The Spatial Agglomeration of High-tech Industries: Empirical Evidence and Theoretical Explanations from a Micro-Perspective

Inauguraldissertation
zur Erlangung des akademischen Grades
Doctor rerum politicarum
der Universität Dortmund

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May 2006

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Preface

This dissertation presents the research I undertook during the two years I was holding a scholarship of the German Research Foundation at the Graduiertenkolleg "Allokationstheorie, Wirtschaftspolitik und kollektive Entscheidungen", University of Dortmund, and later when I was a teaching and research assistant at the Chair of Public Finance and the Chair of Micro-Economics.

I have highly benefited from discussions with professors and fellow doctoral students of the Graduiertenkolleg and at several European conferences. In particular, I want to thank Wolfgang Leininger, Wolfram Richter and Kornelius Kraft, who supervised my dissertation. Moreover, I am indebted to Michael Roos, Christian Bayer, Pavel Stoimenov, Björn Alecke, Gerhard Untiedt, Tony Jevcak, and Falko Jüßen who all helped me to improve this thesis in various ways. I thank Christian Bayer and Michael Roos for encouraging me to do research based on formal models and to begin writing down my results at a very early stage of my time in Dortmund. I appreciate their and Julia Angerhausen's and Tony Jevcak's friendship and advice in all non-academic needs. Not only academically, but also personally this has been an enriching time for me.

I am grateful to Björn Alecke and Gerhard Untiedt for introducing me into the world of (regional) economics and for all their helpful suggestions and I thank Wolfgang Leininger and Wolfram Richter for offering me this challenging opportunity to move from business administration to economics and for letting me gain some first experience in the field of teaching students.

Cologne, May 2006

Christoph Alsleben

"There's a velocity of information here in the Valley that is very high, not as high as it used to be, but I can assure you that it is much higher than it is in most other areas of the country."

From Saxenian (1994, p. xi)

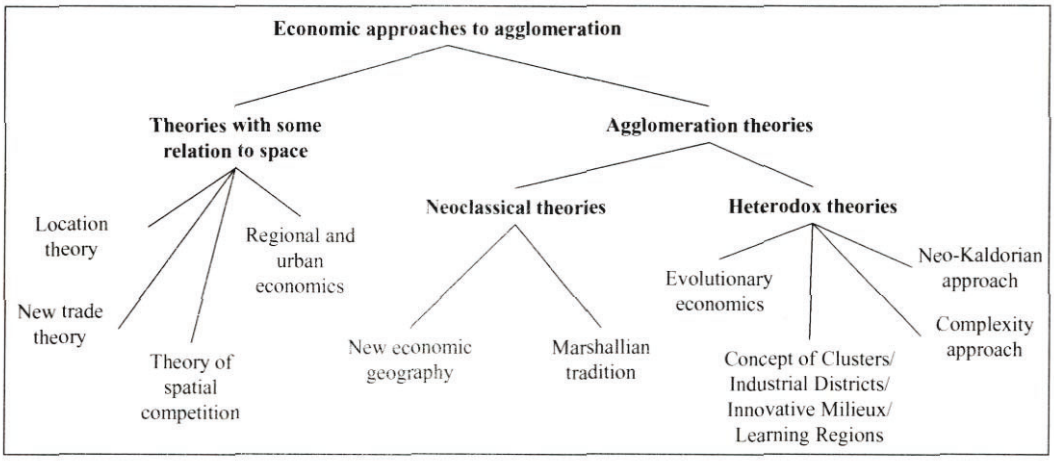
1 Introduction

Set off by Krugman's seminal work (1991a, b) there was a surge in mainstream economists' interest in the spatial pattern of economic activity at the beginning of the 1990s. This resulted in an explosion of research devoted to the very issue and a huge range of approaches. One strand of the literature has been concerned with identifying the reasons for the economic success of particular regions and has developed descriptive concepts such as the "Industrial District" (Piore and Sabel 1984), the "Innovative Milieu" (Camagni 1991), the "Learning Region" (Lawson 1999, 2000, Lawson and Lorenz 1999, Boekema 2000 and Lorenzen 2001) and the "Cluster" (Porter 1990, 1998; see Asheim 2000 for a survey of these concepts).

Another strand of the literature attempts to explain spatial phenomena more generally with the help of economic theory and draws from a number of very different fields of research. Figure 1.1 shows how these approaches to agglomeration can be classified.

The work presented here examines firms' incentive for agglomeration from a micro- (firm-level) perspective. It is neoclassical insofar as it employs equilibrium analysis of profit-maximising firms and it stands in Marshall's (1920) tradition as it focuses on one of his inter-firm externalities, namely the aspect of "knowledge spillovers".

Figure 1.1: Classification of economic approaches to agglomeration



Source: Own depiction based on classifications proposed in Roos (2002) and FISI (2000).

This focus is motivated, first, by the empirical evidence that there is no general relationship between the degree of agglomeration and high-technology related business in German manufacturing industries (this somewhat unexpected result is presented in chapter 2). The corresponding analysis in turn is motivated by the observation that European regional policy—and partially even regional research studies—are obsessed with the notion of "high-tech clusters" and the "learning region" and conceive them as a universal tool against unemployment and other economic problems in backward regions (see, for example, BMBF 2001, 2002, BMWI 2005, OECD 2001 for such declarations and policy initiatives, Brenner and Fornahl 2002 for a method of establishing clusters, and Lovering 1999, Glasmeier 2000, Martin and Sunley 2003, Morgan 2004, Malmberg and Maskell 2004 for critical surveys and evaluations of regional policy programmes). Our results are clearly against this common perception.

Second, our focus is motivated by the fact that the field of new economic geography has become relatively mature and that recent contributions only add minor extensions to an already sophisticated literature. There have been important—sometimes even contradictory[1]—insights from this field into what drives agglomeration, but its models are usually general equilibrium models which remain highly stylised: even too stylised to explain real world phenomena properly, some critics say (see the discussion in Overman 2004). In fact, it has almost become a question of belief whether one resorts to new economic geography models (and believes in demand linkages as an important agglomeration force) or to Marshall's more demonstrative concept of inter-firm externalities (input-sharing, labour market pooling and knowledge spillovers).[2]

There is much empirical evidence for the agglomeration of economic activity and for the importance of Marshall's agglomeration forces (Rosenthal and Strange 2001, Dumais et al. 2002). Yet, some of this evidence is mixed and there are only very few rigorous models which explain why precisely firms should colocate in the presence of Marshall's inter-firm externalities.[3] Unfortunately, new economic geography models have no room for such firm-level phenomena.

Porter (1990) already argued that taking a micro-perspective is important for understanding the phenomenon of agglomeration and its influence on an industry's competitiveness. In a cross-country study he found that successful firms of certain industries tend to be geographically concentrated in few regions and he proposed a framework for describing the factors that determine the international success of these industry which he called *diamond* (see also Porter 1998).[4] He concludes that the characteristics of these locations combined with spatial proximity must intensify the positive impact of the *diamond* and the interplay of its forces. His most prominent examples comprise Silicon Valley (computers), Italy (shoes and leather) and

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[1] Helpman's (1998) model reverses the impact of transportation costs. In his model they increase agglomeration while in most earlier models (for example, Krugman 1991a) they decrease it.
[2] At least, this is the author's impression from talks with Richard Baldwin and Henry Overman about this topic at the ZEW Summer Workshop for Young Economists, Mannheim 2003, and the Spring Meeting of Young Economists, Geneva 2005.
[3] There is a model with input-sharing (Abdel-Rahman and Fujita 1990) and one with labour market pooling (Helsley and Strange 1990).
[4] The *diamond* describes the business environment of an industry and has four elements: (i) *factor conditions* describe a country's endowment with resources and infrastructure relevant to the particular industry, (ii) *demand conditions* comprise the qualitative and quantitative structure and dynamics of national demand for the products of an industry, (iii) *supporting and related industries* measures if and to what extent internationally competitive suppliers or related industries exist, (iv) *firm strategy and rivalry* measures how new business develops, how business is organised and managed and how intensive rivalry is.

Germany's Solingen (cutlery). Consequently, he extends the concept of the national business environment by the notion of *clusters*. A cluster is a

> *"geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities"*

whereby the geographic scope ranges from a city to a region and can even encompass parts of different countries (Porter 2000, p. 16). According to him, clusters promote economic performance in several ways two of which refer to knowledge spillovers in the sense of Marshall (1920). First, clusters increase productivity, for example because spatial proximity facilitates the flow of information due to personal relationships and community ties and amplifies peer pressure and the "desire to look good". The result is increased local rivalry even between non-competing companies. Secondly, clusters stimulate innovation, i.e., the growth of productivity. Firms learn earlier about new customer demands and evolving technologies because of their tight relationships with each other and increased peer pressure spurs them to stay ahead with innovation.

The approach pursued in this dissertation is different from Porter's one as it does a more systematic empirical analysis of the geographic concentration of industries and employs more rigorous models for theoretical analysis. Both, our empirical and theoretical results, suggest that Porter's approach needs to be improved: there are important phenomena which his descriptive concept incorrectly does not take into account but which may reverse the complete line of argument, thus leading to a different conclusion.

The following analysis is structured as follows. In chapter 2 we extend and discuss in more detail the empirical study published in Alecke et al. (2006). Since knowledge spillovers are the agglomeration externality most relevant to our findings, we examine their effect in a location decision model in chapter 3. That chapter (and parts of chapter 4) present and discuss in more detail the model published in Alsleben (2005). In that model "knowledge spillovers" work through labour poaching and we argue that it is a very important channel of knowledge transmission.

It is shown that opposed to the obvious benefit there is a noticeable disadvantage of sharing private knowledge with rival firms, so that firms may have a strong incentive to separate rather than colocate. The results serve as a (stylised) explanation for the empirical results of chapter 2.

Chapter 4 extends chapter 3 in that it discusses the incentives to colocate when firms are heterogeneous. This analysis is motivated by the empirical evidence that for sufficiently different firms, too, there is no mutual benefit from colocation (and spillovers in a broad sense). Rather, firms may face asymmetric contributions of, and exposure to, agglomeration externalities so that it is not clear a priori which type of firms wants to cluster. Additionally, it appears that on average larger firms colocate more often than smaller firms. Our empirical results in chapter 2 support this finding and we propose a model that relates firm size to "creativity" of R&D personnel and helps explain this observation.

In chapter 5 we discuss the relationship between an industry's degree of competition and spatial agglomeration. From the labour poaching model presented in chapter 3 emerges an hypothesis saying that more intense competition will have a negative effect on the degree of agglomeration. We test this prediction with the help of the data already used in the empirical analysis in chapter 2 and by extending Rosenthal and Strange's (2001) seminal study. The latter step becomes possible because the authors kindly provided their complete data set. There is indeed evidence for the hypothesis put forward, and to our knowledge both, the suggestion and the result, are novel to the literature.

Chapter 6 concludes with some tentative policy implications and is followed by an Appendix which contains mathematical proofs and additional material omitted in the text.

2 The agglomeration of German manufacturing industries and its determinants

2.1 Introduction[5]

Being much inspired by case study work such as Porter (1990) one explicit aim of European and German regional policy has become the promotion of high-technology industry clusters which are believed to be a universal tool for bringing growth and prosperity to backward regions.[6] The "BioRegio" contest set up in 1995 was an initiative that gave financial aid to the three most promising biotechnology clusters in Germany, and the "InnoRegio" initiative launched in 1999 allocated funds to the least developed regions in East Germany in order to promote the emergence of business clusters. Two important questions are associated with such policy initiatives: (i) which industries tend to agglomerate at all and (ii) why do they do so? Answering these questions may reveal important leverages for policy initiatives be they for efficiency or equality reasons.

In this chapter we choose Ellison and Glaeser's (1997) index of geographic concentration (EG index) and explore to what degree German manufacturing industries agglomerate due to natural advantages or spillovers.[7] The focus is on high-technology industries because German regional policy appears to be obsessed with the idea of "high-tech clusters" and devotes large funds to their promotion all over

[5] This chapter extends the work published in Alecke et al. (2006).
[6] See the Introduction for references to the relevant literature.
[7] In the following the terms "geographic concentration" and "agglomeration" are used synonymously.

the country. We explore the geographic concentration of national industries and explain it in a regression analysis. The main result is that neither in absolute nor in relative terms high-tech business is much spatially concentrated. Since we examine three-digit industries, this result can be interpreted as evidence against localisation economies from knowledge spillovers.

The next section presents a short survey of the huge literature. Section 2.3 then discusses the concentration measure used and describes the agglomeration pattern of German manufacturing industries. The results of the regression analysis are presented in section 2.4 and discussed in section 2.5. Section 2.6 concludes.

2.2 The literature on knowledge spillovers and agglomeration

There is a substantial literature on geographic concentration of industry and agglomeration economies in the sense of Marshall (1920) and the reader is referred to Rosenthal and Strange (2004) for a comprehensive survey. One strand of the literature looks for direct evidence of knowledge spillovers in the sense that it quantifies the effect of agglomeration.[8] Jaffe et al. (1993) estimate the effect of agglomeration on local patent citations, Glaeser et al. (1992) and Henderson (1997) on the growth of industry employment, Dekle (2002) on firms' total factor productivity and Rosenthal and Strange (2003) on the birth rate of new establishments and their employment, and Anselin et al. (1997) examine the impact of university R&D on the R&D of nearby private firms. Peri and Bottazzi (2003) estimate the range of research externalities in Europe and find that spillovers exist within a distance of about 300 km. According to their estimates, doubling R&D spending in a region would increase its innovative output by 80–90% but that of other regions within 300 km distance only by 2–3%. The estimates in Anselin et al. (1997) and Funke and Niebuhr (2000) suggest that the range of spillovers is at least 50–75 miles.

[8] By contrast, in their handbook survey, Rosenthal and Strange (2004) denote by "direct approach" the estimation of a production function (related to agglomeration effects).

From these studies we have learnt that proximity matters and that knowledge does flow somehow between private and/or public institutions. However, there is still a long-standing debate about the relative importance of inter- vs. intra-industry spillovers, i.e. urbanisation economies in the spirit of Jacobs (1969) vs. localisation economies stemming from regional specialisation. Glaeser et al. (1992) and Henderson (1997) argue in favour of the former while Henderson et al. (1995) show that the age of an industry matters and that there is evidence for both. By contrast, Black and Henderson (1999) and Dekle (2002) find evidence only for the latter one, and in another contribution Acs et al. (2002) look at high-technology industries and find evidence for neither type of externalities.

Another part of the empirical literature takes an indirect approach and examines geographic concentration of industries, which, according to the theory, is a prerequisite for spatial spillovers, in detail and with the help of more sophisticated measures. Audretsch and Feldman (1996) show that even after controlling for the concentration of production, knowledge-intensive industries in the U.S. tend to cluster. In more recent studies plant-level data is exploited and Ellison and Glaeser's (1997) index of agglomeration is used, such as in Maurel and Sédillot (1999) for France, Mayerhofer and Palme (2001) for Austria, Devereux et al. (2004) for the UK and in Barrios et al. (2003), who compare in depth Portugal, Ireland and Belgium. An exception is Duranton and Overman (2002), who propose and apply a distance-based measure. In addition to exploring geographic concentration in the U.S. and in West Germany, respectively, Rosenthal and Strange (2001), Dumais et al. (2002) and Keilbach (2002) explain it in a regression analysis to determine the forces that drive agglomeration. In many of these studies extractive industries tend to be the most concentrated ones, and there is already some tentative evidence that high-technology industries are only relatively little concentrated.

Our work is in the spirit of this literature and it centres on high-tech industries which, to our best knowledge, has not yet been done explicitly.

2.3 The agglomeration of German industries

2.3.1 The measure of agglomeration

A widely used measure of geographic concentration (Brülhart and Torstensson 1996, Audretsch and Feldman 1996, Amiti 1999) is the spatial variant of the Gini coefficient, proposed by Krugman (1991a). However, it has the severe disadvantage that it measures concentration of economic activity both due to internal economies of scale, i.e. the "concentration" within a firm and due to natural advantages or external economies of scale, i.e. concentration resulting from the colocation of firms (or plants). In order to distinguish between these two causes of concentration, we focus on a different measure instead.

Ellison and Glaeser (1997) (henceforth EG) proposed a measure of agglomeration derived from an explicit location decision model. In this model, geographic concentration is the result of a sequence of profit-maximising location decisions made by firms (or plants). Suppose that there are N such business units and M regions to choose from. Furthermore, firm k's profits from locating in region i, $k \in \{1,...,N\}$, $i \in \{1,...,M\}$, shall be given by

$$\pi_{ki} = \overline{\pi}_i + g_{ki}(v_1,...,v_{k-1}) + \varepsilon_{ki} \tag{2.1}$$

where $\overline{\pi}_i$ is the average profit from locating in region i, $g_i(v_1,...,v_{k-1})$ is a function of the location decisions made previously by other firms and ε_{ki} is the (random) component idiosyncratic to firm k in region i. $\overline{\pi}_i$ is a random variable and reflects natural advantages that are assumed to be chosen by nature before firms make their decision. In order to keep the model solvable, two restrictions are made for the distribution of $\overline{\pi}_i$. First, it is assumed that

$$\mathrm{E}\left(\frac{\overline{\pi}_i}{\sum_j \overline{\pi}_j}\right) = x_i \tag{2.2}$$

where x_i is region i's observed percentage of overall employment. Given $\bar{\pi}_1,...,\bar{\pi}_M$ and with no spillovers ($g_i(\cdot)=0$) firms would choose their location according to a standard logit model and the probability that a particular area is chosen reads

$$\text{prob}(v_k = i | \bar{\pi}_1,...,\bar{\pi}_M) = \frac{\bar{\pi}_i}{\sum_j \bar{\pi}_j}.$$

Equation (2.2) aligns this probability in such a way that, on average, across industries the model reproduces the overall distribution of employment. Second, suppose there is a parameter $\gamma^{na} \in [0,1]$ such that

$$\text{var}\left(\frac{\bar{\pi}_i}{\sum_j \bar{\pi}_j}\right) = \gamma^{na} x_i (1-x_i).$$

The parameter γ^{na} reflects the importance of natural advantages. When $\gamma^{na}=0$ this means there is no variance in an area's probability and each area i is chosen with probability x_i. At the other extreme, when $\gamma^{na}=1$, the random variable $\bar{\pi}_i / \sum_j \bar{\pi}_j$ attains its maximum possible variance meaning that state characteristics become so important that they overwhelm firm-specific factors.

The function $g_i(\cdot)$ in the expression for profits (2.1) captures a second class of agglomeration forces, namely spillovers in a broad sense. Again, to keep the model tractable, the simplifying assumption is made that spillovers are of an all-or-nothing type regardless of proximity. If there are spillovers between a pair of firms (or plants), then firms receive the full benefit of them if they choose to locate in the same region and they receive nothing should they locate apart. Formally, spillovers are incorporated with the help of a "punishment" component in the profit function:

$$\begin{aligned} g_{ki}(v_1,...,v_{k-1}) &= \sum_{\substack{l \neq k \\ l=1}}^{k} e_{kl}(1-u_{li}(v_1,...,v_{k-1}))(-\infty) \\ u_{li}(v_1,...,v_{k-1}) &= \begin{cases} 1 & \text{if } v_l = i \\ 0 & \text{else} \end{cases} \end{aligned} \tag{2.3}$$

where e_{kl} is a Bernoulli random variable equal to one with probability γ^{so} that indicates whether spillovers exist between plants k and l, and $u_{li}(v_1,...,v_{k-1})$ is an indicator for whether plant l locates in area i. The function $g_{ki}(v_1,...,v_{k-1})$ "punishes" k by rendering its profits $-\infty$ if there is at least one other firm l such that there exist spillovers between firm k and l and firm k decides not to locate in the same region as firm l. Suppose further that spillovers between plants are symmetric and transitive. This assures that the distribution of locations is independent of the order in which plants make their choices. Note the importance of the parameter γ^{so}, which marks the fraction of pairs of plants between which spillovers occur.

