive from the point of view of encouraging R&D activity and growth.

8.2.4 Regional policy

It follows from the analysis so far that the challenge for regional policy consists in building an environment that is favourable for clustering without hindering

excludability and control over the diffusion process. The aim of regional policy should therefore lie in facilitating the flow of information and knowledge for which the diffusion process cannot be made controllable while upholding and enforcing intellectual property rights where a knowledge market can be created.

The potential implications of the view of clustering developed in this work for regional policy makers aiming to attract and foster innovative clusters are substantial. If firms are seen to cluster mainly in order to benefit from knowledge spillovers, this has fundamentally different implications than when they cluster mainly in order to minimise informational imperfections and transaction costs. To assess which of the two scenarios is applicable, the policy maker again has to categorise what type of knowledge he is dealing with and act accordingly. For those types of knowledge for which the sender can in principle control the diffusion process, policy makers should aim to minimise informational imperfections within the cluster while strictly protecting individual firms´ property rights to enable the market to work. This is contrary to the alternative of facilitating knowledge spillovers, which basically amounts to enhancing an instance of market failure.

Would policy implications be different in practice? In both cases it is desirable that local agents interact frequently and get to know each other to build up trust. In the LKS story this serves to spill their tacit knowledge, and in the market-based story to exchange information and minimise transaction costs in the knowledge market. There will be differences, however, in some important areas. Strict property rights protection especially with respect to exchanges through the labour market and en-

forceability of such regulation are imperative for the market-based view of clustering. The opposite is the case from the point of view of the LKS story.

However, the regional policy maker might not be able to influence both parameters, the degree of excludability and the degree of control over knowledge diffusion. In particular the latter is – depending on the country – likely to be vested mainly with legislative and executive authority at a higher than the regional (e.g. the national) level and might depend on the cooperation of many agents in order to be valid beyond national borders. As alluded to above, the latter might be necessary to ensure effective control over diffusion for at least some types of knowledge. While the regional policy maker might find to have no or very little influence on the degree of diffusion control for the knowledge producer, he is likely to have significant (even if not exclusive) influence on excludability of knowledge of local agents, for instance through shaping local networks and business ethics or by exercising certain judicial and executive powers which might be delegated to his authority. As a consequence of shared and higher-level authority the regional policy maker might find himself in a game with many players, or be able to exercise significant influence on only one of the determinants of the type of ensuing knowledge exchange, namely the degree of excludability of knowledge.

Consider for instance the stylised situation in which an (inter-)national policy maker sets policies relevant for diffusion control, while the regional policy maker determines the excludability of knowledge. The optimal policy choice of the regional decision maker now depends on whether he trusts the national decision maker to manage to ensure control over the diffusion process. If the regional policy maker

expects control over knowledge diffusion to hold, then he will choose excludability as the local policy and the scenario identified as the most preferred from a social welfare perspective in Table 2 is attained. However, if he expects the national level to fail to provide innovators with control over the diffusion process, then he should choose non-excludability as the local option to prevent the worst-case scenario III in Table 2. Co-ordination of the different layers (regional, national, international) and branches (legislative, executive, and judiciary) of authority as well as the question of whether decisions are made simultaneously or sequentially (and if so in which order) therefore arise as important questions with regard to the institutional set-up determining effectiveness and success of policy design.

8.3 Summary

Knowledge trading and geographical clustering of economic activity were shown to be welfare enhancing and therefore desirable from the perspective of the policy maker. M&A activity on the other hand could not be shown to be welfare enhancing in general, while there is no reason that it should be harmful in general either. A case by case evaluation was therefore argued to be the most suitable policy approach to regulating M&A activity, which is consistent with the current practice in most countries.