EG use the dartboard metaphor and think of a two-stage process in which nature first randomly chooses to weld some darts together (representing groups of plants that are interrelated through spillovers and hence will always locate together) and then each cluster is thrown randomly at the dartboard.

Now turning to the index of agglomeration, the point of departure is an industry's "raw concentration" G defined as

$$G = \sum_i (s_i - x_i)^2 \tag{2.4}$$

where s_i is the portion of the industry's employment located in region i and, as above, x_i is the percentage of total employment in that region. G measures concentration relative to total employment, i.e. as long as an industry mimics the pattern of aggregate employment it will not be considered as being concentrated. The advantage of defining concentration relative to overall employment (as opposed to, for example, population or land area) is that one can take the overall distribution of employment (i.e. cities) as given and does not have to take into account location-specific characteristics such as commuting patterns, size and age of the population, soil conditions etc. which certainly determine the distribution of employment. Also, one does not need to take an equal distribution of employment as a benchmark which is clearly no reasonable hypothesis.

In the model described, x_i is exogenous while s_i is determined endogenously by $s_i = \sum_k z_k u_{ki}(\cdot)$ where z_k is the kth plant's share of the industry's employment and $u_{ki}(\cdot)$ the above indicator indicating whether plant k is located in region i. (In fact, s_i and x_i are both endogenously determined but this would render the model untractable.) EG show that

$$\mathrm{E}(G) = \left(1 - \sum_i x_i^2\right)(\gamma + (1-\gamma)H)$$

where $H = \sum_k z_k^2$ is the Herfindahl index of the industry's plant size distribution and $\gamma = \gamma^{na} + \gamma^{so} - \gamma^{na}\gamma^{so}$ is a combined index of the importance of natural advantages and inter-firm spillovers. Solving for γ, which is the variable of interest, yields

$$\gamma = \frac{E(G) - \left(1 - \sum_i x_i^2\right)H}{\left(1 - \sum_i x_i^2\right)(1-H)} \tag{2.5}$$

where $\mathrm{E}(G)$ will be substituted by the *observed* raw concentration G. If plants choose their location in accordance with the model, then equation (2.5) provides an unbiased estimate for $\gamma = \gamma^{na} + \gamma^{so} - \gamma^{na}\gamma^{so}$ which reflects the strength of agglomeration forces in the model.

Thus defined, the index has three important advantages. First, the model behind it builds on a statistical distribution which allows to test an observation against the unique null hypothesis that there is no agglomeration, i.e. plants choose their location in a pure random manner as if darts were thrown at a dartboard independently from each other. In that case one would have $\gamma = 0$ and consequently $\mathrm{E}(G) = \left(1 - \sum_i x_i^2\right)H$. Since the variance is also known, one can test for the significance of G.[9]

Second, the index is comparable across industries because its expected value is independent of the size distribution of plants—if, of course, location decisions are made in the way assumed in the model.

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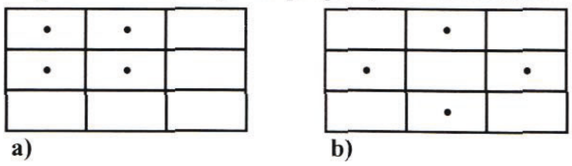
[9] According to EG $\mathrm{var}(G) = 2\left\{H^2\left[\sum_i x_i^2 - 2\sum_i x_i^3 + \left(\sum_i x_i^2\right)^2\right] - \sum_j z_j^4\left[\sum_i x_i^2 - 4\sum_i x_i^3 + \left(\sum_i x_i^2\right)^2\right]\right\}$.

Third, the index is comparable regardless of differences in the level of geographic aggregation at which employment data are used. It is easy to show that the distribution generated by a model with M locations and parameters $x_1,..., x_M, \gamma^{na}, \gamma^{so}$ will be the same as that generated from a $M-1$ locations model with parameters $x_1 + x_2, x_3, ..., x_M, \gamma^{na}, \gamma^{so}$.

However, there are also three important disadvantages of this approach. First, a world with natural advantages and a world with spillovers between plants are observationally equivalent. We try to overcome this limitation in section 2.4 where we relate the index of agglomeration to agglomeration forces in a regression analysis. Second, interpreting the index in absolute terms remains difficult despite EG's attempt to get a feel for it. But here we are primarily interested in the relative concentration of industries and therefore refrain from a precise interpretation of absolute values. The third and perhaps most severe weakness is that the model behind the index is "a-spatial" in the sense that it treats space as discrete units. In the model, spillovers are of an all-or-nothing type and when applied to the data, regions are treated as isolated islands: spillovers are assumed to operate entirely within a region so that there is no effect on or from contiguous regions. Consequently, their order on the map, i.e. spatial correlation, is not taken into account. For an illustration, consider Figure 2.1. The EG index will be the same for the two employment patterns depicted, although one would consider pattern a) to exhibit stronger agglomeration than pattern b) because it entails (stronger) spatial correlation ($\frac{7}{24}$ vs. -1). We comment on this below when we compare the results of different regional levels.

Figure 2.1: The a-spatial property of the EG index



In general, the EG index can be used for a variety of aspects of "concentration" due to its "a-spatial" property. In this paper it is used to measure the concentration of firms of the *same* industry thus examining the existence and strength of *localisation* economies as opposed to *urbanisation* economies which occur *across* industries. When we use the term "cluster" we refer to the agglomeration of an industry. What is "within" industries and what "across" is ultimately a matter of degree. The focus is on three-digit industries but we also look at the concentration of two-digit industry groups. As two-digit industry groups contain a fairly broad range of industries, our work is to some degree also a test for urbanisation effects.

When the agglomeration index is calculated we also report the Gini coefficient for illustrative purpose and a measure α for comparison with the EG index. The index α is a similar but simpler measure, namely a modified version of Devereux's et al. (2004) proposition. They define a measure

$$\alpha = \tilde{G} - M \tag{2.6}$$

where

$$\tilde{G} = \left(\sum_i s_i^2\right) - \frac{1}{M^*}$$
$$M^* = \min(N, M)$$
$$M = H - \frac{1}{N},$$

N is the number of plants in the industry and M the number of geographic regions. $\tilde{G}$ is the geographic (raw) concentration of employment relative to the uniform share controlling for the maximum number of regions in which employment may be located given that there are (only) N plants. To be consistent with the EG index which is relative to total employment, not to a uniform distribution, we use G as defined in equation (2.4) instead of $\tilde{G}$. M measures the concentration of employment within firms (Herfindahl index) but relative to a uniform distribution. Then for any given geographic raw concentration G, the "internal" concentration of employment is subtracted while controlling for industry size (N). Note that unlike the EG index, α is linear in H; all else equal, a higher industrial concentration unambiguously decreases geographic concentration. One has $\alpha > 0$ when the agglomeration of industry employment (relative to total employment) across regions "exceeds" that across plants, $\alpha = 0$ whenever the two are of the same magnitude and $\alpha < 0$ otherwise.

2.3.2 The data

The database used provides the 1998 plant-level employment across counties for Germany's 219 three-digit industries, consisting of 116 manufacturing (and extractive) industries and 103 service industries. The focus of the analysis will be on manufacturing industries but for robustness issues we will check how our results change when all industries are taken into account. The employment data are not classified and contain precise figures for each plant regardless of its size. No further improvement in the data is necessary and we directly compute the Herfindahl index from it. However, the confidentiality of the data means that we are not able to aggregate plants to firms, i.e. determine whether plants are under common ownership. But this is not a constraint since, according to EG's model, firms choose the location for each of their plants separately. Furthermore, we are able to group total employment of a plant by education and by occupation (production, management, R&D etc.) which we will make use of when explaining agglomeration in a regression analysis in section 2.4. Table 2.1 gives a description of the data.

Table 2.1: Descriptive statistics of the employment data (1998)

	Manufacturing	Services
Number of 3-digit industries (NACE 3)	116	103
Number of 2-digit industries (NACE 2)	25	32
Number of plants	216,545	1,310,039
Total employment	7,534,781	16,798,093
Average employment per plant	34.8	12.8
Geographic units	439 counties, 225 labour market regions, 97 planning regions	

2.3.3 How much are industries agglomerated?

In EG's simple dartboard model not considering spillovers and natural advantages, the plants of an industry choose their location in a random manner and consequently $G_0 = \mathrm{E}(G)|_{\gamma=0} = \left(1 - \sum_i x_i^2\right)H$. A natural first step is to test whether the observed raw concentration, G, is statistically significantly different from G_0, and to our knowledge this is the first formal test for the significance of the agglomeration of German industries. The mean values of G and G_0 are 0.057 and 0.040, respectively, and their difference is highly significant (it is nearly three times larger than the average standard deviation of G). More precisely, 91 out of the 116 manufacturing industries are significantly more geographically concentrated than what one would expect if location decisions were pure random.[10] Accordingly, for 25 industries the hypothesis of a pure random location decision cannot be rejected. These numbers are in line with those in Maurel and Sédillot (1999), Barrios et al. (2003) and Duranton and Overman (2002), who find for other European countries that the majority of industries, albeit not all of them, exhibit a location pattern significantly different from a random outcome.

Moreover, one can interpret $\phi = (G - G_0)/G$ as the rough fraction of raw concentration attributable to some form of spillovers/natural advantage rather than randomness.[11] Randomness is at least as important for raw concentration as actual agglomeration of plants for more than 60% of the industries (see Table 2.2); in a sub-sample of high-G industries (the upper quartile consisting of 29 industries) this share amounts even to 75%. In other words, for less than half of all industries—and for only few industries with strong raw concentration—natural advantages and/or spillovers play a dominant role in agglomeration. In total, randomness seems to have a stronger influence on observed agglomeration than agglomeration forces themselves. With a very different approach Roos (2005) shows that in Germany agglomeration forces are much more important for observed concentration than natural advantages.

[10] For these industries the difference between G and G_0 is larger than 1.96 times its standard deviation.
[11] Note that Ellison and Glaeser (1997), p. 909, use a slightly different expression.

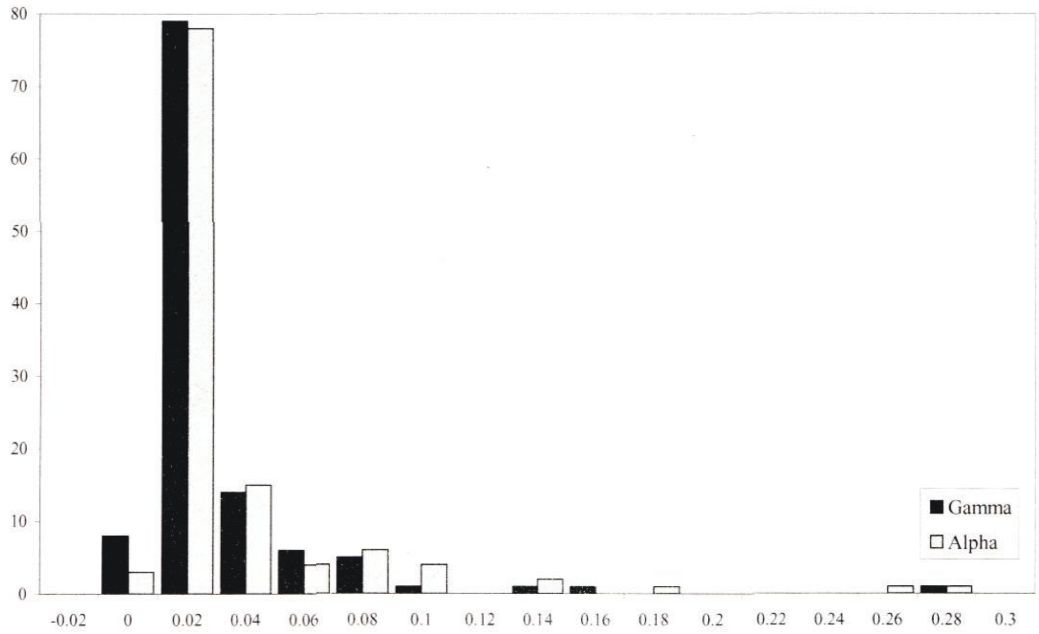
Table 2.2: Raw concentration attributable to spillovers and/or natural advantage

Range of ϕ	Manufacturing industries	High-G industries
0.00	7%	14%
0.25	28%	28%
0.50	30%	34%
0.75	24%	14%
1.00	11%	10%

Figure 2.2 shows the histogram of the two agglomeration indices γ and α. Both variables are presumably not normally distributed with mean and median being 0.018 and 0.006 for γ and 0.029 and 0.008 for α. We comment on the skewed distribution of γ when we do the regression analysis.

Table 2.3 shows the most and least agglomerated industries. What is striking is that "high-tech" and "medium-tech" industries are not among the most concentrated ones but lie in the middle field or even at the bottom of the ranking as Table 2.4 demonstrates in more detail. The classification of high- and medium-tech industries has been used before and is due to Grupp et al. (2000); see Table A.1 in the Appendix for more details. Obviously, extractive industries dominate the top group and a large number of industries (75%) is associated with a γ lower than 0.02, which, as argued in EG, can be interpreted as low concentration. Only about 10% of the industries have a γ greater than 0.05. The alternative measure α produces a fairly similar picture. The Spearman rank correlation with γ is 0.84. Note, however, that there are a few industries which the index α ranks completely differently. As Table 2.3 indicates, it would put Mining of uranium and thorium ores (NACE 120), which is the least agglomerated industry according to γ, right on top of the list. Similarly, Manufacture of coke oven products (NACE 231), which is the last but fourth, would be ranked fourth. These two industries consist of only 6 and 2 plants, respectively, each of which is located in a different region so that there is in fact no agglomeration of plants at all. Still, both industries are underrepresented in the majority of the regions which leads to a very high raw concentration G. While the statistical model behind γ accounts for the fact that this particular location pattern may well be the outcome of pure random (in fact both have an insignificant raw concentration), α is much more responsive to the high raw concentration although both industries are also highly internally concentrated.

Figure 2.2: Histogram of γ and α



The rank correlation with the Gini coefficient is only 0.59. Like α it produces a similar ranking for many industries but shows substantial differences for some industries, especially the very strongly and very little concentrated ones.

We conclude that in Germany slight concentration (at the county level) is widespread while strong concentration is found only in a small subset of industries. Additionally, measures that take into account an industry's internal concentration of employment (such as a or γ) produce fairly different results than does the widely used Gini coefficient.

Table 2.3: Most and least concentrated German manufacturing industries (three-digit)

Rank γ	γ	H	G	α	Gini	Industry (NACE 3)	T.**	Rank Moran	Rank α	Rank Gini
1	0.264	0.070	0.314	0.268	0.994	Service activities incidental to oil and gas extraction, excluding surveying		84	2	98
2	0.156	0.204	0.327	0.248	0.989	Mining of iron ores		109	3	111
3	0.124	0.027	0.147	0.125	0.970	Manufacture of watches and clocks		17	6	20
4	0.096	0.010	0.105	0.096	0.853	Manufacture of jewellery and related articles		18	7	42
5	0.077	0.045	0.118	0.087	0.962	Mining and agglomeration of hard coal		6	9	4
6	0.072	0.097	0.162	0.086	0.987	Mining of chemical and fertilizer minerals		43	10	54
7	0.072	0.177	0.235	0.094	0.983	Mining of non-ferrous metal ores, except uranium and thorium ores		104	8	103
8	0.070	0.026	0.093	0.072	0.969	Processing and preserving of fish and fish products		3	14	12
9	0.069	0.044	0.109	0.074	0.980	Extraction and agglomeration of peat		5	13	5
10	0.059	0.098	0.151	0.076	0.985	Manufacture of ceramic tiles and flags		106	11	101
11	0.049	0.069	0.115	0.060	0.979	Extraction of crude petroleum and natural gas		22	16	38
12	0.047	0.012	0.058	0.048	0.899	Manufacture of knitted and crocheted fabrics		24	18	15
13	0.041	0.039	0.078	0.045	0.935	Manufacture of refined petroleum products		54	19	81
14	0.041	0.050	0.089	0.063	0.980	Mining and agglomeration of lignite		1	15	7
15	0.040	0.072	0.109	0.055	0.946	Manufacture of tobacco products		99	17	105
102	0.001	0.001	0.002	0.002	0.412	Printing and service activities related to printing		59	107	34
103	0.001	0.001	0.002	0.002	0.447	Manufacture of structural metal products		9	109	3
104	0.001	0.002	0.003	0.002	0.465	Manufacture of other general purpose machinery		61	108	69
105	0.001	0.001	0.001	0.001	0.345	Manufacture of other food products		41	112	21
106	0.001*	0.009	0.010	0.002	0.713	Manufacture of wooden containers		83	100	102
107	0.001*	0.003	0.003	0.001	0.530	Manufacture of beverages		58	111	30
108	0.000*	0.008	0.008	0.001	0.693	Manufacture of bodies (coachwork) for motor vehicles		101	113	95
109	0.000*	0.014	0.014	0.001	0.730	Manufacture of parts and accessories for motor	MT	66	110	58
110	-0.001*	0.057	0.056	0.000	0.793	Manufacture of electric motors, generators and transformers	MT	57	114	37
111	-0.001*	0.021	0.019	-0.001	0.744	Manufacture of electrical equipment n.e.c.	MT	107	115	110
112	-0.001*	0.182	0.180	0.003	0.928	Manufacture of motorcycles and bicycles		100	97	106
113	-0.002*	0.263	0.260	0.164	0.988	Manufacture of coke oven products		25	4	51
114	-0.004*	0.046	0.042	-0.001	0.874	Manufacture of motor vehicles	MT	78	116	94
115	-0.005*	0.186	0.182	0.034	0.973	Manufacture of pesticides and other agro-chemical products	HT	92	23	85
116	-0.010*	0.654	0.648	0.493	0.993	Mining of uranium and thorium ores		102	1	104

Notes: * "no" means not significant at the 5% level. **MT = medium-tech, HT = high-tech industry

Table 2.4: The agglomeration of high- and medium-tech manufacturing industries

Rank γ	γ	H	Industry (NACE 3)	Sign.[1]
			High-technology industries	
16	0.037	0.072	Manufacture of weapons and ammunition	
19	0.032	0.263	Processing of nuclear fuel	no
23	0.027	0.050	Manufacture of aircraft and spacecraft	
51	0.007	0.035	Manufacture of office machinery and computers	
53	0.007	0.019	Manufacture of television and radio transmitters and apparatus for line telephony and line telegraphy	
59	0.006	0.124	Manufacture of industrial process control equipment	no
76	0.004	0.012	Manufacture of electronic valves and tubes and other electronic components	
84	0.003	0.018	Manufacture of pharmaceuticals, medicinal chemicals and botanical products	no
			Medium-technology industries	
32	0.015	0.020	Manufacture of optical instruments and photographic equipment	
38	0.011	0.042	Manufacture of railway and tramway locomotives and rolling stock	
43	0.009	0.034	Manufacture of lighting equipment and electric lamps	
50	0.007	0.010	Manufacture of other chemical products	
57	0.006	0.046	Manufacture of accumulators, primary cells and primary batteries	no
56	0.006	0.006	Manufacture of machinery for the production and use of mechanical power, except aircraft, vehicle and cycle engines	
64	0.005	0.020	Manufacture of television and radio receivers, sound or video recording or reproducing apparatus and associated goods	
68	0.005	0.009	Manufacture of agricultural and forestry machinery	
73	0.004	0.014	Manufacture of paints, varnishes and similar coatings, printing ink and mastics	
74	0.004	0.002	Manufacture of machine tools	
82	0.003	0.002	Manufacture of medical and surgical equipment and orthopaedic appliances	
96	0.002	0.071	Manufacture of basic chemicals	no
101	0.002	0.002	Manufacture of other special purpose machinery	
109	0.000	0.014	Manufacture of parts and accessories for motor vehicles and their engines	no
111	-0.001	0.021	Manufacture of electrical equipment n.e.c.	no
110	-0.001	0.057	Manufacture of electric motors, generators and transformers	no
114	-0.004	0.046	Manufacture of motor vehicles	no
116	-0.005	0.186	Manufacture of pesticides and other agro-chemical products	no

Note: 1) "no" means not significant at the 5% level.

2.3.4 The industrial scope of agglomeration

As there is—at least some—degree of agglomeration *within industries*, an interesting question is whether one can also identify concentration at a more aggregated industry level, i.e. at the two-digit industry level (NACE 2). Is the concentration of industry *groups* due merely to the concentration of its (sub)industries which would imply that natural advantages and spillovers are industry-specific or is there a *common* effect on the industries of a two-digit industry group? In order to explore this issue the degree of concentration at the two-digit industry level (NACE 2) is calculated for the 25 manufacturing industry groups that contain more than one industry, using EG's measure of coagglomeration

$$\gamma^c = \frac{G/\left(1-\sum_i x_i^2\right) - \bar{H} - \sum_{j=1}^{r} \gamma_j w_j^2 (1-\bar{H})}{1-\sum_{j=1}^{r} w_j^2} \tag{2.7}$$

where w_j is the share of industry *j*'s employment in the two-digit industry group and $\bar{H} = \sum_j w_j^2 H_j$ the Herfindahl index of the group. The coagglomeration index γ^c reflects how much the location decisions of firms of the same industry group are correlated; $\gamma^c = 0$ would indicate that there is no correlation across industries and hence no more agglomeration in the industry *group* than that simply resulting from the concentration of its industries.

Table 2.5 shows the results for all 25 industry groups. Similar to EG's results for the U.S., there is no coagglomeration in industry groups like automobiles, communication technology, furniture, machinery and rubber but some coagglomeration in the textile, metal, lumber and paper industry. However, in absolute terms Germany's manufacturing industry groups exhibit only little concentration at the county level if one takes 0.05 and 0.02 as an upper and lower benchmark, again.

Table 2.5: The coagglomeration of manufacturing industries (two-digit)

Rank γ^c	γ^c	Intra-industry concentr. as % of group's concentr.	Industry group (NACE 2)	Employment (000's)
1	0.0508	68%	Extraction of crude petroleum and natural gas; service activities incidental to oil and gas extraction, excluding surveying	7
2	0.0147	93%	Manufacture of coke, refined petroleum products and nuclear fuel	32
3	0.0073	33%	Manufacture of textiles	150
4	0.0052	55%	Manufacture of other transport equipment	146
5	0.0033	56%	Manufacture of basic metals	354
6	0.0032	37%	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	185
7	0.0031	59%	Publishing, printing and reproduction of recorded media	382
8	0.0029	57%	Manufacture of pulp, paper and paper products	149
9	0.0027	64%	Recycling	35
10	0.0021	30%	Manufacture of chemicals and chemical products	490
11	0.0021	66%	Other mining and quarrying	66
12	0.0020	49%	Manufacture of other non-metallic mineral products	284
13	0.0018	97%	Manufacture of wearing apparel; dressing and dyeing of fur	90
14	0.0016	93%	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear	34
15	0.0016	49%	Manufacture of fabricated metal products, except machinery and equipment	797
16	0.0010	89%	Manufacture of furniture; manufacturing n.e.c.	287
17	0.0009	65%	Manufacture of medical, precision and optical instruments, watches and clocks	394
18	0.0007	43%	Manufacture of food products and beverages	733
19	0.0005	90%	Manufacture of rubber and plastic products	393
20	0.0005	62%	Manufacture of machinery and equipment n.e.c.	1057
21	-0.0002	-3%	Manufacture of electrical machinery and apparatus n.e.c.	444
22	-0.0008	134%	Manufacture of radio, television and communication equipment and apparatus	192
23	-0.0016	67%	Manufacture of motor vehicles, trailers and semi-trailers	667
24	-0.0021	101%	Mining of metal ores	2
25	-0.0024	103%	Mining of coal and lignite; extraction of peat	103

Another way to quantify the relative strength of industry-specific and group-specific agglomeration has been proposed by Maurel and Sédillot (1999). They note that the concentration of a whole industry group measured by the "simple" γ calculated for the *group*, can be written as the weighted average of the γ 's of the *industries* ("intra-industry concentration") and some group-specific component ("inter-industry concentration") which is not to be confused with EG's γ^c. It is then possible to express intra-industry agglomeration (the weighted γ 's) as a fraction of the group's total concentration. This ratio ranges from as low as -2% to 134% (see column 3 in

Table 2.5). A fraction of intra-industry concentration greater than 100% corresponds to a negative contribution of the inter-industry component. Communications Engineering on rank 22, for example, is a group whose industries by themselves are more concentrated than the group which amounts to a dispersing inter-industry component. The same is true for Manufacture of Electrical Equipment on rank 21; here the negative sign reflects that the group as a whole is even dispersed while the intra-industry component is positive.

Additionally, there is no general relationship between the degree of concentration of an industry group and the relative magnitude of the intra- and inter-industry component. Obviously some industry groups are by far more concentrated than the average of their industries (column 3 in Table 2.5, Textiles, Chemicals) but in absolute terms most groups are only little concentrated (column 2). One implication of these results is that one always wants to look at absolute concentration of a group and its source at the same time.

When examining industry groups, an obvious question is whether there is some evidence on economising of transportation costs as a motivation for agglomeration of industries with strong upstream-downstream ties. Unfortunately, input/output dependencies are available only at the two-digit industry level so that one cannot create pairs of individual three-digit industries but has to look at the coagglomeration of industries of entire two-digit groups.

From the input/output table of the Federal Statistical Office we calculate input/output coefficients for all pairs of two-digit industries and choose those ten with the highest coefficient for the analysis of coagglomeration. As Table 2.6 demonstrates, the five most coagglomerated groups are relatively strongly coagglomerated when compared to all other industry groups. In fact, if one excludes from Table 2.5 the two most coagglomerated groups, which are both resource related, the leading two trade pairs in Table 2.6 become the most coagglomerated groups altogether. We conclude that economising in transportation costs may indeed play a role for industries with strong trade relationships which is in line with EG's results for the U.S.

Table 2.6: The coagglomeration of upstream/downstream industries

NACE 2 industry groups		γ^c	Intra-industry concentr. as % of group's concentr.	Rank (among all NACE 2 industry groups)
19+24	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear + Manufacture of chemicals and chemical products	0.0132	0%	3
17+24	Manufacture of textiles + Manufacture of chemicals and chemical products	0.0080	5%	4
17+18	Manufacture of textiles + Manufacture of wearing apparel; dressing and dyeing of fur	0.0050	31%	7
16+21	Manufacture of tobacco products + Manufacture of pulp, paper and paper products	0.0020	62%	16
27+28	Manufacture of basic metals + Manufacture of fabricated metal products, except machinery and equipment	0.0018	35%	18
10+28	Mining of coal and lignite; extraction of peat + Manufacture of fabricated metal products, except machinery and equipment	0.0010	64%	23
28+29	Manufacture of fabricated metal products, except machinery and equipment + Manufacture of machinery and equipment n.e.c.	0.0007	38%	26
28+35	Manufacture of fabricated metal products, except machinery and equipment + Manufacture of other transport equipment	0.0006	67%	30
24+25	Manufacture of chemicals and chemical products + Manufacture of rubber and plastic products	0.0001	84%	34
10+31	Mining of coal and lignite; extraction of peat + Manufacture of electrical machinery and apparatus n.e.c.	-0.0014	498%	40

Turning to the agglomeration of high-tech industries, it is important to note that the NACE classification system may misrepresent plants with many different or very innovative activities. Especially in the area of high-technology where new fields of economic activity develop constantly, the traditional industry classification system may fail. In order to see whether a potentially inappropriate industry definition masks concentration of related industries we compile by hand a "high-tech" and "medium-tech" industry group and five groups consisting of closely related, research-intensive industries following a common classification by Grupp et al. (2000) (see Table A.1 in the Appendix for a list of the industries contained).

Table 2.7: Agglomeration of "high-tech" industry groups (two-digit)

Group	γ^c	Intra-industry concentr. as % of group's concentr.	Rank (among all NACE 2 industry groups)
High-tech	0.0007	67%	25
Medium-tech	-0.0012	-2%	39
R&D-intensive Chemicals	0.0027	31%	12
R&D-intensive Manufacture of Machinery	0.0006	70%	28
R&D-intensive Electronic, Optical and Communication Equipment	0.0005	60%	31
R&D-intensive Automobiles	-0.0006	78%	36
R&D-intensive Manufacture of Electrical Machinery and Apparatus	-0.0008	28%	37

The results in Table 2.7 are in contrast to what common wisdom about inter-firm spillovers in the high-technology field suggests. First, both the high-tech and medium-tech group have a γ^c close to zero and firms in the medium-tech industry group are even dispersed. Secondly, they rank very low compared to the NACE two-digit groups. The same is true for the more narrowly defined research-intensive groups except for Chemicals which exhibits some degree of coagglomeration and a substantial inter-industry component at the same time.

We conclude, first, that there is some inter-industry concentration in German manufacturing industries which implies that plants of the same industry do share the benefits of natural advantages and/or spillovers to some degree. But for the very majority of industry groups agglomeration *within* industries is stronger than *across* industries. Furthermore, in the high- and medium-tech business not only *industries* but also *industry groups* are not agglomerated much in absolute and relative terms.

2.3.5 The geographic scope of agglomeration

In order to explore whether agglomeration forces exist at a higher geographic level and to account for the fact that administrative boundaries are not necessarily economically relevant, the analysis is repeated for Germany's 97 planning regions (*Raumordnungsregionen*) which represent functional, economically self-contained areas with minimum inter-regional commuting.

Table 2.8 shows that there is a strong tendency of the two agglomeration measures to increase with higher geographic levels (for illustrative purpose the result for Germany's 225 labour market regions (*Arbeitsmarktregionen*) is included). Interestingly, the overall ranking, especially the top group, remains nearly unchanged. The rank correlation with the county level is 0.84 for both the LMR and PR, but more industries are agglomerated insignificantly now. Thus, roughly speaking, in absolute terms agglomeration increases substantially while in relative terms it does not change much.

Table 2.8: Average agglomeration at higher geographic levels

	G	γ	α
	County level (440)		
Two-digit	0.050	0.004	0.014
Three-digit	0.057	0.018	0.029
	LMR level (225)		
Two-digit	0.029	0.007	0.022
Three-digit	0.063	0.026	0.035
	PR level (97)		
Two-digit	0.063	0.010	0.027
Three-digit	0.072	0.036	0.044

Suppose that firms do choose between counties according to EG's location model. If spillovers are of an all-or-nothing type and natural advantages are uncorrelated[12], γ measured at the aggregate level remains an unbiased estimator for the agglomeration forces in the model and the observed increase in agglomeration would be due to measurement error.[13] However, if natural advantages are correlated across counties and/or if spillovers reach beyond counties so that firms actually choose between—say—planning regions, then measuring γ at the county level becomes inconsistent with the true location model and thus is meaningless. The substantial increase of agglomeration at the more aggregate level suggests that there

[12] Spatial correlation means that there is a tendency of neighbouring regions to have the same characteristics.

is spatial correlation across counties which the index does not take into account at that low level because of its "a-spatial" property discussed above. In fact the average diameter of German counties is only about 10 kilometres which is probably too short a distance to capture the full range of spillovers. While precise estimates of the range of spillovers are rare, Anselin et al. (1997) and Funke and Niebuhr (2000) suggest that the range is at least 50 – 75 miles. Looking at planning regions removes this issue because they are larger and economically meaningful units of space. For this reason we will include them in the following discussion and the regression analysis below.

2.3.6 Robustness test 1: Spatial correlation

So far we have dealt with issues of robustness of the EG index that have been raised by other authors such Devereux et al. (2004) or EG themselves. This section and the next section discuss two additional issues that—to our knowledge—have not been dealt with explicitly in earlier work.

The first issue harks back to the a-spatial property of the EG index, which implies that the index does not take into account spatial correlation, as depicted in Figure 2.1 on page 14. Spatial correlation of economic activity may be the result of "large scale" spatial pecuniary externalities. Krugman (1980) and Krugman (1991a) demonstrated in a monopolistic competition framework that transportation costs combined with internal economies of scale of production produce demand and input-output "linkages" which in turn result in spatial pecuniary externalities (see also Lafourcade and Mion 2003). There are a few papers that empirically test such "new economic geography" models and that find evidence for spatial pecuniary externalities (Hanson 1998 for the U.S. and Mion 2004, who improves Hanson's methodology, for Italy).

In the following we examine to what extent the findings about agglomeration change when one looks at spatial correlation. Spatial correlation of manufacturing employment is measured with the help of Moran's I (Moran 1950),

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[13] Not much can be said about the error with which γ is measured. See the footnote in Ellison and Glaeser (1997), p. 908.

$$I = \frac{M \sum_i \sum_j w_{i,j} (y_i - \bar{y})(y_j - \bar{y})}{\left(\sum_i \sum_j w_{i,j}\right) \sum_i (y_i - \bar{y})^2}$$

where M is the number of regions, $w_{i,j}$ the weight applied to the observation pair (i, j) and y the variable under study. To be consistent with EG's approach and using familiar notation, we set

$$y_i = s_i - x_i$$

so that we analyse the spatial correlation of "excess concentration" in a region. Intuitively, the question is whether neighbouring regions have the tendency to exhibit the same (positive or negative) excess concentration of employment. Note that here one has $\bar{y} = 0$ by definition. Weights are set according to a first-order contiguity matrix letting $w_{i,j}$ be equal to one if area i and j are neighbours and zero otherwise.[14] As suggested in Anselin (1988), the matrix is row-standardised so that $\sum_i \sum_j w_{i,j} = M$. Lafourcade and Mion (2003) point at an intuitive interpretation of Moran's index found in the regression context. If, one regresses the spatially weighted variable **WY** on **Y** (using matrix notation), then I is equal to the slope coefficient of the regression line. In order to control for industry size, Lafourcade and Mion (2003) eliminate from the weight matrix for each industry those regions where there is no employment of the industry. This procedure is motivated by the fact that an industry with a small number of plants may appear strongly spatially correlated just because it is not present in the majority of regions. However, this approach seems to be ad hoc, and apart from that it is extremely awkward in terms of calculation so that it is not pursued here. Instead we follow the traditional definition of spatial correlation and Moran's I.

Figure 2.3 shows that there is no correlation in ranks between the EG index and Moran's I at the county level and the same holds at the more aggregate PR level. About half of the industries exhibit a degree of spatial correlation that is not

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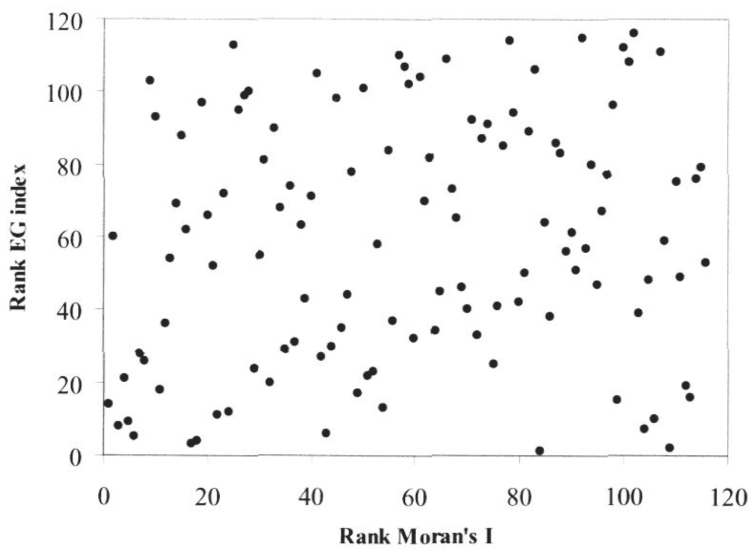
[14] We are grateful to the German *Bundesamt für Raumordnung* for kindly providing a list of neighbouring counties.

significantly different from zero and the highest value attained is 0.34. Interestingly, on average spatial correlation does not disappear at the PR level but remains almost unchanged. As EG note, one may usually expect an increase in spatial correlation when one moves to higher spatial levels due to correlated natural characteristics (such as rivers or mountains) and due to the fact that small administrative areas (such as counties) probably do not reflect the range of economically relevant spillovers. Here, spatial correlation remains unchanged either because of correlated natural advantages or because the PR level still does not entirely capture the range of spillovers. Since there is no further meaningful level of spatial aggregation available for Germany and since PR appear to be big enough to capture spatial spillovers at least partially, one can only speculate if correlated natural advantages cause this effect. Additionally, given that one half of the industries is associated with an insignificant degree of correlation and that the maximum is only 0.34, our estimates of γ should be fairly unbiased.

Figure 2.3: Rank correlation of the EG index and Moran's I

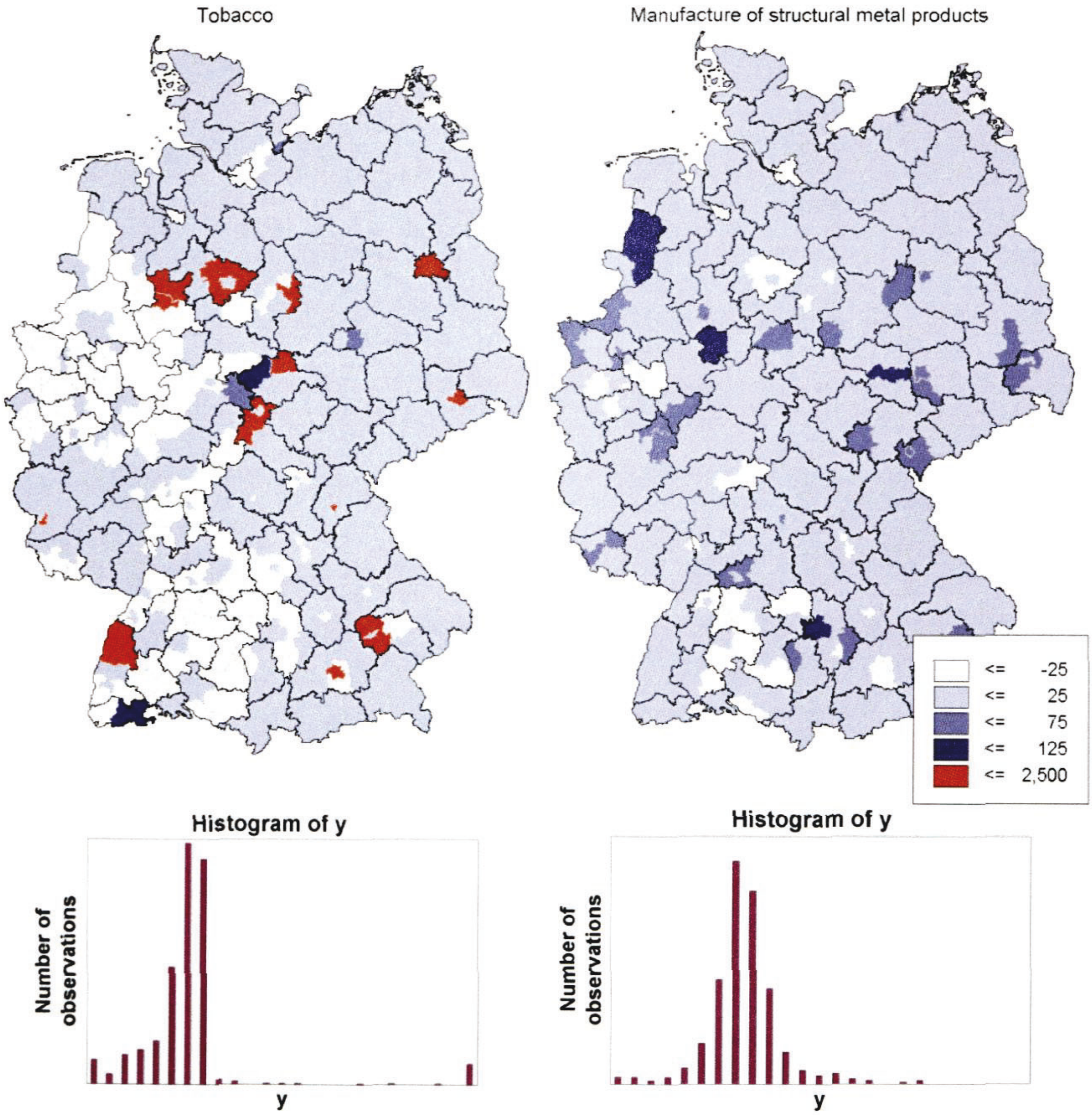


It is not easy to visualise strong agglomeration and spatial correlation in real industry data so that they can be understood intuitively. The problem is that the variable $y_i = s_i - x_i$ is not ratio-scaled. Consequently it is not meaningful to say that, for example, $y_1 = 0.5$ implies twice as much "excess concentration" as $y_2 = 0.25$. However, one can compare differences which means that, for example, the difference between y_2 and y_1 is the same as the difference between $y_4 = 0$ and $y_3 = -0.25$. An additional problem is due to the fact that the industries exhibit very different distributions of excess concentration (across regions). Therefore, in Figure 2.4 the distribution of y_i is included for each industry.