Next, it was shown how excludability of knowledge and the seller´s control over the diffusion process determine what type of knowledge exchange will take place. The welfare implications of the different possible scenarios characterised by these two properties were identified, and it was possible to rank them with regard to

their social welfare impact. In particular, knowledge excludability and control over the ensuing diffusion process (scenario II) were found to be preferable to the case of non-excludability and a consequent lack of control over the diffusion process (scenario I) from a welfare maximisation point of view. The reason for this is to be found largely in the dynamic advantages of the former scenario with regard to setting incentives for private R&D activity, while at the same time providing for the diffusion of knowledge with advantageous consequences for economic growth. The worst case scenario was found to consist of a combination of the characteristics of excludability and the lack of control over the diffusion process (scenario III). This leads to severe under-provision of R&D activity due to a large gap between private and social marginal benefits as well as to duplicative and wasteful R&D. Furthermore, in this scenario the diffusion of knowledge is prevented by the profit-maximising firm with negative consequences for economic growth. The policy objectives should therefore be inspired by the aim of achieving scenario II, where possible, and avoiding scenario III through steering towards scenario I otherwise.

The degree of excludability and the control of the sender over the diffusion process were thereby identified as the relevant policy targets to influence the welfare impact of knowledge exchanges. It followed from this that it is an important task for policy makers to decide what type of knowledge they are dealing with and to apply a different type of policy mix to different types of knowledge. According to the arguments in this work, policy needs to distinguish between knowledge of which the diffusion can be controlled and knowledge where this is not possible. For the latter, it should foster LKS. For the former, it is best advised to focus on the elimination of

informational imperfections, while upholding intellectual property rights in order to enable knowledge trading. It was further argued that legislative and executive authority to ensure control over the diffusion process typically lie dominantly at the national level. Furthermore, in the context of globalisation and international trade establishing and enforcing control over the diffusion process of knowledge might require extensive international cooperation beyond national boundaries. This is particularly important as the degree of control over the diffusion process determines what is the optimal choice of regional policy which exerts influence mainly on the degree of excludability of knowledge.

The policy tools at the disposal of the policy maker to affect the policy targets identified in this chapter are mainly labour market legislation, intellectual property rights protection (and the design of the patent system) and in particular their enforceability and associated costs through the judicial system. Furthermore, given the potential conflicts of interest between owner and carrier of knowledge it assumes a pivotal role for growth and innovation enhancing policy design to enable contracting, for instance through strict and effective intellectual property rights protection in the relations of firms and employees.

In summary, the design of a legal and regulatory framework conducive to knowledge production and exchanges and hence growth and welfare is an important area for economic policy. It is a contribution of the model developed in this work that it provides the micro-foundations for a differentiated and well-grounded set of policy recommendations based on a clear identification of targets and tools.

9 Conclusion

This work set out to build a model of the exchange of knowledge between agents of the private sector to study its implications for innovation, social welfare and economic policy. For this purpose, chapters 2 and 3 identified the special characteristics of knowledge in economic activity and discussed the peculiarities of its exchange, both of which differentiate it from ordinary inputs and outputs. The main findings of these chapters can be summarised as follows: Previous attempts at modelling the role of knowledge in economic activity did not take into account the importance of the joint effects of uncertainty, cumulativeness and complementarity in innovative activity, which was the subject of Chapter 2. Chapter 3 then showed that the LKS-dominated view of knowledge exchanges misses the point that important types of tacit knowledge are likely to be excludable, undermining the standard spillover story. Given excludability, it comes down to the degree of the knowledge producer´s control over the knowledge diffusion process after having shared it with other agents to determine whether it is tradable in a market or not. The degree of the producer´s diffusion control is dependent on his ability to contract, monitor and enforce agreements with buyers of his knowledge and – depending on the type of knowledge concerned – his ability to register and enforce patents, which points to the importance of the legal and regulatory framework for knowledge tradability.

The discussion of the nature of innovative activity and knowledge exchanges provided the motivation for developing a general model of knowledge trading in chapters 4 and 5. Chapter 4 introduced vector methodology as a tool to capture

those aspects of knowledge in innovative activity which have gone unnoticed in previous models. Chapter 5 then built a model of market-mediated exchanges of knowledge in a setting of perfect information, identifying both, necessary and sufficient conditions for knowledge trading to take place, and using these conditions to identify and discuss its drivers. The main contribution of this effort is twofold. Firstly, the methodological innovation of capturing knowledge-specific characteristics with the help of vectors instead of one-dimensional variables is new to the literature. This is useful because the characteristics of knowledge which went unnoticed in one-dimensional modelling attempts might be drivers of dynamics, which for lack of alternative explanations have been attributed to other causal factors. Furthermore, it enables future research to re-visit previous research results to test their sensitivity with regard to the left-out characteristics of knowledge. The second main contribution lies in the finding that exactly those knowledge properties, which were not captured in the set-up of previous attempts to model knowledge in economic activity, turn out to be important drivers of knowledge trading. These are in particular the degree of complementarity and the impact of cumulativeness and uncertainty, as well as the productivity and the efficiency effect with respect to the impact of current innovative activity on future success at finding and commercialising new knowledge.

Chapters 6 and 7 then explored extensions and applications of the model of knowledge trading. Chapter 6 looked at the break-down of two assumptions: First, the impact of the inability of the knowledge producer to commit to a post-trade market-structure that excludes himself from the use of his knowledge. Second, the consequences of the producer´s inability to control the knowledge diffusion process.

In particular the latter is a fundamental extension of the model, as it addresses the failure of the assumption that was previously identified as a condition for knowledge tradability. Both cases discussed in chapter 6 were found to give rise to M&A activity as an alternative to knowledge trading for the reallocation of knowledge to those agents that are most efficient at commercially exploiting it. This added two motives from the perspective of knowledge economics to the literature on potential drivers of M&A activity, namely to gain control over the post-trade market structure for the commercial exploitation of new knowledge, and the lack of alternative channels for knowledge reallocation. Chapter 7 then extended the model to a setting of imperfect information to address the phenomenon of geographical clustering of economic activity. Drawing on the existence of costs of processing and evaluating information from the Theory of Institutions literature and the assumption that these are rising in geographical distance, as well as on tools from game theory, it was possible to show that clustering emerges as the equilibrium location structure of profit-maximising individual firms´ location decisions. The significance of this result is that clustering is explained without recourse to LKS, which were shown to be a widely accepted yet weak concept, both theoretically and empirically, in chapter 3. Finally, it was shown that the alternative explanation of clustering provided in this chapter is consistent with empirical evidence.

The final part of this work turned to the analysis of welfare and policy implications. Knowledge trading and clustering were found to be desirable from a social welfare perspective, while M&A activity should be evaluated on a case by case basis. Importantly, it was possible to identify excludability and the degree of the seller´s

control over the diffusion process as policy targets which determine the type and welfare impact of ensuing knowledge exchanges. It was identified as one main task for the policy maker to classify the type of knowledge he deals with in the diffusion control - excludability dimension, and to apply the right policy mix accordingly. Finally, the policy tools at the disposal of the policy maker were identified, and institutional issues with regard to the coordination of different layers and branches of policy design and implementation were discussed. Overall, this provided a comprehensive and differentiated set of policy recommendations based on the model of knowledge exchanges developed in the previous chapters.

With regard to future research this work raised several questions, which can help structure the research agenda. A promising first step towards an empirical validation of the concept and potential importance of market-based exchanges of tacit knowledge postulated here lies in a systematic evaluation of the possible internalisation of knowledge flows through the labour market. For this purpose it seems useful to employ the distinction of the concept of knowledge sender into knowledge owner and carrier which was introduced in chapter 8, and to extend it with a theoretical analysis of their interaction in the market. A comparison of the extent to which owners´ appropriability options are protected at different locations and the impact this might have on the carriers´ wage curve and the respective locations´ innovative success are a promising starting point for the empirical operationalisation of such an analysis.