Unfortunately, spatial correlation cannot be incorporated into EG's location decision model unless one knows the joint distribution of the indicator variables u_{ki} (indicating whether plant k is located in region i). Intuitively speaking, allowing for spatial correlation in the model would imply that (apart from natural advantages being correlated) spillovers reach beyond spatial units. Suppose firm A and B colocate while firm C locates somewhere apart. It will be impossible in the framework of EG's model to tell if firm A and B chose the same region because of short-distance spillovers between them or if, instead, they benefit from long-distance spillovers with firm C and just happen to be in the same region. The two cases are observationally equivalent.

To conclude, agglomeration as measured by EG's index of concentration and spatial agglomeration are distinct phenomena albeit one would like to consider them simultaneously. The EG index captures only the first and we have compared relative agglomeration to relative spatial correlation. There is no rank correlation between them which implies that one has to consider both measures if one is interested in the geographic pattern of industries. Combining them in a single model-based measure is a desirable task that cannot be carried out, however, within the EG model so that it must be left for future work.

Figure 2.4: Spatial correlation vs agglomeration. Tobacco (left-hand side) exhibits strong agglomeration (EG index) but very low spatial correlation. Conversely, Manufacture (right-hand side) of structural metal products exhibits almost no agglomeration but strong spatial correlation. The colours correspond to the value of $y_i = s_i - x_i$. In the histogram below, the fat tail of the distribution of the y's of Tobacco reflects the strong degree of agglomeration.



Note: The variable y has been scaled by 1000 for ease of exposition.

2.3.7 Robustness test 2: Incorporating service industries

Manufacturing constitutes only about 30% of Germany's employed workforce. Roughly 17 million people work in service industries. Unlike previous studies, we possess employment data for all service industries and are thus able (i) to analyse the agglomeration of service industries and (ii) to check the results involving only manufacturing industries against the results involving *all* industries. From a theoretical perspective, nothing can be said about how EG's index changes when one adds more industries to the population under study.

Overall, the results do not change much. The ranking of manufacturing industries remains almost the same (the correlation with the old ranking is 0.96). As before, the simpler measure α produces very similar results (rank correlation of 0.90) while the Gini performs worse (rank correlation of 0.60). Accordingly, high-tech and medium-tech industries and industry groups still show a very low degree of absolute and relative agglomeration, as Table 2.9 and Table 2.10 show.

Table 2.9: Agglomeration of high-tech industries when service industries are taken into account

Rank γ	γ	Industry (NACE 3)	Sign.[1)]
		High-technology industries	
27	0.039	Manufacture of weapons and ammunition	
30	0.037	Processing of nuclear fuel	no
55	0.021	Manufacture of aircraft and spacecraft	
102	0.008	Manufacture of office machinery and computers	
107	0.008	Manufacture of industrial process control equipment	no
134	0.005	Manufacture of electronic valves and tubes and other electronic components	
136	0.004	Manufacture of television and radio transmitters and apparatus for line telephony and line telegraphy	
194	0.000	Manufacture of pharmaceuticals, medicinal chemicals and botanical products	no
		Medium-technology industries	
68	0.016	Manufacture of optical instruments and photographic equipment	
85	0.010	Manufacture of railway and tramway locomotives and rolling stock	
93	0.009	Manufacture of machinery for the production and use of mechanical power, except aircraft, vehicle and cycle engines	
94	0.009	Manufacture of lighting equipment and electric lamps	
108	0.008	Manufacture of agricultural and forestry machinery	
109	0.007	Manufacture of accumulators, primary cells and primary batteries	no
110	0.007	Manufacture of machine tools	
115	0.007	Manufacture of other chemical products	
117	0.007	Manufacture of television and radio receivers, sound or video recording or reproducing apparatus and associated goods	

Rank γ	γ	Industry (NACE 3)	Sign.[1)]
124	0.006	Manufacture of basic chemicals	no
126	0.006	Manufacture of paints, varnishes and similar coatings, printing ink and mastics	
147	0.004	Manufacture of other special purpose machinery	
159	0.003	Manufacture of medical and surgical equipment and orthopaedic appliances	
169	0.002	Manufacture of parts and accessories for motor vehicles and their engines	no
196	0.000	Manufacture of electrical equipment n.e.c.	no
207	-0.001	Manufacture of motor vehicles	no
214	-0.006	Manufacture of electric motors, generators and transformers	no
217	-0.016	Manufacture of pesticides and other agro-chemical products	no

Note: 1) "no" means not significant at the 95% level.

Table 2.10: Coagglomeration of high-tech industries (two-digit) when service industries are taken into account

Industry group	γ^c	Intra-industry concentr. as % of group's concentr.	Rank (among all NACE 2 industry groups)
High-tech Manufacturing	-0.0009	475%	53
Medium-tech Manufacturing	0.0003	46%	47
R&D-intensive Chemicals	0.0034	40%	23
R&D-intensive Manufacture of Machinery	0.0031	45%	26
R&D-intensive Manufacture of Electrical Machinery and Apparatus	-0.0020	47%	57
R&D-intensive Automobiles	0.0004	-30%	46
R&D-intensive Electronic, Optical and Communication Equipment	0.0002	73%	49
Knowledge-intensive Services	0.0068	15%	14
Human capital-intensive Services	0.0020	9%	32
Information- and telecommunication industry (including service industries)	0.0019	1%	33

2.4 The determinants of agglomeration

As noted earlier, the EG index does not distinguish between the various forces that may drive agglomeration. Any value of the index is consistent with a world only with natural advantages, only with spillovers or with both of them. Furthermore, the index captures "spillovers" only in a very broad sense. In this section we want to determine what forces are actually at work by relating the index to a variety of industry characteristics that shall measure agglomeration externalities.

Based on Marshall (1920) the literature has established three types of forces: (1) a pooled market for specialised input services (input sharing), (2) a pooled market for specialised labour and (3) non-pecuniary knowledge spillovers. The following section describes the variables used.

2.4.1 Variables for Marshallian agglomeration economies

Input sharing. With fixed costs of production, product specialisation can lead to a cumulative process of concentration. The more customers an industry producing a non-tradable service has the more it can specialise and exploit the increasing returns to scale. This increases productivity and/or the variety of the products which in turn benefits the purchasing industry which is assumed to like variety à la Dixit and Stiglitz (1977). This mechanism may eventually lead to the agglomeration of specialised input producers and specialised purchasing industries (see Abdel-Rahman and Fujita (1990) for a formal model).

From the 1998 survey on the cost structure of German manufacturing industries carried out by the German Census Bureau we have for each industry detailed data about various types of production costs. The portion of *technical and industrial services* and the portion of *manufactured inputs* in total shipments are taken as an indicator of how specialised the goods produced are and hence how large gains from sharing inputs could be. Technical and industrial service inputs are likely to be very industry-specific with the largest potential for scale economies while manufactured inputs are less specialised so that we expect a positive sign for both but a much stronger impact of the former.

Labour market pooling. If an industry needs workers with industry-specific skills it benefits from locating in an area where this specialised labour supply is high because it increases the probability of finding capable personnel (if demand and supply of labour are stochastic). Conversely, specialised workers reduce the probability of their being unemployed by moving where the demand for their skills is relatively high. All else equal, an industry with specific needs for labour skills should agglomerate (see Helsley and Strange (1990) for a formal model).

Two measures are used. The first is an industry's share of employees with a highly specialised occupation following the common definition of the German Federal Bureau of Labour. A measure *"secondary services"* is created which includes management, supervision, teaching and R&D (as opposed to "primary services": trading, security, office and general duties). The second measure accounts for employees' education and takes the percentage of an industry's workers with a university degree. While less precise than the measure of occupation, one should still expect that workers with a university degree are most likely to perform specialised tasks. The data are taken from the employment database.[15]

The agglomeration force we are most interested in is *knowledge spillovers*. An important insight from new growth theory is that firms cannot completely appropriate the knowledge they create by doing research because some fraction of it spills over to other firms. If this knowledge is tacit, it cannot spread over long distances but requires personal contact and spatial proximity to be transmitted. We assume that if such spatially bounded knowledge spillovers exist between plants, they render a single plant and consequently the whole industry the more innovative the more concentrated it is. Accordingly, one can expect that plants optimise their location with respect to spillovers to the extent that innovative capacity is crucial for their industry, which is basically Arrow's (1962) argument: knowledge spillovers are relatively more important in research-intensive industries.

Unfortunately, patent data are not available for the NACE industry classification system, and data on innovations are available only from panel surveys at a highly aggregate level. Following Audretsch and Feldman (1996) one could use an industry's R&D intensity measured by the share of R&D personnel in total employment and we will do so for comparison. However, this variable is highly correlated with an industry's share of specialised workers which reflects that ultimately labour market pooling and knowledge spillovers (through labour mobility) are hard to separate: an industry with a high share of researchers might cluster

[15] In Alecke et al. (2004) an industry's deviation from the average labour composition (across all types of occupations) was used a third measure of labour specificity. The results are insignificant.

because it benefits from knowledge spillovers as well as from pooling specialised workers. We deal with this problem by taking instead a high-tech and medium-tech dummy according to the common classification by Grupp et al. (2000) which was already used when describing the pattern of agglomeration in the previous section. If knowledge spillovers in high-technology industries are an agglomeration force, these dummies should have a positive impact on the concentration index.

2.4.2 Other control variables

Transportation costs and internal increasing returns. New trade theory (Helpman and Krugman 1985) and the new economic geography (for example, Krugman 1991b) predict that industries with stronger economies of scale in production technology and lower trade costs are more concentrated.[16] Marshall (1920), too, argued that higher transportation costs induce firms to locate closer to suppliers and customers. But note that this leads to colocation of trade partners and must be distinguished from pure localisation economies because it can render a *single industry* either agglomerated or dispersed. Although we do not want to test any particular new economic geography model and refrain from interpreting the regression coefficients structurally, we still want to test whether these predictions find any support in the data. Hummels (2001) shows that for the majority of traded goods "explicit costs" such as tariffs and freight costs are the most important components in trade costs. Therefore, we measure the average trade cost of an industry by the inverse of its unit value. From trade data containing both the total weight (tons) and value of goods imported and exported the average reciprocal unit value is calculated as

$$\frac{1}{UV} = \frac{weight\,(imports + exports)}{value\,(imports + exports)}$$

where transportation costs per unit of weight are assumed to be constant across industries so that the portion of total transportation costs in output, i.e. the

[16] There has been an explosion in new economic geography models. Some reverse this relationship so that higher trade costs imply more agglomeration. See, for example, Helpman (1998) and Head and Mayer (2003) for a survey.

importance of transportation cost, $(cost/ton)(weight/output)$, is proportional to the inverse unit value. Following Brülhart and Torstensson (1996) and Amiti (1999), internal economies of scale are measured by plant size.

Natural advantages. In principle one needs to account for the possibility that industries are geographically concentrated just because they rely on natural resources that are distributed unevenly in space. However, compared to the U.S. for example, Germany is a small country with a relatively even distribution of regional and local power stations so that access to electricity and gas should be fairly the same in all regions. Additionally, Germany is poor in natural resources and extractive industries are small. In sum, natural advantages should be relevant for only very few industries. In order to control for them an *extractive industry* dummy is included which is set equal to one for the industries with NACE code 10.1 – 14.5.

Size. For any given area, a larger but otherwise identical industry will find it more difficult to agglomerate due to congestion effects. The EG index is affected by the size of an industry only indirectly and in a non-linear fashion through the Herfindahl index. This is because it is designed to take into account the overall distribution of employment and it is not due to a congestion cost argument. To capture potential congestion effects, however, the size of an industry measured by total employment is included in the regression.

The model to be estimated is

$$\gamma = \alpha + \beta \mathbf{X} + \varepsilon$$

where γ is EG's index and $\mathbf{X}$ is a vector of the above industry characteristics. Three extreme outliers (Watches, Jewellery and Fish Processing) are excluded. All are very small (0.08%, 0.23% and 0.1% of manufacturing employment); Watches and Jewellery are characterised by family-owned, small-scale handcrafts for which the location decision is presumably determined by family tradition. Naturally, Fish processing is located only at Germany's short coastline in the North. For 8 non-extractive industries no transportation cost are available and they are assigned the average value (as suggested in Green 2002, Ch. 6.8); 7 industries are excluded because data for more than one variable is missing; and there remain 106 observations.

2.4.3 Regression results

Before we present the results there is one thing to note about identification. Agglomeration theory predicts that plants sensitive to specialised labour, specialised inputs or innovation tend to agglomerate because this will reduce production costs. Especially where we proxy "sensitivity" by cost shares there rises the question of identification. A high share of costs of—say—manufactured inputs indicates susceptibility to sharing inputs and thus a propensity to agglomerate. But this in turn should lower these costs and hence their portion in output. Consequently, what we observe is the equilibrium relationship between industry characteristics and agglomeration which tends to push the regression coefficients towards zero. If we find an insignificant relationship in equilibrium we cannot rule out the possibility that in fact there exists one. On the other hand, if we find a significant relationship we can expect it to be even stronger.[17]

A natural first approach is to use OLS estimation technique. White's (1980) test for heteroskedasticity is positive in some specifications so that his covariance estimator is used in place of the standard OLS formula. The results are shown in Table 2.11.

First of all, *industry size* is highly significant and has the anticipated negative sign in all regressions, that is, bigger industries are less geographically concentrated.

The *extractive industry* dummy is positive and always highly significant and it contributes substantially to the fit of the regression. *Transportation costs* are negative as expected, highly significant in all regressions and it is one of the most robust explanatory variables. Similarly, *internal economies of scale* has the correct sign and is significant in all regressions.

[17] See also Rosenthal and Strange (2001).

Table 2.11: OLS regression results

	County level			Planning Region level		
	(1)	(2)	(3)	(4)	(5)	(6)
Constant	0.0155***	0.0142***	0.0158***	0.0274***	0.0247***	0.0259***
	(0.0031)	(0.0032)	(0.0037)	(0.0058)	(0.0060)	(0.0069)
Employment	-0.0573***	-0.0552***	-0.0551***	-0.1025***	-0.1010***	-0.1014***
	(0.0155)	(0.0163)	(0.0163)	(0.0292)	(0.0306)	(0.0306)
Extractive industry	0.0382***	0.0372***	0.0384***	0.0897***	0.0862***	0.0878***
	(0.0075)	(0.0078)	(0.0077)	(0.0141)	(0.0145)	(0.0145)
Internal EoS	0.0147**	0.0143**	0.0148**	0.0496***	0.0499***	0.0505***
	(0.0083)	(0.0085)	(0.0085)	(0.0157)	(0.0159)	(0.0159)
Transportation costs	-0.0008***	-0.0008***	-0.0008***	-0.0015***	-0.0015***	-0.0015***
	(0.0003)	(0.0003)	(0.0003)	(0.0005)	(0.0005)	(0.0005)
Service inputs	0.0816***	0.0810***	0.0809***	0.1261***	0.1238***	0.1234***
	(0.0284)	(0.0289)	(0.0288)	(0.0535)	(0.0540)	(0.0542)
Manufactured inputs	-0.0329**	-0.0302	-0.0318	-0.0906***	-0.0841***	-0.0853***
	(0.0196)	(0.0205)	(0.0205)	(0.0368)	(0.0383)	(0.0385)
R&D intensity	-0.0152			-0.0096		
	(0.0161)			(0.0303)		
Dummy High-tech		-0.0007	0.0019		-0.0109	-0.0073
		(0.0061)	(0.0059)		(0.0114)	(0.0112)
Dummy Medium-tech		-0.0024	-0.0012		-0.0051	-0.0038
		(0.0039)	(0.0039)		(0.0072)	(0.0074)
Occupation			-0.0150			0.0080
			(0.0204)			(0.0383)
University		-0.0025			0.0397	
		(0.0315)			(0.0589)	
Adjusted R^2	0.46	0.44	0.45	0.56	0.56	0.56

Notes: Standard errors in brackets. * denotes significant at 10%, ** at 5%, *** at 1% level.

Technical and industrial services have the anticipated positive sign and are significant at the county level while *manufactured inputs*—somewhat surprisingly—are associated with a significant negative sign in some specifications. We conclude that, consistent with theory, industries that rely relatively more on services tend to agglomerate while the employment of more standardised (manufactured) inputs reduces agglomeration. This result seems contrary to Rosenthal and Strange (2001) who find that manufactured inputs significantly increase agglomeration while "non-manufactured" ones, containing financial, legal, repair etc. services, decrease it. The crucial question is whether manufactured or non-manufactured inputs are more industry-specific, more difficult to transport over distance and more likely to be produced under increasing returns. The theory is about increasing returns and extremely high transportation costs which applies foremost to services which drive the inputs-sharing argument more than physical goods. One explanation for the different results is the subtle but important difference in what the variables really measure. Our service variable takes only technical and industrial services as opposed to Rosenthal and Strange's variable which also contains items such as legal and financial services which may indeed be "available everywhere" (ibid, p. 17). In the end, our *manufactured inputs* variable corresponds to their "non-manufactured" one and it is all about naming variables.

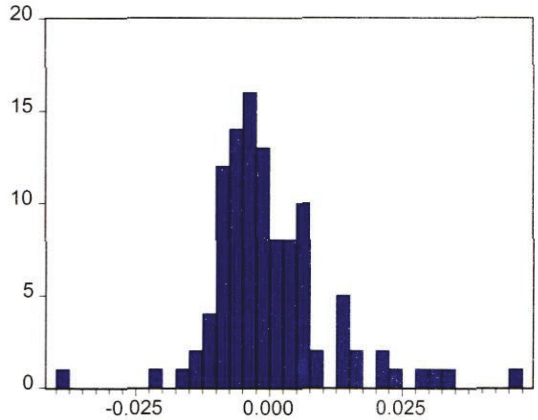
Unfortunately, both measures for *specialised occupations* are insignificant so that there is no direct evidence for labour market pooling in German industries. This is in contrast to Dumais et al. (2002) and Rosenthal and Strange (2001) who do find such evidence for the U.S.

Concerning knowledge spillovers the results confirm the insights from the previous sections. Neither the high-tech nor medium-tech dummy turn significant and in most cases they are even associated with a negative sign. Additionally, when experimenting with slightly different specifications we find that the variable *R&D intensity*, which should at least partially reflect the potential for knowledge spillovers in an industry, in some case even significantly *reduces* agglomeration.

2.4.4 Robustness tests

Inference from the standard t-test might be misleading because the regression residuals are almost certainly not normally distributed as the Eviews report in Figure 2.5 suggests. The White statistic, which is positive for some specifications, suggests that there is some type of heteroskedasticity. However, visual inspection does not help to determine which type of heteroskedasticity is at work so that it is not easy to solve the problem by explicitly modelling the error term. Although bootstrap tests need not be more reliable when the form of heteroskedasticity is unknown (MacKinnon 2002), an additional robustness check could still be to estimate the coefficients with the help of non-parametric bootstrapping. In light of the skewed error distribution it would not be reasonable to assume right from the beginning that the true distribution is symmetric. Furthermore, it is not clear if the expression $\bar{x} - \mu_x$, where $\bar{x}$ is the bootstrap estimate of any variable (e.g. the variance of γ) and μ_x its true (unknown) value, is a pivot, i.e. its distribution is independent of μ_x. For example, $(\bar{x} - \mu_x/\sigma_x) \sim N(0,1)$ is a pivot, i.e. its distribution is independent of the value μ takes, if $\bar{x}$ is normally distributed. For our case, Carpenter and Bithell (2000) propose to use the "bias corrected accelerated" method for calculating the bootstrap confidence intervals. Following Efron and Tibshirani (1993, p. 162) the bootstrap is run with 1000 replications (see Table 2.12).

Figure 2.5: Residuals from OLS regression (specification (1))



Mean	-8.28E-18
Median	-0.002227
Maximum	0.045998
Minimum	-0.038746
Std. Dev.	0.011301
Skewness	1.005623
Kurtosis	6.613223
Jarque-Bera	75.52715
Probability	0.000000

As can be seen, the previous results appear to be fairly robust. In particular, the technology dummies and the variable *R&D personnel* remain insignificant. Admittedly, the *Transportation costs* variable, which we found to be very robust in various OLS specifications, turns insignificant. We believe that the measure is quite precise so that it is not clear how this is to be interpreted. It could be due to the fact that the bootstrap methodology is usually extremely conservative in the sense of loss of power (see, for example, Corcoran and Mehta 2001).

Table 2.12: Bootstrap estimates for county and PR level

	County level		Planning Region level	
	(1)	(2)	(3)	(4)
Constant	0.0142**	0.0155**	0.0247**	0.0274**
	(0.0036)	(0.0033)	(0.0070)	(0.0062)
Employment	-0.0552**	-0.0573**	-0.1010**	-0.1025**
	(0.0116)	(0.0117)	(0.0231)	(0.0234)
Extractive industry	0.0372**	0.0382*	0.0862**	0.0897**
	(0.0186)	(0.0179)	(0.0355)	(0.0359)
Internal EoS	0.0143*	0.0147*	0.0499**	0.0496**
	(0.0164)	(0.0171)	(0.0371)	(0.0374)
Transportation costs	-0.0008	-0.0008	-0.0015	-0.0015
	(0.0005)	(0.0005)	(0.0012)	(0.0012)
Service inputs	0.0810**	0.0816*	0.1238**	0.1261**
	(0.0536)	(0.0580)	(0.1090)	(0.1102)
Manufactured inputs	-0.0302**	-0.0329*	-0.0841**	-0.0906**
	(0.0176)	(0.0165)	(0.0392)	(0.0353)
R&D intensity	-0.0152		-0.0096	
	(0.0157)		(0.0307)	
Dummy High-tech		-0.0024		-0.0051
		(0.0027)		(0.0052)
Dummy Medium-tech		-0.0007		-0.0109
		(0.0075)		(0.0130)
University		-0.0025		0.0397
		(0.0337)		(0.0667)

Notes: Standard errors in brackets. * denotes significant at 10%, ** at 5%, *** at 1% level.

Although γ is metric, one must keep in mind that it is an index whose absolute interpretation is difficult despite EG's attempt to get a feel for its scale. OLS regression is probably the most intuitive approach to answering the questions we posed but obviously there is the need for a robustness check with the help of a censored-type regression. It can be argued that the variation of very low γ's is economically meaningless because one does not know how much more "agglomeration" there really is if γ rises from—say 0.001—to 0.01.[18] this means there is a threshold below which one would consider industries to be not agglomerated at all. Therefore, in Alecke et al. (2004) we checked the OLS results with a Tobit regression where γ is left-censored at 0.005.[19] However, recognising

[18] We thank an anonymous referee for this remark.
[19] The value is chosen so that 43% of the observations are censored. In EG 43% of the industries are "not much" concentrated.

that the dependent variable is an index suggests that ultimately Ordered Probit is an appropriate way to check the results. Here, it is the rare case that the observed variable is continuous so that it needs to be discretised. Discretising γ also removes the issue of the skewed distribution of residuals and potentially unreliable OLS results. The results reported in Table 2.13 pertain to a discretisation using eleven quantiles (thus yielding a uniform distribution).[20] It appears from both the Tobit and Probit regression that our main results are robust. In particular, the variables for "high-tech" and "medium-tech" remain insignificant.

We conclude that R&D- and technology-related business is at neither geographic level more agglomerated than other industries which is in line with Rosenthal and Strange (2001) who find only very weak evidence for knowledge spillovers at the zip code level and no evidence at higher levels.

[20] Unreported results with 8, 9, 10 quantiles are very similar. The thresholds proposed by EG (0.02 and 0.05) cannot be used because there would be too few observations in the high- and medium-γ category.

Table 2.13: Ordered Probit regression results

	County level			Planning Region level		
	(1)	(2)	(3)	(4)	(5)	(6)
Employment	-4.8064***	-5.1956***	-5.1661***	-6.8021***	-7.2126***	-7.2000***
	(1.4323)	(1.4957)	(1.4933)	(1.4768)	(1.5486)	(1.5472)
Extractive industry	2.3441***	2.3576***	2.4460***	2.4024***	2.3480***	2.4105***
	(0.7419)	(0.7512)	(0.7506)	(0.7447)	(0.7582)	(0.7562)
Internal EoS	2.3122***	2.2143***	2.2529***	2.5975***	2.5166***	2.5490***
	(0.7870)	(0.7909)	(0.7888)	(0.7972)	(0.8016)	(0.8002)
Transportation costs	-0.0441**	-0.0435**	-0.0456**	-0.0467**	-0.0450**	-0.0466**
	(0.0245)	(0.0246)	(0.0245)	(0.0246)	(0.0249)	(0.0248)
Service inputs	2.5129	2.7366	2.8190	2.0280	2.0600	2.1757
	(3.3057)	(3.3317)	(3.3322)	(3.3133)	(3.3229)	(3.3308)
Manufactured inputs	-3.5542***	-3.9021***	-4.0469***	-5.4677***	-5.7030***	-5.7802***
	(1.7559)	(1.8155)	(1.8214)	(1.7775)	(1.8404)	(1.8462)
R&D intensity	-0.8895			-0.4570		
	(1.4267)			(1.4321)		
Dummy High-tech		-0.0667	0.1381		-0.3817	-0.2039
		(0.5341)	(0.5211)		(0.5363)	(0.5223)
Dummy Medium-tech		0.2367	0.3360		0.1317	0.2028
		(0.3348)	(0.3412)		(0.3358)	(0.3417)
Occupation			-1.6476			-0.2284
			(1.8118)			(1.8168)
University		-0.8456			1.0289	
		(2.8094)			(2.8249)	
Log likelihood	-234.78	-234.58	-234.21	-229.07	-228.61	-228.67

Notes: Standard errors in brackets. * denotes significant at 10%, ** at 5%, *** at 1% level.

2.5 Discussion

Either spillovers are not limited to knowledge-intensive activities (within industries) but instead are much more general than has been assumed so far or they simply do not spur agglomeration. Concerning the first point we should emphasise that our approach is a top-down one. But although using the EG index implies aggregating detailed regional data to one industry measure, the statistical model behind it helps to make more systematic statements than is possible in case studies or the analysis of regional employment shares where often ad-hoc criteria for what makes a "cluster" are used. Additionally, if case studies keep finding evidence for a certain agglomeration pattern this should show up in some way in this more systematic approach with three-digit or two-digit industries. Nevertheless, there remains the standard caveat concerning the definition of industry. We know from case studies that fast growing industries like biotechnology or micro- and system technology do have a tendency to cluster. But they are still too young and too small to be appropriately captured by the manufacturing industry classification system.

One can interpret our regression as evidence against localisation economies from knowledge spillovers. If it is "cross-fertilisation" in the spirit of Jacobs (1969) that counts, then knowledge may flow between plants of any possible pair of industries and we would hardly observe single-industry (high-tech) clusters on the map, which would be consistent with our finding.

There are two explanations for the latter point, namely that spillovers do not necessarily spur agglomeration (at the regional level). The first concerns the range of knowledge spillovers. Spillovers could work at an extremely localised level such as the city-level. Our approach would not necessarily capture such mini-spillovers, and case-studies would perhaps be more appropriate. However, at such a low geographic level agglomeration is likely to be the result of administrative conditions (e.g. a city's allocation of industrial estate). Alternatively, distance may actually not matter for knowledge flows. Orlando (2003) finds for the U.S. that unlike inter-industry R&D spillovers, intra-industry spillovers do not attenuate by distance. If this were true there would be no need for industries to agglomerate in order to benefit from such spillovers. As Germany is a relatively small country with every major city within one day travel-distance, spatial proximity could be a poor proxy for the importance of personal contact, trust etc. Still, Bode (2004) shows in a recent study that in Germany only a very small share of regional knowledge spills over to neighbouring regions due to the existence of substantial spatial transaction costs. This indicates that spillovers are indeed spatially bounded which justifies our approach.

A last caveat is that we cannot include in our analysis the proximity to public research facilities which seem also to be important for knowledge spillovers (Anselin et al. 1997, Bode 1998).

A second explanation for why spillovers may not spur agglomeration has been addressed by Shaver and Flyer (2000). They argue that heterogeneity among firms can lead to asymmetric contributions to and benefits from agglomeration externalities and that firms' location choice becomes strategic then. They give empirical evidence that firms with superior technologies, human capital or suppliers have the incentive to locate distant from other firms, especially from firms within their industry, i.e. from direct competitors. Our systematic analysis of manufacturing industries gives some support to their firm-level study.

2.6 Conclusion

This paper has explored the geographic concentration of German manufacturing industries using Ellison and Glaeser's (1997) concentration index for the first time. The questions we asked are (i) how much are plants of an industry agglomerated and (ii) what factors determine concentration, i.e. we consider the pattern and magnitude of localisation economies. The focus has been on high-technology related industries motivated by the fact that the notion of "high-tech clusters" is en vogue and has inspired many regional policy initiatives.

Concerning the first question, we found that 80% of the 116 industries are statistically significantly more concentrated than what would result if location decisions were pure random. However, the degree of concentration is rather low; only resource related industries exhibit strong concentration and they dominate the group of the top 15. In particular, high-tech and medium-tech *industries* and *industry groups* are only little concentrated, partly even not significantly so, and rank medium or even lowest.

To answer the second question, we related the concentration index to a variety of industry characteristics that shall reflect theoretical agglomeration forces in a regression analysis. The result is that transportation costs significantly reduce agglomeration while internal increasing returns increase it which is line with the predictions of the new economic geography.

Concerning Marshall's (1920) agglomeration forces there is evidence for input sharing (specialised service inputs) but no evidence for knowledge spillovers. Thus we give support to one important finding in Rosenthal and Strange (2001), namely that there is only very weak, if any, evidence for spatially bounded knowledge spillovers within industries.

To conclude, there is no general relationship between agglomeration and high-technology related business among German manufacturing industries which means that simply being "high-tech" does not make an industry agglomerate. This in turn suggests that German regional policy which currently puts much hope into the fast and effective development of high-tech clusters could experience some disappointments in the future or might even be wasting tax payers' money.

3 The downside of knowledge spillovers: An explanation for the dispersion of symmetric firms

3.1 Introduction[21]

It is implicitly assumed in much of the work on spatial spillovers and in many precipitant policy measures that there exists a general and mutual advantage for profit-maximising firms to locate close to each other. If trade partners reduce transportation costs by locating close to each other this argument is very plausible because they can share the surplus. But regarding knowledge spillovers it is important to point out that the benefit from absorbing external knowledge is only one of actually two aspects in the location decision. Opposed to the benefit is the disadvantage of sharing private knowledge with other (competing) firms so that in addition to the incentive to cluster there is one to separate. The negative aspect of clustering becomes even more vital if one considers firms that differ with regard to the quality of knowledge—or more generally: the quality of agglomeration benefits—they emit. While a "poor" firm certainly benefits from the "good" one, the good one may be concerned about making its rival stronger while not receiving any benefit itself and may thus have no incentive to colocate.

In fact, the empirical work presented in the previous chapter can be interpreted as strong evidence in this direction. There we have shown that among German manufacturing industries there is no general relationship between

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[21] This chapter is an extension of the work published in Alsleben (2005).

geographic concentration and R&D or high-technology related business (which should be most susceptible to spillovers) which means that these characteristics do not necessarily make industries agglomerate.

The aim of this chapter is to give a possible explanation for this phenomenon. We follow Combes and Duranton (2001) (henceforth CD) who present a duopoly model of location choice by firms in which "knowledge spillovers" occur through mutual labour poaching, i.e. the degree of spillovers is endogenously determined in equilibrium. In contrast to CD, who postulate Bertrand competition with differentiated goods, we assume standard Cournot competition with homogenous goods. This modification not only allows for a robustness check of CD's results with respect to product market structure, but also represents a research question in its own right as Cournot competition models are one of the basic "work horses" of theoretical industrial organisation. Indeed, a more clear-cut picture emerges with Cournot competition and the main result is that firms always prefer spatial separation unless they exchange their *entire* personnel through poaching, which constitutes a corner solution. Moreover, the Cournot extension allows us to look at two important extensions: the consideration of more than two firms and asymmetries between firms.[22]

The remainder of this chapter is organised as follows. The next section gives a short review of the literature on knowledge spillovers and agglomeration. Section 3.3 presents the Cournot model, section 3.4 discusses the results and section 3.5 concludes.

3.2 The literature on knowledge spillovers and labour poaching

The discussion of knowledge spillovers has lacked a thorough micro-foundation and has been treated as a "black box" for a long time both in regional economics and in industrial organisation (see Breschi and Lissoni 2001 for a critical survey). Amir (2000) discusses and compares in detail the d'Aspremont and

[22] For a Bertrand model that is less relevant for our main questions see Combes and Duranton (2001) and Combes and Duranton (2003) which is a revised version of the former.

Jacquemin (1988) model in which there are spillovers on firms' stock of knowledge to the Kamien et al. (1992) model in which spillovers work on R&D expenditure. He shows that the seemingly innocuous difference in representing spillovers results in the two different models with even contradictory policy implications. In the same spirit Grünfeld (2003) concludes his paper about absorptive capacity saying

> *"The main message of this paper is that results derived from the study of optimal R&D investment with spillovers depend strongly on how we model the R&D spillover mechanism" (p. 1106).*

It is therefore important to give a clear account of how "spillovers" emerge and through which channels they are transmitted.

In regional economics and in industrial organisation spillovers are usually understood as purely unintended and non-pecuniary externalities. Even in more recent models which introduce "absorptive capacity", i.e. firms' ability to learn from their rivals (for example Kamien and Zang 2000, Grünfeld 2003), and which thus endogenise the *extent* of spillovers, it remains unclear how precisely spillovers operate.

Possible channels through which knowledge may leak out of a firm or research institute are labour turnover, local spin-offs, reverse engineering, sub-contracting, cooperation and public presentation or publication.[23] Subcontracting, cooperation and publication obviously are not involuntary at all; and when an employee possesses key knowledge, a firm must offer him an adequate compensation to keep him from joining a competitor or starting his own business. In the latter case spillovers actually pass through (labour) markets and need to be modelled in such a framework. Hence, the transmission of knowledge is not necessarily as unwilling and non-pecuniary as a "black-box" concept of spillovers suggests.

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[23] Take for example the "Bio it Ruhr" iniative, (http://www.bio-it-ruhr.de), which aims at bringing together professionals from various fields of high-tech related business and research and at establishing a network of experts.

The focus of this paper is on labour poaching as the source of knowledge spillovers. Often firms turn to external sources such as suppliers, universities, consultants and competitors in order to generate the knowledge required for technological development. As Kogut and Zander (1992) have shown, a substantial portion of the knowledge that firms want to acquire is tacit and hence embedded in individuals. Argote and Ingram (2000) have shown that these individuals can effectively apply this knowledge to new contexts thereby transferring the knowledge across firms. Consequently, human mobility may play an important role in a firm's knowledge-building process, especially when knowledge is "sticky" and remains highly localised. Moen's (2000) study suggests that the mobility of engineers (within and between firms) can significantly influence how knowledge and capabilities are transferred and that it is an important "spillover" channel. In a similar study, Almeida and Kogut (1999) tracked the movements of over 400 engineers and demonstrated that their patterns of mobility influenced the intra-regional structure of knowledge flows. By studying the patenting activities of engineers who moved from U.S. firms to non-U.S. firms, Song et al. (2003) investigate the conditions under which learning-by-hiring, i.e. the acquisition of knowledge through hiring experts from other firms, is more likely and more effective. They show that both domestic and international labour mobility are conducive to learning-by-hiring and that this helps firms to extend their geographic reach. Franco and Filson (2005) present a general industry model in which employees imitate their employers' know-how and, under certain circumstances, leave the firm, found their own enterprise and thus transfer knowledge across institutions. The authors also demonstrate that the results of the model are consistent with data from the U.S. rigid disk drive industry.

There is also anecdotal evidence that in high-tech industries and in the banking business key employees are wooed by head-hunters and may easily switch their employer for a salary increase. The investment bank Credit Suisse First Boston is reported to have tried to woo away all of Dresdner Kleinwort Wassersteins' managing directors in Frankfurt. CSFB aimed at strengthening their expertise at their Frankfurt based office. Only after the personal intervention of the CEO and supposedly substantial concessions in compensation, DRKW accomplished to retain most of their managers.[24] In April 2005 the International Herald Tribune reported that in New York the investment bank Morgan Stanley "has been shaken by another round of defections, adding to a stream of executive departures in recent weeks".[25] Eight senior traders had left the firm for Deutsche Bank. "In addition to rival firms' drawing up lists of top bankers and approaching them with offers, headhunters are sending 70-page books to some of Morgan Stanley's competitors, with detailed organization charts, highlighting who the top traders and bankers are and even how much they are paid", the newspaper writes. A survey of 111 German firms believed to belong to the "Hamburg aviation cluster" reveals that there is in fact a strong concern about head-hunting.[26]

The German law system provides contractual instruments for firms to protect themselves against such labour poaching (and to protect company secrets in general) but most of them remain relatively ineffective because legal practice is usually in favour of the employee and free job mobility.[27] Then the only valuable instrument that firms maintain is the carrot, i.e. bonus payments, additional old-age pensions etc.[28]

Finally, our focus on labour poaching is motivated by studies at the more aggregate level such as Wheaton and Lewis (2002) who find that observationally equivalent workers earn higher wages when they are in urban labour markets that have a larger share of metropolitan employment in their same occupation and industry. This can be interpreted both as evidence for knowledge flows in places with dense economic activity and for labour market pooling in the spirit of Marshall (1920) which has also been found by Dumais et al. (2002) and Essletzbichler and Rigby (2002).

There are a few contributions that explicitly model the channel of "knowledge spillovers". In Gersbach and Schmutzler (2003) firms compete for R&D employees who have valuable knowledge but there is no spatial dimension. Stahl and Walz

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[24] Frankfurter Allgemeine Zeitung, July 2nd 2004.
[25] International Herald Tribune, April 22nd 2005
[26] Pfähler and Lublinski (2003), p. 115.
[27] From a report in Frankfurter Allgemeine Zeitung, September 21st 2005.