Furthermore, with regard to the debates that have started the interest in the phenomenon of LKS, this work points to the following distinct research questions:

For the economic geography debate it is decisive to understand to what extent flows of (tacit) knowledge are in fact local. For this purpose the mobility of knowledge carriers rather than knowledge owners needs to be analysed. Regional extension is of relevance here, because it was shown above that the desirable dynamics regarding external scale economies and growth are attainable in case of both, LKS and market-mediated local knowledge exchanges. The focus on LKS in the existing literature resulted from the view that either knowledge is non-excludable and spills over, or it is excludable and does not diffuse at all, with the negative welfare implications which were outlined in scenario III of Table 2. The possibility of knowledge trading was not taken into account. This view, however, was shown to be mistaken in this work, and consequently so was the focus on spillovers of knowledge.

For the New Growth context, on the other hand, it is the amount of knowledge flows rather than the extent to which such flows are internalised which is most important. The reason for this is that the former determines the extent of external scale economies. To study this question, it again seems sensible for future work to focus on the interactions of knowledge owners and carriers and how they organise their "fight" to determine who gets to appropriate the value of their knowledge. In this context, the institutional, legal and cultural environment is likely to be an important determinant of the amount of knowledge produced and the amount of knowledge exchanged in any particular location and industry.

The final area which promises to be fruitful for future research is at the intersection of law and economics. From the perspective of the policy maker, it is important to understand exactly how and to what extent policies and the regulatory

framework can affect the two policy targets of excludability of knowledge and the seller´s control over the knowledge diffusion process identified in chapter 8. Research into this question involves the analysis of the type of legal, regulatory and even cultural environment, which is required for the policy maker to treat these two parameters as endogenous and steerable.

In summary, it was the ambition of this work to develop a more satisfactory framework for addressing the special characteristics of innovative activity and their implications. A market-based model of knowledge production, exchange and geographical diffusion was developed, which serves both, to weaken the concept of LKS and to provide an alternative micro-foundation for theories that rely on them. Most importantly these are Geographical Economics and New Growth Theory. By using a bottom-up approach of moving from first principles to the outcome of optimising individual behaviour under certain well-identified assumptions, it was possible to address the problem of circular causation pointed out by Krugman (1995). This is one of the major shortcomings of the top-down approach of the existing literature relying on a "black-box" type of concept like LKS to justify its assumptions at the micro-level. The results of this effort are a re-evaluation of the social welfare impact of knowledge exchanges as well as a guide for policy design and the future research agenda.

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2002–03	M.Sc. Economics, London School of Economics and Political Sciences, UK; passed with Merit and offer to proceed to MPhil/PhD stage GRE test: Quantitative (800/97%), Analytical (780/96%), Verbal (680/95%)
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1986–95	Abitur (A-Levels), Hermann-Tast-Schule, Husum, Germany; final mark: 1.0

<u>Academic prizes and scholarships</u>

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- Economic and Social Research Council, UK; merit-based scholarship, "Full Studentship" for 1+3 MSc/ PhD Economics program, Oct. 02–Sept. 06

- George Webb Medley Prize 1999 for the best economics undergraduate thesis at Oxford University, UK
- Howarth Prize 1999 in Economics, University College, Oxford University, UK
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Publications

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2000–2002	longhours GmbH, Hamburg, Germany (consulting and IT-solutions) MD and Partner ("Geschäftsführender Gesellschafter")
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1998	Merrill Lynch, London, UK; summer internship with M&A team
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1995–96	Camphill Community Dunshane, Naas, Ireland, and Pestalozzi Schule, Husum, Germany; Social Service ("Zivildienst")

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- "Gründerwettbewerb Multimedia 2000", 1st prize of national business plan competition of the "Bundesministerium für Wirtschaft und Technologie"
- "Award for Typographic Excellence, 2000", Type Directors Club, New York, USA
- "Investmentforum 2001: Sonderpreis für das beste unternehmerische Team", prize for the best entrepreneurial management team in national competition of start-up companies in Germany
- "eConomy Award 2001", elected one of Germany´s top-20 startup companies (jury comprising among others Boston Consulting Group, Sun and Wirtschaftswoche)