(2001) discuss spatial spillovers and show that there can be a disadvantage of agglomeration by combining a labour market pooling argument with industry-specific retraining costs. On the one hand, a firm in their model likes to colocate with firms of a *different industry* because then it is hedged against industry-specific shocks (in their model: rationing in labour supply in case of a positive product market shock). But when a firm expands business by absorbing labour from the declining industry in case of an (asymmetric) industry-specific shock it has to pay (higher) retraining cost. On the other hand, these retraining cost make agglomeration with firms of the *same industry* attractive; but then firms may be rationed in case of a positive industry-specific shock. In the model it depends on the probabilities of firm- and industry-specific shocks and the amount of the retraining cost whether firms prefer to cluster with alikes or firms of a different industry.

Fosfuri and Rønde (2003) focus on labour poaching as the source of knowledge spillovers. In an R&D-setup where unsuccessful firms can catch up with the innovative rival by poaching its key employees (when located in the same region) they show that firms want to colocate only for certain constellations of the value and probability of an innovation and the degree of product market competition.

3.3 The Cournot Model

3.3.1 Duopoly

The model presented here follows CD's model but is adjusted to the case of Cournot competition between firms producing a homogenous good. This adjustment is motivated by the fact that in our empirical analysis (chapter 2) we measure the geographic concentration of narrow, three-digit manufacturing industries and hence the degree of *localisation* rather than *urbanisation* economies. In manufacturing industries (as opposed to service industries) adjusting capacity and output is presumably more difficult than changing prices. Consequently, firms can be expected to name prices after they have decided about production capacity and actual output.

[28] From a report in Frankfurter Allgemeine Zeitung, June 16th 2004.

Kreps and Scheinkman (1983) have shown that such a (stylised) game yields Cournot-like outcomes which justifies the use of a Cournot model.

The basic idea behind the model is the same as in CD. Knowledge is incorporated in "key employees" (e.g. engineers, managing directors) and may flow between firms through labour poaching if firms locate close to each other. In particular, there are two firms which have to choose between two locations. If they colocate (in any of the two regions) they can poach strategic workers from their rival. If they separate, no poaching is possible because labour is immobile across regions. Each firm has an initial endowment of strategic workers of mass 1. After choosing their location, firms are ready to start production. The idea is that strategic workers appropriate key knowledge about customers, the organisation, technical layout, production process etc. during the (exogenous) period when they build up the production facilities. This knowledge is complementary and each firm enjoys a (constant) reduction of its production costs if it poaches (λ) workers from its rival, $c_i = \overline{c} - \lambda_i$. However, to employ the rival's workers, some retraining is necessary which costs $T\lambda^2$. Instead of strategic workers one could also think of researchers who are required to make the firm ready for production (e.g. they develop a certain business organisation or a particular production process). Once they have accomplished this, they have no more direct value for their employer, i.e. they produce only one innovation per firm (in their lifetime). For the competitor, however, they are highly valuable because they possess complementary knowledge.

Poaching is assumed to take place via a simple auction process: if a firm offers a salary equal to or higher than that of the rival, it can poach as many workers as it wishes. Knowing this, firms can protect themselves against such poaching by offering their workers higher wages and hence making poaching by the rival more costly.[29]

Finally, quantity competition takes place given strategic wages (w), poaching (λ) and production costs (c_i) determined in the previous sub-games. In sum, "spillovers" are endogenous in this model as firms decide about how much they receive (by poaching workers) and how much they emit (by setting own wages) and they are pecuniary in the sense that they affect wages.

The inverse demand function is given by

$$p = \alpha - \beta(q_i + q_j). \tag{3.1}$$

After re-scaling initial production costs to unity ($\overline{c} = 1$), firm i's profit function reads[30]

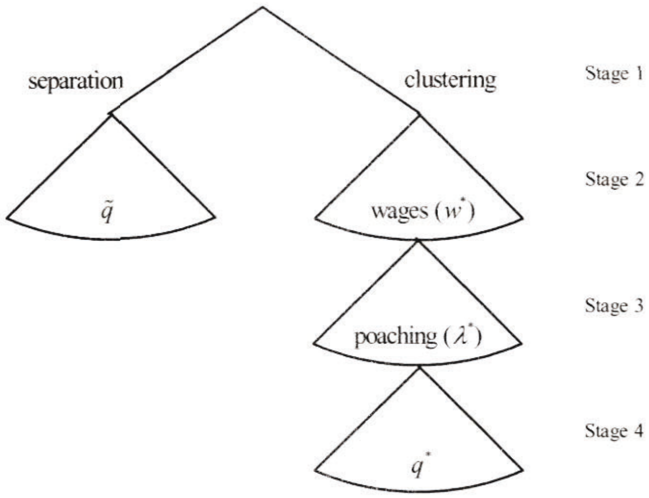
$$\pi_i = \underbrace{(p - c_i)q_i}_{\text{operating profit}} - \underbrace{w_i(1 - \lambda_j)}_{\text{wage bill for retained workers}} - \underbrace{w_j\lambda_i}_{\text{wage bill for poached workers}} - \underbrace{T\lambda_i^2}_{\text{training costs}}. \tag{3.2}$$

This expression allows for a more general interpretation: firms can reduce their variable costs if they "invest" in cost-saving technology (poaching) and incur some fixed costs (with respect to output). They also control wages which means they determine the "price" of the rival's investment. Figure 3.1 depicts the game; at each stage firms make their choices simultaneously.

[29] This means workers face no "mobility cost". In Combes and Duranton (2003) workers are associated with positive switching cost and can be ranked according to them, and these cost are assumed to be uniformly distributed. In that model there is, for given wages, a type of worker who is indifferent between joining the rival and staying with his firm (taking into account his idiosyncratic switching cost). Strategic wages and the level of poaching are determined simultaneously which reduces the number of stages of the game. Combes and Duranton (2003, p.8) regard the approach pursued here (and which follows their 2001 version) as producing "richer results" while the basic mechanisms developed in their 2003 version would "carry through in this more complex setting".

[30] Together with the number of initial workers being expressed as a continuum of mass 1, the standardisation of $\overline{c}$ re-scales minimum production costs to zero and allows for full poaching.

Figure 3.1: The structure of the labour poaching game



This paper analyses only equilibria in pure strategies and the focus is on symmetric (interior) equilibria. The following assumption is made.

Assumption 3.1. *Assume that* $T\beta > \frac{3}{4}$ *and* $\alpha > 1$.

This ensures that an interior solution of the wage-setting subgame exists and that the market is big enough so that firms find it worthwhile to engage in production at all.

At the last stage Cournot competition takes place and firms maximise profits with respect to quantity which gives the best-response

$$q_i^{BR} = \frac{1}{2\beta}\left(\alpha - \beta q_j - (1 - \lambda_i)\right) \tag{3.3}$$

and the familiar equilibrium

$$q_i^* = \frac{1}{3\beta}\left(\alpha - 1 + 2\lambda_i - \lambda_j\right) \tag{3.4}$$

Clearly, poaching increases the quantity produced because it lowers variable costs.

At stage 3 firms must choose their optimal level of poaching. Using the envelope theorem and the fact that $\frac{\partial \pi_i}{\partial q_i^*}\frac{\partial q_i^*}{\partial \lambda_i} = 0$ yields

$$\frac{d\pi_i(q_i^*(\lambda_i,\lambda_j),q_j^*(\lambda_i,\lambda_j))}{d\lambda_i}=\underbrace{\frac{\partial p}{\partial q_j^*}\frac{\partial q_j^*}{\partial \lambda_i}q_i^*-\frac{\partial c_i}{\partial \lambda_i}q_i^*}_{\text{V}}\underbrace{-w_j-2T\lambda_i}_{\text{N}}=0. \tag{3.5}$$

V is positive and reflects the benefit of poaching, which consists of the cost reduction and the resulting increase in equilibrium sales (indirect effect). N is negative and reflects the poaching costs, namely the rival's wage that one has to match and the training cost. This gives the best-response (see also Figure 3.2)

$$\lambda_i^{BR}=\begin{cases} 0 & \lambda_j>\overline{\lambda} \\ \frac{1}{9T\beta-4}\left(2(\alpha-1-\lambda_j)-\tfrac{9}{2}\beta w_j\right) & \underline{\lambda}\le\lambda_j\le\overline{\lambda} \\ 1 & \lambda_j<\underline{\lambda} \end{cases}$$

$$\underline{\lambda}=\alpha-1-\tfrac{9}{4}\beta w_j-\frac{9T\beta-4}{2} \tag{3.6}$$

$$\overline{\lambda}=\alpha-1-\tfrac{9}{4}\beta w_j.$$

The poaching equilibrium is stable[31] and reads

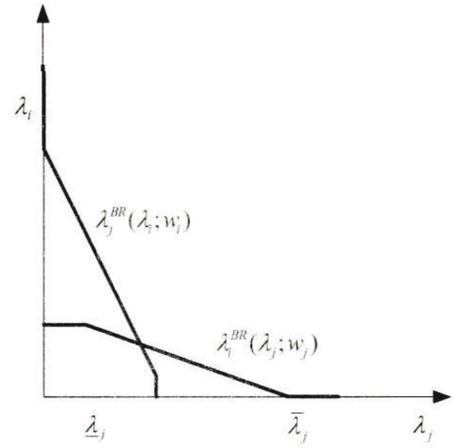
$$\lambda_i^*=\frac{1}{9T\beta-2}\left(2(\alpha-1)+\frac{\beta}{3T\beta-2}(3w_i-\tfrac{3}{2}(9T\beta-4)w_j)\right). \tag{3.7}$$

For the second-order condition $\partial^2\pi/\partial^2\lambda<0$ to be satisfied it is necessary that $T>4/(9\beta)$ which is fulfilled due to Assumption 3.1. This in turn makes the poaching variables strategic substitutes[32] and decreasing in the rival's strategic wage. From the economic perspective this is plausible because the rival's wage corresponds to the (fixed) cost of the investment, and as a parameter in the poaching decision it should lower it.

[31] The usual stability condition is $1-\left(\partial\lambda_i^{BR}(\lambda_j)/\partial\lambda_j\,\partial\lambda_j^{BR}(\lambda_i)/\partial\lambda_i\right)\ge 0$ which implies $(9T\beta-4)^2>4$ which is true for any T,β fulfilling Assumption 3.1.

[32] Two action variables are called *strategic substitutes* if their best-response functions are downward sloping. They are called *strategic complements* if they are up-ward sloping.

Figure 3.2: The poaching best-response



At stage 2 firms optimise their wage offer

$$\frac{d\pi_i\left[q_i^*\left(\lambda_i^*(w_i,w_j),\lambda_j^*(w_i,w_j)\right),q_j^*\left(\lambda_i^*(w_i,w_j),\lambda_j^*(w_i,w_j)\right)\right]}{dw_i}$$
$$=\underbrace{-\left(1-\lambda_j^*\right)}_{N_1}+\left(\underbrace{\frac{\partial p}{\partial q_j^*}\frac{\partial q_j^*}{\partial \lambda_j^*}q_i^*}_{V}+\underbrace{w_i}_{N_2}\right)\frac{\partial \lambda_j^*}{\partial w_i}=0 \tag{3.8}$$

and they balance the strategic advantage that a higher wage reduces poaching by the rival and makes him less aggressive (V), against a direct and indirect disadvantage in the wage bill: (i) higher wages mean higher cost per worker (N_1) and (ii) if the rival takes fewer employees away this means that the wage must be paid to more people (N_2). Each firm's best-response is

$$w_i^{BR}=\begin{cases}0 & w_j>\dfrac{P_1+\alpha P_2}{6T\beta^2}\\ \dfrac{1}{P_3}\left(-6T\beta^2 w_j+P_1+\alpha P_2\right) & \text{else}\end{cases} \tag{3.9}$$

with

$$P_1=-2T\beta(3T\beta-2)(81T^2\beta^2-63T\beta+8)<0$$
$$P_2=162T^3\beta^3-22T^2\beta^2+96T\beta-\tfrac{32}{3}>0$$
$$P_3=\beta(9T\beta-4)(54T^2\beta^2-51T\beta+8)>0$$

so that the wage variables are strategic substitutes. The equilibrium is stable[33] and reads as

$$w_i^* \in \begin{cases} \{0\} & 1 \le \alpha \le \underline{\alpha} \\ \left\{\frac{1}{P_6}(P_4 + \alpha P_5)\right\} & \underline{\alpha} < \alpha < \overline{\alpha} \\ [0, \underline{w}] & \overline{\alpha} \le \alpha \end{cases} \tag{3.10}$$

where

$$\begin{aligned} P_4 &= -162T^3\beta^3 + 126T^2\beta^2 - 16T\beta < 0 \\ P_5 &= 54T^2\beta^2 - 40T\beta + \tfrac{16}{3} > 0 \\ P_6 &= \beta\left(162T^2\beta^2 - 117T\beta + 16\right) > 0 \\ \underline{\alpha} &= \frac{-P_4}{P_5}, \ \overline{\alpha} = 9T\beta \\ \underline{w} &= \frac{4\alpha}{9\beta} - 2T. \end{aligned}$$

The second-order condition, $\partial\pi_i/\partial^2 w_i < 0$, requires that $T\beta > \left(\sqrt{97} + 17\right)/36 \approx \frac{3}{4}$ which is fulfilled due to Assumption 3.1. The subgame equilibrium and hence the equilibrium of the whole game is unique and symmetric for $1 \le \alpha < \overline{\alpha}$. For $\alpha < \underline{\alpha}$ the constraint that the wages be non-negative is binding and the subgame equilibrium hence zero. Zero wages can be interpreted as firms dismissing their key workers and leaving them for the rival at no cost. Furthermore, one has $\lambda_i^*\left(w_i^*, w_j^*\right) > 0$ for all $\alpha \ge 1$, which means that in equilibrium firms will always find it optimal to poach some employees but they will protect themselves with positive strategic wages only if market size exceeds a certain threshold $\underline{\alpha}$.

There exists a second threshold, $\overline{\alpha}$, from which on the poaching subgame equilibrium is a corner solution with $\lambda^* = 1$. For any market size greater than $\overline{\alpha}$ the condition $\lambda^*\left(w^*, w^*\right) \le 1 \Leftrightarrow w^* > \underline{w}$ becomes binding and market size affects the

[33] The usual stability condition is $1 - \left(\partial\lambda_i^{BR}(\lambda_j)/\partial\lambda_j \, \partial\lambda_j^{BR}(\lambda_i)/\partial\lambda_i\right) \ge 0$ which implies $\beta^2(9T\beta - 2)(3T\beta - 2)(52T^2\beta^2 - 63T\beta + 16)(162T^2\beta^2 - 117T\beta + 16) > 0$ so that the equilibrium is stable.

level of poaching neither directly nor through equilibrium wages anymore. It induces firms to woo away *all* employees from their rival, irrespective of their own (protective) wages. As a result, firms do not pay the wages they offer their own workers in the first place and hence any pair of (non-negative) wage offers which leads to full poaching is an equilibrium ($\underline{w} = 4\alpha/(9\beta) - 2T$ is the highest wage level that leads to full poaching). Note that, in order to poach, firms must still pay the poached workers the salary that these were unsuccessfully offered by the *other* firm.

Finally, firms choose between colocation and separation by comparing the profits in each case, given the equilibria of the poaching and wage-setting subgame. If they locate in different regions no poaching and no cost reduction are possible. Profit-maximising wages are hence zero and the quantity produced is $q = (\alpha - 1)/(3\beta)$ leading to profits of $\pi^{sep} = (\alpha - 1)^2/(9\beta)$.

Proposition 3.1. *Any subgame-perfect equilibrium path of the above four-stage game implies either colocation and full poaching or separation:*

$$\alpha \geq \bar{\alpha}: \begin{cases} \text{co-location}, \ w_i, w_j \in [0; \underline{w}], \ \lambda = 1, \ q = \dfrac{\alpha}{3\beta} & \text{if } w_i, w_j < \tilde{w} \\ \text{separation}, \ w_i, w_j \in [0; \underline{w}], \ \lambda = 0, \ q = \dfrac{(\alpha - 1)}{3\beta} & \text{if } w_i, w_j \geq \tilde{w} \end{cases}$$

$$\alpha < \bar{\alpha}: \ \text{separation}, \ w = 0, \ \lambda = 0, \ q = \frac{\alpha}{3\beta} \tag{3.11}$$

$$\bar{\alpha} = 9T\beta$$

$$\tilde{w} = \frac{2\alpha - 1}{9\beta} - T$$

Proof. *See Appendix B.1.*

Remarks. *(i) For $\alpha \geq \bar{\alpha}$ there is a continuum of equilibria in the wage-setting subgame both with colocation and with separation. If firms had a co-ordination device they would co-ordinate on colocation and zero wages.*[34] *(ii) For $\alpha \geq \bar{\alpha}$ there*

[34] For $\bar{\alpha} \leq \alpha$ all $w_i, w_j \in [0; \underline{w}]$ are equilibria of the wage-setting subgame. One equilibrium refinement is trembling-hand perfectness. In this case "separation" is not trembling-hand perfect because a perturbation leading to colocation would result in full poaching.

is no equilibrium in pure strategies in the location decision subgame if $w_i^* > \tilde{w}$, $w_j^* < \tilde{w}$. *In this case colocation is too expensive for firm j but worth for firm i.*[35]

Therefore, this paper wants to emphasise that CD's main point, namely that profit-maximising firms *may* choose to separate under partial poaching, is reinforced with a different type of competition. In the case of Cournot competition with homogenous goods firms never colocate with partial poaching. At the same time this means that the parameter range over which firms *do* agglomerate is very sensitive to the type of competition prevailing in the market.

In view of our empirical finding that high-technology manufacturing industries are not significantly agglomerated, we propose this model as a stylised explanation: market size determines whether firms agglomerate or not. A clear empirically testable hypothesis emerges. Larger high-technology industries are more agglomerated but there is no linear relationship; instead there exists a critical market size, $\bar{\alpha}$, which divides industries into a group with no concentration and one with strong concentration.

3.3.2 Oligopoly

An obvious question is whether the trade-off between the benefits and costs of clustering eases or even disappears with an increasing number of firms. CD speculate that the benefit might increase with the number of firms while the rivalry effect could be diluted as workers leave for many different firms. In order to analyse whether this is true in the Cournot model, we solve it for an arbitrary number of firms.

[35] In general, it is not clear if firms really "achieve" the desired equilibrium. This is only if they can co-ordinate on which region they finally choose. If they cannot, there exist also equilibria in mixed strategies and the equilibrium probabilities determine how often firms really locate in different regions. Following CD's model it is assumed that firms are able to co-ordinate. Alternatively, suppose the two regions are of different size and that in the small region only a single firm can locate and operate business (e.g. due to insufficient public infrastructure, commercial estate or natural advantages). If firms choose their location in a sequential order they will end up clustering in the big region only if this is profitable for both of them. If it is not, the first moving firm can avoid unwanted colocation by choosing the small region.

When considering more than two firms an important question is what the poaching process looks like. In order to keep the model solvable, the above auction procedure shall be extended in a very simple way. Firms still decide about how many workers to poach but it is assumed that they cannot determine a particular firm to poach from. Instead, the number of poached workers is composed of equal shares from each rival. Then the wage that a firm pays to attract external workers can be interpreted as the average of the rivals' strategic wages.[36] Although this model does not consider time, one could interpret strategic wages as long-term wages. Then in the long-run, firms recruit workers from all nearby rivals and thus pay average industry wages. Firm i's profit function is

$$\begin{aligned} \pi_i &= (p - c_i)q_i - w_i(1-\lambda_{-i}) - w_{-i}\lambda_i - T\lambda_i^2 \\ \lambda_{-i} &= \sum_{j\neq i}\frac{1}{n-1}\lambda_j \\ w_{-i} &= \sum_{j\neq i}\frac{1}{n-1}w_j. \end{aligned} \tag{3.12}$$

Observe that it is the same profit function as in the duopoly case. Solving the game in the same way as before shows that, when clustering, the increase in market revenue is still outweighed by the total cost of poaching. Hence the terms of the trade-off do not change in oligopoly and the result for the duopoly (Proposition 3.1) can be generalised to an arbitrary number of firms:

Proposition 3.2. *In the above four-stage game with n firms any equilibrium path implies either colocation and full poaching or separation:*[37]

[36] Essentially, this assumption is a way to break ties if the subgame equilibrium at the wage-setting stage is symmetric. With equal wages, what matters for an individual firm is the number of workers it attracts. Whether it poaches a given number of workers from many rivals or just one, is not important in the poaching subgame.

[37] The remark after Proposition 1 applies again.

$$\alpha \geq \bar{\alpha}: \begin{cases} \textit{co-location},\ w \in [0, \underline{w}],\ \lambda = 1,\ q = \dfrac{\alpha}{(n+1)\beta} & \textit{if } \dfrac{1}{n}\sum_{i=1}^{n} w_i^* \leq \tilde{w} \\ \textit{separation},\ w \in [0, \underline{w}], \lambda = 0,\ q = \dfrac{\alpha - 1}{(n+1)\beta} & \textit{if } \dfrac{1}{n}\sum_{i=1}^{n} w_i^* > \tilde{w} \end{cases} \quad (3.13)$$

$$\alpha < \bar{\alpha}: \ \textit{separation},\ w = 0,\ \lambda = 0,\ q = \frac{\alpha - 1}{(n+1)\beta}$$

where

$$\begin{aligned} \bar{\alpha} &= \frac{(n+1)^2}{n-1} T\beta \\ \underline{w} &= \frac{2n\alpha}{\beta(n+1)^2} - 2T,\ \tilde{w} = \frac{2\alpha - 1}{\beta(n+1)^2} - T \end{aligned} \quad (3.14)$$

Proof. *See Appendix B.2 and B.3.*

As in the duopoly case, $\bar{\alpha}$ is the market size that leads to full poaching in the poaching subgame. For any market size greater than $\bar{\alpha}$ the condition $\lambda^* \leq 1$ becomes binding and market size affects the level of poaching neither directly nor through equilibrium wages anymore. It induces firms to woo away *all* employees from their rivals irrespective of their own (protective) wages. As a result, firms do not pay the wage they offer their own workers in the first place and any combination of (non-negative) wage offers which lead to full poaching is a subgame equilibrium. What becomes relevant for the location decision is thus the *average wage* that an *individual* firm must pay in order to poach workers, $w_{-i}^* = \sum_{j \neq i} \frac{1}{n-1} w_j$. It is shown in the Appendix that an *individual* firm prefers colocation over separation if $w_{-i}^* \leq \tilde{w}$. Colocation is a subgame equilibrium if *all* firms prefer colocation which requires $w_{-i}^* = \sum_{j \neq i} \frac{1}{n-1} w_j$ to hold for all *i*. This means that, to induce firms to cluster, the average industry wage must be low enough.

Proposition 3.2 says that one would observe colocation only if $\alpha > T\beta(n+1)^2/(n-1)$. One can re-arrange this condition to get

$$\frac{\alpha}{\beta} \frac{n-1}{(n+1)^2} > T \quad (3.15)$$

where the left-hand side is readily interpretable as a measure of the degree of competition. A smaller market (lower α), a steeper demand curve (higher β) and more firms imply stronger competition in the product market. As discussed above, competition must be low enough to make agglomeration worthwhile.

3.3.3 Welfare

Poaching in the symmetric case can be too high as well as too low with respect to the social optimum. As discussed above, this ambiguous result reflects the tendency towards excessive poaching and at the same time towards excessive strategic wages which in turn mitigates the former.

Let welfare be the sum of consumers', workers' and producers' surplus. Strategic wages only change the distribution of welfare and cancel out:

$$\begin{aligned} W &= \underbrace{\tfrac{1}{2}\sum_n q_i(\alpha - p)}_{\text{consumer surplus}} + \underbrace{\sum_n \left((p - c_i)q_i - w_i(1-\lambda_{-i}) - w_{-i}\lambda_i - T\lambda_i^2\right)}_{\text{firms' profits}} + \underbrace{nw}_{\text{wages}} \\ &= n\left((\tfrac{1}{2}\alpha + \tfrac{1}{2}p - c)q - T\lambda^2\right). \end{aligned} \tag{3.16}$$

As in the CD's model, imperfect competition clearly implies too high prices and too little output. For a first-best solution, a social planner would choose

$$\tilde{q} = \frac{\alpha - 1 + \lambda}{n\beta}$$

and, assuming identical poaching per firm,

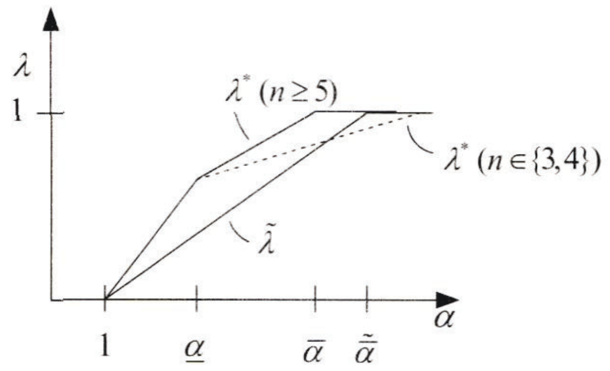
$$\tilde{\lambda} = \frac{\alpha - 1}{2nT\beta - 1}$$

instead of the equilibrium

$$\lambda^* = \frac{n(\alpha - 1) - \frac{1}{2}(n+1)^2 \beta w^*}{(n+1)^2 T\beta - n}.$$

Now assume that the market is small so that $w^* = 0$. Then it is easy to show that in equilibrium there is too little poaching for $n = 2$ and too much poaching for $n \geq 3$. Now assume that market size induces partial poaching and $w^* > 0$. Observe that for a market size $\alpha \geq \tilde{\tilde{\alpha}} = 2nT\beta$ the upper bound on the socially optimal poaching, $\tilde{\lambda}$, becomes binding. Moreover recall that without a social planner the critical market size from which on poaching is a corner solution is $\bar{\alpha} = T\beta(n+1)^2/(n-1)$. Then for $n \geq 5$, $\tilde{\bar{a}}$ lies right of $\bar{\alpha}$ which means that for any market size, $1 < \alpha < \tilde{\bar{\alpha}}$, size firms poach too much. For $n \in \{3,4\}$ there is a first range in which firms poach too much and a second in which they poach too little (see Figure 4). Only in the duopoly case $(n = 2)$ firms always poach too little which is a stronger result than in CD.

Figure 3.3: Welfare and poaching



With the second-best solution the social planner takes the imperfect competition in the product market as given and optimises only the level of poaching. Maximising welfare as given in equation (3.16) with respect to poaching, she would choose

$$\tilde{\lambda} = \frac{\alpha - 1}{2(n+1)^2 T\beta - 1}$$

which is less than in the first-best solution. Clearly, firms poach too much, if market size is small and $w^* = 0$. To see that firms also poach too much if market size induces $w^* > 0$, note that $\tilde{\lambda} \leq 1$ requires $\alpha \leq 2(n+1)^2 T\beta = \tilde{\bar{\alpha}}$. Clearly, $\tilde{\bar{\alpha}} > \bar{\alpha}$ holds for $n \geq 2$ so that, similar to the graphical argument made above, the socially optimal poaching curve always lies below the market solution. Here, firms unambiguously poach too much.

Finally, because poaching implies cost reduction and does no direct harm to poached firms, the social optimum involves some degree of it in any case and colocation is preferable to separation.

3.4 Discussion

Comparing this model to CD's one with Bertrand competition and differentiated products is difficult because of the different types of competition involved. However, a few things can be said.

The Cournot version has the main features of the original model: poaching and wages are strategic substitutes; when full poaching takes place and firms co-ordinate on sufficiently low wages (e.g. $w_i^* = w_j^* = 0$) clustering is more profitable than separation; and poaching decreases with rivalry (measured by the degree of product differentiation in CD or by the parameters α, β of the demand curve in the Cournot model). The lower product differentiation in the *original* model, the better the difference between Cournot and Bertrand competition becomes visible. The better substitutes goods are, the stronger is competition and the lower the incentive to reduce cost as a larger part of the surplus goes to consumers. In the symmetric equilibrium of the Bertrand model the impact of poaching on "market revenue", $\overline{MR} = (\overline{p} - \overline{c})\overline{q}$, is

$$\frac{\partial \overline{MR}}{\partial \lambda^*} = \frac{2(\alpha + \lambda^*)(1-\beta)}{(2-\beta)^2(\beta+1)} \tag{3.17}$$

which goes to zero for $\beta \to 1$ (here, β is the inverse degree of product differentiation). At the same time the sufficient condition for the existence of a pure-strategy equilibrium in the wage game (SCE) (see CD, p. 10) requires that $T > (5-\beta)/(20-20\beta)$ which goes to infinity when $\beta \to 1$. Hence, in the limit, when price competition with (almost) homogenous goods takes place, firms will not engage in poaching and strategic wages will be zero.

With Cournot competition and homogenous goods, however, competition is imperfect and firms can appropriate parts of the surplus of cost reduction. In the Cournot version

$$\frac{\partial MR}{\partial \lambda^*} = \frac{8(\alpha - 1 + \lambda^*)}{9\beta} \tag{3.18}$$

so that poaching is worthwhile (recall that here β is the slope of the demand curve).

It is a phenomenon of Cournot competition that with an interior solution firms commit to too high a level of poaching and protective wages. In fact, firms face a prisoner's dilemma when deciding about poaching. There is a "moderate" level of poaching that maximises joint profits but each firm has got an incentive to deviate by poaching more and the strategic interaction induces them to behave predatorily. The resulting equilibrium is a lot worse than the case with symmetric "moderate" poaching. This result is well-known in industrial economics and has been analysed in different frameworks; see, for example, Brander and Spencer (1983) for a simple R&D set-up and Brander and Lewis (1986) for a financial perspective. The same effect works at the wage-setting stage inducing firms to pay too high strategic wages. But although higher wages mitigate excessive poaching and hence reduce the training costs associated with it, this does not eliminate the effect in this model. The reason is that there is only a shift in fixed costs from too much poaching to too high strategic wages. Firms anticipate this result and opt to separate in order to avoid these subgames with too costly commitment.

Only when competition is low enough (high α, low β) so that the poaching equilibrium is a corner solution, the prisoner's dilemma disappears. As the level of poaching is unaffected by wages, there is a continuum of wage equilibria and it is up to firms to co-ordinate to achieve the best solution, which is zero wages, knowing that full poaching takes place anyway.

Both, this model (with quantity competition) and the one by CD (with price competition) allow for a complete mutual exchange of strategic workers. Realistically, one would like to make full poaching prohibitively expensive as in the short-run firms will certainly not be able to hire away *all* rival's key workers. This refers to modelling training costs that become infinitely large if poaching gets close to its maximum possible value. Alternatively, firms might have no interest in such full poaching because the poaching technology, i.e. the cost reduction, itself is convex. This would imply a non-linear relationship between labour unit requirement, c, and poaching. However, a model with such a type of training costs or with a more realistic non-linear cost reduction is no longer analytically solvable. Thus, while full poaching is an important but perhaps unrealistic element in these models, any improvements in that direction would need to be studied in a different set-up.

3.5 Conclusion

This chapter has given a stylised explanation for the unexpected evidence that among German manufacturing industries there exists no significant relationship between geographic concentration and high-tech related business which contradicts the common perception that knowledge spillovers are ubiquitous, generally beneficial and spur agglomeration. In order to explain this phenomenon, we have presented an alternative to a model of location choice by Combes and Duranton (2001) in which knowledge is incorporated in workers. It reinforces their point that even in the presence of knowledge spillovers firms *might* choose to separate. More precisely, it has been shown for an arbitrary number of firms that under Cournot rivalry with homogeneous goods, symmetric firms *always* prefer spatial separation as long as market size does not make them swap their entire personnel through poaching (which constitutes a corner solution). This is because, when co-locating, firms increase the wage of their own workers in order to protect themselves against poaching by the rival. It turns out that the profit-maximising defence is too costly compared to the option of spatial separation, and consequently firms choose not to cluster.

This is an important result for regional policy because it means that policy initiatives aiming at the promotion of high-tech clusters could be ineffective or perhaps even wasteful as there are strong forces against the colocation of firms.

There is also a clear empirically testable hypothesis. Larger high-technology industries are more agglomerated but there is no linear relationship; instead there exists a critical market size which divides industries into a group with no concentration and one with strong concentration. Additionally, we have argued that this condition for colocation can be rewritten so that the threshold can be interpreted as the critical degree of product market competition. This way the prediction of the model is that, all else equal, industries with stronger competition avoid agglomeration while those with weaker competition do cluster. An empirical test of this hypothesis is carried out in chapter 5.

4 The incentives for agglomeration when firms are heterogeneous

4.1 Introduction

Realistically, firms may face asymmetric contributions of, or exposure to, agglomeration "externalities". So, how does the incentive for agglomeration change when firms differ with respect to size or productivity? With homogeneous firms more than ever it is not clear which firms want to cluster and which firms do not. The empirical literature finds evidence that firms with superior technologies, human capital or suppliers tend to locate distant from firms of lower quality, especially from firms within their industry. We discuss this literature in more detail in the next section.

As regards firm size, European regional policy has a clear focus. Most initiatives aim at the promotion of networks and/or "clusters" of *small* firms because they are believed to be the engine of innovation and growth and to be more prone to colocation. Interestingly, however, there is also some evidence that large firms cluster more than small firms.

The aim of this chapter is to incorporate the more general case where firms differ with respect to size or "quality" into a formal model and to study their location choice. Despite the empirical evidence this issue has been given surprisingly little attention in theory so far. Two different approaches are possible. On the one hand one can analyse how the (equilibrium) location decision of firms is affected when two (or more) firms are made heterogeneous. On the other hand, one can study the equilibrium location decision of two (or more) different pairs of symmetric firms. In this chapter both approaches are pursued and it is structured as follows. The next section presents a brief discussion of the literature on agglomeration and heterogeneous firms. Section 4.3 deals with asymmetric "quality" of firms and examines asymmetric equilibria in the labour poaching framework. In section 4.4 the focus is on differences in firm size and the aim is to give a potential explanation for why large firms agglomerate more than small firms. This makes it necessary to alter the framework of the model.

4.2 The literature on firm heterogeneity and agglomeration

In the empirical literature there is evidence for two stylised facts. First, firm heterogeneity makes firms benefit from a localised community to a different degree and is hence an important factor influencing their location decision. More precisely, being located in a cluster is not beneficial per se but it depends on the relative position of a firm vis-a-vis others, and consequently superior firms tend to seek isolation because they cannot gain much but only lose.

Secondly, on average, large firms agglomerate more than small firms do.

There is a number of studies that lend support to the first fact. Jaffe (1986) has shown that when one regards the economic return to R&D, the competitive effect of other firms' R&D comes into play. Comparing firms whose neighbours do a lot of R&D to those whose neighbours do little, the former are characterised by lower profits and market value if they do little R&D themselves, but a higher return to doing R&D. But for firms with average or above-average R&D efforts the net effect is positive. It follows that not only aggregate R&D output is higher due to spillovers but also that the average or above-average firm benefits from R&D of other firms in terms of profits and market value.

Beal and Gimeno (2002) distinguish more clearly between the effect of knowledge spillovers and local rivalry and thereby pick up the argumentation of Porter (which we discuss in connection with the empirical analysis of competition and agglomeration in section 5). Their study highlights the ambiguous role of agglomeration: on one hand it increases commitment to R&D but on the other hand the free-rider problem associated with knowledge spillovers makes firms with substantial R&D reduce their commitment relative to firms with little engagement. Moreover, larger firms contribute more than smaller ones and a minimum of R&D is necessary for firms to absorb any spillovers at all.

Shaver and Flyer (2000) find that the probability of a plant's survival during the first eight years after erection is significantly reduced by agglomeration. Under the assumption that bigger firms disseminate more knowledge spillovers than small ones, relative plant size becomes a proxy for the contribution of a plant to the common knowledge pool. They find that bigger plants are much less likely to agglomerate than small ones. A similar result is found by Bender et al. (2002). They look at the financial performance of firms listed at Germany's (former) "Neuer Markt" stock exchange and show that superior firms, measured by greater size, tend to suffer from being in a cluster in terms of several performance measures. At the same time inferior (smaller) firms appear to be net beneficiaries from spillovers.

The insight from these studies is that firms with inferior capabilities—and hence little spillovers—have little to lose but gain a lot from clustering while "good" firms are concerned with negative net benefits and tend to refrain from clustering. Consequently, the location choice becomes strategic, and in the long run "good" firms would seek isolation while "bad" ones cluster together leading to some type of adverse selection.

A criticism of the methodology involving firm size is that there is the implicit assumption that firms do not contribute equally while their capacity to absorb spillovers is identical. It is doubtful whether firm size is an appropriate proxy for the capability to absorb. Larger firms are likely to be more mature than small ones and might refrain from clustering simply because spillovers have less value for them (as shown empirically in Henderson 1997). Additionally, one could argue that it is smaller firms that suffer from negative net benefits because they do not have the necessary resources to safeguard their property rights (Koschatzky 2001, p. 142).

Nevertheless, there is evidence that firms do take into account heterogeneity when they decide where to locate. Kalnins and Chung (2004) examine the location decision of new hotels. In addition to taking firm size as a proxy for the quality of firms' resources they include chain-affiliation. Their main result is that entrants prefer to locate near incumbent hotels possessing resources that can spill over (branded upscale hotels), but will avoid locations where existing firms will exploit spillovers without contributing.

To our knowledge there is only one theoretical model which explicitly examines firms' location decision in the presence of heterogeneity. The model is due to Baldwin and Okubo (2004) and incorporates differences in capital productivity in a new economic geography framework. Heterogeneity has an important effect on the (re-)location behaviour of firms and hence regional policy. The authors show that a subsidy encouraging production in the periphery tends to attract the least efficient firms because they have the least to lose from leaving the core region. This has an important implication for empirical work. Measuring Marshallian agglomeration economies by looking at regional productivity may overstate their importance because firms that cluster in a region exhibit above average firm-level productivity independently of any Marshallian agglomeration economies.

As concerns the stylised facts about firm size, there is evidence from studies by Holmes and Stevens (2002) and Lafourcade and Mion (2003). They examine the geographic concentration of industries in the U.S. and Italy, respectively, and dividing an industry into a group of small and large firms they find that large ones are more agglomerated.[38] The results of our regression analysis in chapter 2 support this finding for Germany. We found that industries with greater average firm size tend to be more agglomerated. Holmes and Stevens (2002) also show that plants located in areas where an industry concentrates are larger than plants in the same industry outside such areas.

We are aware of only one theoretical model which is explicitly about agglomeration and firm size. Holmes and Stevens (2004) propose a framework that

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[38] Lafourcade and Mion differentiate between "geographic concentration" as captured by Ellison and Glaeser's (1997) index and "agglomeration" in the sense of spatial correlation to which the index is insensitive. Small firms exhibit higher spatial correlation but are more dispersed as measured by the EG index.

departs from the traditional Dixit and Stiglitz (1977) monopolistic competition structure of standard new economic geography models because these have no room for firm-level phenomena such as size. In their model there is a continuum of locations, and some aspects of an industry (for example, custom work) always need a local presence so that firms do not entirely concentrate in one location. In equilibrium, small plants provide this custom work and establishments are larger in those locations which specialise in their industry, thus replicating the observations in Holmes and Stevens (2002). This model has an implication for empirical work, too. If it is correct, it suggests that measures of geographic concentration like the EG index may in some sense understate the degree of concentration. If one considered only that portion of production that is involved in trade (large firms), industries would geographically be more concentrated than if one also included small plants doing only non-tradeable work.

In sum, empirical evidence and theoretical considerations suggest that firm heterogeneity is an important issue when analysing firms' incentives to cluster and that there are notable implications for regional policy. However, while the models cited are well established and some even characterise a general equilibrium, they do not look at the incentive to cluster from a real micro-perspective. This shall be done in the following section.

4.3 Asymmetric duopoly in the labour poaching set-up

4.3.1 Asymmetric "quality" of firms

The labour poaching model presented in chapter 3 shows that symmetric firms hardly cluster. In this section firm heterogeneity is introduced in this framework and the resulting location decision equilibrium is studied.

More precisely, suppose firms are of different "quality" in terms of knowledge transferability. Following Combes and Duranton (2001), the relationship between poaching and production costs is specified as

$$c_i = \overline{c} - a_j \lambda_i \tag{4.1}$$

where α_j is an index of how strongly external knowledge reduces own costs which can be interpreted as an index of the rival's "quality".

Assumption 4.1. *Let* $a_i = 1$ *and* $a_j < 1$.

This means firm *i* is of "high-quality" and firm *j* is of "low-quality". Now firm *i* faces a poaching technology with an (absolute) slope smaller than one

$$\begin{aligned} c_i &= \overline{c} - a_j \lambda_i \\ c_j &= \overline{c} - \lambda_j . \end{aligned} \tag{4.2}$$

Introducing different quality renders all equilibria asymmetric. Now firm *i* has a strategic disadvantage as the lower quality makes it less aggressive. Poaching increases its own and decreases the rival's equilibrium quantity by less. Further, market size becomes a weaker incentive in the poaching decision.

Consider, for example, the extreme case of $a_j = 0$ which means that the knowledge of firm *j* has no value at all to firm *i*. Consequently firm *i* cannot gain anything from poaching while firm *j* benefits from it just as before. Now the wage-setting and poaching decision involve no true strategic interaction because at both stages the best-response function of one firm is constantly zero. Hence both the wage equilibrium and the poaching equilibrium correspond to the first-best (open-loop) solution of firm *i* and *j*, respectively. Using the best-responses from equations (3.3), (3.6) and (3.9), the equilibria of the subgames are

$$\begin{array}{ll} q_i^* = \dfrac{(\alpha - 1 - \lambda_j)}{3\beta} & q_j^* = \dfrac{(\alpha - 1 + 2\lambda_j)}{3\beta} \\ \lambda_i^* = 0 & \lambda_j^* = \dfrac{2(\alpha-1) - \frac{9}{2}\beta w_i}{9T\beta - 4} \\ w_i^* = \dfrac{P_1 + \alpha P_2}{P_3} & w_j^* = 0 \\ \textit{separate} & \textit{colocate.} \end{array} \tag{4.3}$$

Firm *j* produces more than firm *i* because it can realise lower production costs. Unlike firm *i* it engages in poaching, and only firm *i* protects itself with the help of (positive) wages. As wages are strategic substitutes, firm *i* sets higher wages than in the symmetric case. Similarly, the poaching variables are strategic substitutes. For a given wage level, equilibrium poaching by firm j is much more aggressive than under symmetry. However, more aggressive wages also mitigate more aggressive poaching and in fact the net effect is ambiguous here. As before, the constraint that the wage be non-negative becomes binding for a large range of parameters. But the more aggressive wage-setting leads to the existence of three cases depending on the parameters T, β: (i) only the upper constraint for the wage (ensuring poaching to be positive) is binding, (ii) only the lower constraint (ensuring poaching to be lower than unity) is binding or (iii) both are binding. Hence, now the picture depends much more on the parameters. With asymmetry it may now happen that if rivalry is low enough (high α, low β) firm i sets wages such that it prevents its rival from *any* poaching. By the same token, the wage-setting can be so aggressive that poaching by the rival never reaches its upper limit which makes the lower bound on wages irrelevant. In this case, poaching initially increases with market size (when the wage is zero due to the non-negative-condition) and as soon as the wage turns positive it is so aggressive that it reduces poaching until it is zero.

Regarding the location choice, it is clear that firm i never wants to cluster because it bears the cost of protective wages and has no advantage from proximity. It can be shown that firm j prefers colocation instead. If firm i's strategic wages are zero, poaching involves only retraining costs which can be shown to be low enough to make clustering worthwhile. Should there be a corner solution for poaching, then a continuum of equilibria exists for the strategic wage of firm i as in the symmetric case. If high wages prevent firm j from any poaching it becomes indifferent between colocation and separation and, finally, for interior wage solutions it prefers colocation again which follows from the absence of strategic interaction.

To illustrate the more general case when the quality index varies, assume, for example, $T = 1.5, \beta = 1$. It can be shown that there is a critical quality index, a_j, so that the low-quality firm wants to cluster if its quality is below that value (Figure 4.1). For a given market size, its wage rate falls sharply with its quality because the high-quality firm is discouraged from poaching. At the same time the wage rate of the high-quality firm is almost unaffected by the rival's quality (Figure 4.2).

Consequently, if firms are sufficiently different in terms of quality, the location choice becomes an anti-co-ordination game in which the low-quality firm would like to join the high-quality one but not vice versa. With simultaneous moves there exist only equilibria in mixed strategies. Making the order of the choices endogenous would not help because, naturally, both firms prefer to be the second mover.

This model, albeit illustrated with numerical calculations here, presents a theoretical explanation for the idea that firms may face asymmetric exposure to agglomeration "externalities".

Figure 4.1: Firm *j*'s benefit from colocation for interior poaching solutions ($T = 1.5, \beta = 1$). If firm *j*'s quality a_j is low enough, it prefers agglomeration even for an interior poaching solution. Firm *i* never wants to colocate.

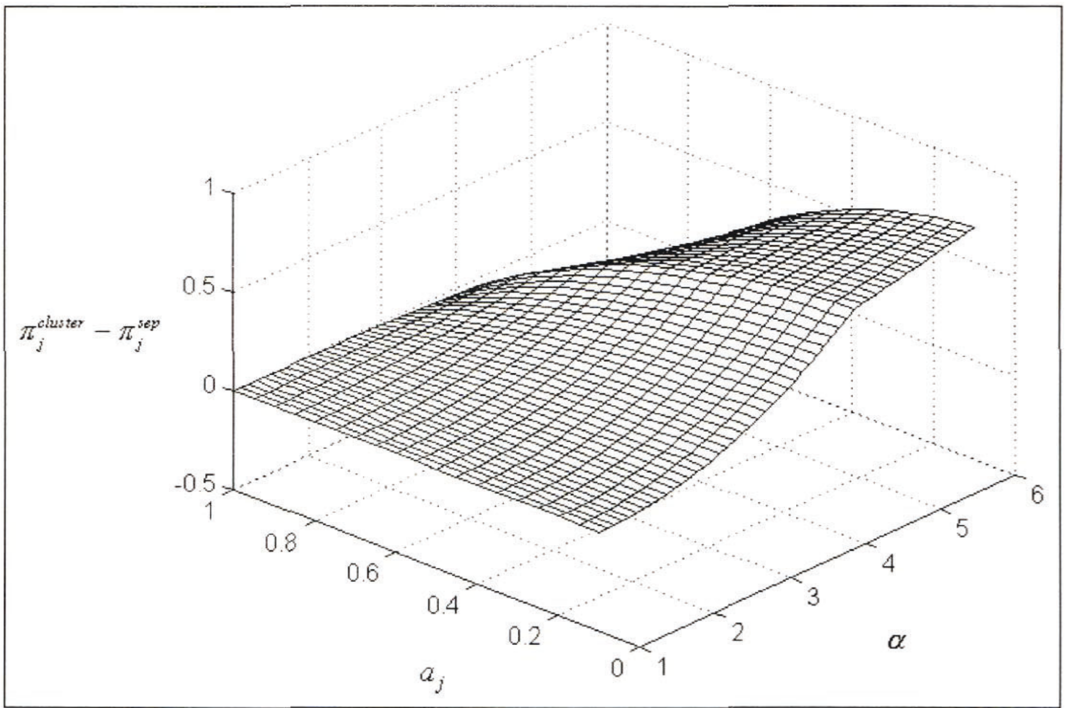
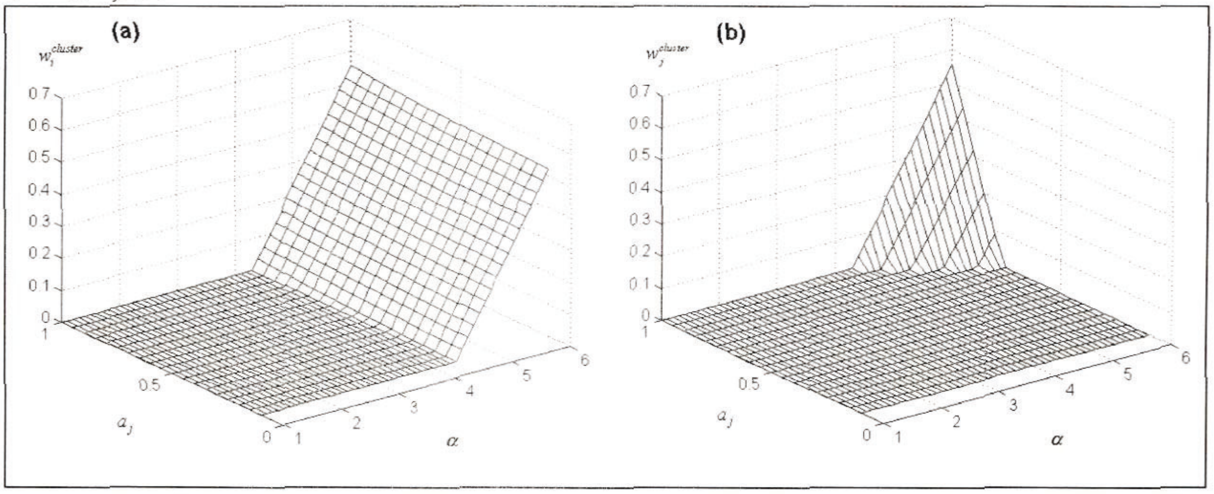


Figure 4.2: Strategic wages of the high-quality firm (a) and the low-quality firm (b) for interior poaching solutions $(T = 1.5, \beta = 1)$. The wage rate of the low-quality firm falls sharply with its quality (b) while the wage rate of the high-quality firm is almost unaffected by the rival's quality, a_j, (a).



4.3.2 Asymmetric firm size

What remains to be shown in the labour poaching framework is what effect firm size has on the incentive to colocate. Different firm size can be modelled by a different level of marginal production costs, i.e. productivity.

Assumption 4.2. *Without loss of generality let* $\overline{c}_i = 1$ *and* $\overline{c}_j > 1$.

This means firm i faces lower variable production costs and is hence larger than firm j in terms of output.

Define by $\Delta MG = MG_j - MG_i$ the difference between the advantage of clustering for the small firm and the large one whereby $MG = \pi^{cluster} - \pi^{sep}$ is the gain in profits from clustering vs. separating. Then one gets

Proposition 4.1. *For any interior solution with* $w_i^* > 0, w_j^* > 0$ *the large firm always benefits more from clustering (with a small firm) than the small firm does (from colocation with the large one), i.e.* $\Delta MG < 0$. *The large firm may even prefer colocation over separation.*

Proof. *See Appendix C.4.1.*

When firms become asymmetric, there are three effects on profits and hence ΔMG. According to the expression for profits in equation (3.2) this effect can be written as the sum of three components

$$\frac{\partial \Delta MG}{\partial \overline{c}_j} = \frac{\partial \Delta MG^{wages}}{\partial \overline{c}_j} + \frac{\partial \Delta MG^{revenue}}{\partial \overline{c}_j} + \frac{\partial \Delta MG^{poaching}}{\partial \overline{c}_j} \tag{4.4}$$

each of which shall be considered separately. The point of reference is the symmetric case with $\overline{c}_j = 1$.

The first effect is on the wage bill and is due to the rival's adjustment of wages for a given level of poaching

$$\begin{aligned} \frac{\partial MG_j^{wages}}{\partial \overline{c}_j} &= -\frac{\partial w_i}{\partial \overline{c}_j} \lambda_j > 0 \\ \frac{\partial MG_i^{wages}}{\partial \overline{c}_j} &= -\frac{\partial w_j}{\partial \overline{c}_j} \lambda_i > 0 \end{aligned} \tag{4.5}$$

which implies an advantage from reduced wages for a given level of poaching for both firms. This advantage can even be greater for firm j than for firm i (for more details of the following discussion see Appendix C.4.2).

The second impact comes from adjusting the degree of poaching for given wages

$$\begin{aligned} \frac{\partial MG_j^{poaching}}{\partial \overline{c}_j} &= w_j \left(\underbrace{\frac{\partial \lambda_i}{\partial \overline{c}_j}}_{\substack{\text{larger incentive}\\ \text{for cost}\\ \text{reduction}\\ \text{as } q_i \text{ rises}}} + \underbrace{\frac{\partial \lambda_i}{\partial w_i}\frac{\partial w_i}{\partial \overline{c}_j}}_{\substack{\text{reaction of } i \text{ to}\\ j\text{'s increase of}\\ \text{poaching due to}\\ \text{lower eq. wages}\\ \text{(strat. substitutes)}}} \right) > 0 \\ \frac{\partial MG_i^{poaching}}{\partial \overline{c}_j} &= w_i \left(\underbrace{\frac{\partial \lambda_j}{\partial \overline{c}_j}}_{\substack{\text{lower incentive}\\ \text{for cost}\\ \text{reduction as}\\ q_j \text{ decreases}}} + \underbrace{\frac{\partial \lambda_j}{\partial w_j}\frac{\partial w_j}{\partial \overline{c}_j}}_{\substack{\text{reaction of } j \text{ to}\\ i\text{'s increase of}\\ \text{poaching due}\\ \text{to lower wages}}} \right) < 0. \end{aligned} \tag{4.6}$$

It is positive, implying a lower wage bill, for firm j and negative for firm i because firm i (j) reacts by poaching more (less) workers.

The third effect works through marginal revenue because the rival adjusts his output quantity due to his adjustment of wages and the level of poaching. For firm j this impact also includes the direct effect of higher production costs and reads

$$\frac{\partial MG_j^{revenue}}{\partial \overline{c}_j} = \underbrace{\frac{\partial p}{\partial q_i}}_{-}\Bigg(\underbrace{\frac{\partial q_i}{\partial \overline{c}_j}}_{\substack{+\\ i\text{'s reaction}\\ \text{to lower}\\ q_j}} + \frac{\partial q_i}{\partial \lambda_i}\underbrace{\left(\frac{\partial \lambda_i}{\partial \overline{c}_j} + \frac{\partial \lambda_i}{\partial w_i}\frac{\partial w_i}{\partial \overline{c}_j}\right)}_{\substack{+\\ \text{firm } i \text{ increases}\\ \text{poaching in}\\ \text{equilibrium}}}\Bigg) q_j^* \underbrace{- q_j^*}_{\substack{+\\ \text{direct}\\ \text{increase}\\ \text{in marg.}\\ \text{cost}}} - \underbrace{\left(\frac{\partial p}{\partial q_i}\frac{\partial q_i}{\partial \overline{c}_j}\overline{q}_j - \overline{q}_j\right)}_{\substack{-\\ \text{losses due to lower}\\ \text{price and higher}\\ \text{marginal cost when}\\ \text{separating}}}. \tag{4.7}$$

For firm i it is

$$\frac{\partial MG_i^{revenue}}{\partial \overline{c}_j} = \underbrace{\frac{\partial p}{\partial q_j}}_{-}\Bigg(\underbrace{\frac{\partial q_j}{\partial \overline{c}_j}}_{\substack{-\\ j\text{'s direct}\\ \text{reduction}\\ \text{of quantity}\\ \text{due to}\\ \text{higher cost}}} + \frac{\partial q_j}{\partial \lambda_j}\underbrace{\left(\frac{\partial \lambda_j}{\partial \overline{c}_j} + \frac{\partial \lambda_j}{\partial w_j}\frac{\partial w_j}{\partial \overline{c}_j}\right)}_{\substack{-\\ \text{firm } j \text{ decreases}\\ \text{poaching in}\\ \text{equilibrium}}}\Bigg) q_i^* - \underbrace{\left(\frac{\partial p}{\partial q_j}\frac{\partial q_j}{\partial \overline{c}_j}\overline{q}_i\right)}_{\substack{+\\ \text{gain from higher}\\ \text{price and lower}\\ \text{cost of } j \text{ when}\\ \text{separating}}}. \tag{4.8}$$

Note that $q^* > \overline{q}$ because both firms have strictly lower production cost when clustering (assuming an interior symmetric equilibrium) and hence produce more than when in isolation.

In sum, the bigger firm unambiguously benefits more from clustering than the small one in terms of revenue. It loses with respect to the relative effect of poaching on the wage bill while the relative effect of wages is ambiguous. Yet, as shown in the Appendix, the partial effects add together to a negative one (Proposition 4.1). The fact that cost reduction implies a greater benefit the greater the amount of output is (simply because it can be spread over a larger output), has been analysed already by Shaked and Sutton (1987) and is used in an R&D set-up in Cohen and Klepper (1996a, b) and in a general industry model in Klepper (1996).

To see that the large firm may even prefer agglomeration over separation, consider the example given in Table 4.1.

Table 4.1: Example: The large firm prefers colocation while the small one does not.

$T = 2,\ \beta = 1,\ \alpha = 8,\ \overline{c}_j = 2.5$			
Colocation		Separation	
$w_i^* = 0.26$	$w_j^* = 0.67$	$w_i^* = 0$	$w_j^* = 0$
$\lambda_i^* = 0.95$	$\lambda_j^* = 0.35$	$\lambda_i^* = 0$	$\lambda_j^* = 0$
$q_i^* = 3.35$	$q_j^* = 1.26$	$\overline{q}_i = 2.83$	$\overline{q}_j = 1.33$
$p^* = 3.40$		$\overline{p} = 3.83$	
$\pi_i^* = 8.60$	$\pi_j^* = 1.19$	$\overline{\pi}_i = 8.03$	$\overline{\pi}_j = 1.78$

A final question that can be answered in this framework is whether a firm prefers to cluster with a symmetric or asymmetric rival. Suppose there are two regions; in one there is a large firm and in the other there is a small one. Suppose there is a third firm.

Proposition 4.2. *If separation is no option, firms prefer to colocate with the smallest possible rival.*
Proof. *See Appendix C.2.*

4.4 Creativity and asymmetric firm size in a simple patent race set-up

4.4.1 Introduction

In the labour poaching framework we established that symmetric firms do not colocate in equilibrium and that with heterogeneous firms the equilibrium may depend on the order in which choices are made. However, this set-up is not suited to explain why large firms agglomerate while small ones do not (so much).

There is the argument that labour market pooling (and hence agglomeration) is more important for large firms than for small firms simply because large firms employ more workers.[39] However, this section presents a model which centres on different degrees of innovative capability. The model is about a simple patent race in which workers are endowed with different levels of "creativity", i.e. ability to produce an innovation. When firms colocate, workers meet and exchange ideas, for example at meetings, trade fairs etc. By doing so they learn from each other and this gives rise to mutual knowledge spillovers. Firms take into account that spillovers improve their rival's stock of knowledge and it turns out that in equilibrium firms with less creative workers mutually benefit from colocation while those with more creative workers would lose.

The set-up of the model is much inspired by Friebel and Gianetti (2004) who relate firm size, firm organisation and occupational choice.[40] Our aim is to give a stylised explanation for the above cited empirical evidence that large firms colocate more than small firms. In the model, firm size will be represented by differences in firms' payment structure which induce firms to hire different workers. Large firms pay fixed salaries while small ones offer workers a share in profits. Friebel and Gianetti (2005) cite much anecdotal and systematic evidence that (on average) large firms pay fixed salaries more often and are more bureaucratic, more risk-averse and less innovative than small firms which provides some support for both the assumption and the main result of the model.

This notion is challenged, however, by the empirical study by Kraft and Ugarkovic (2005). Using data on German firms they find that it is large firms that offer variable compensation schemes more often. This result represents a caveat to our interpretation involving firm size when directly applied to Germany. But there are probably differences across countries and our model is also inspired by the above

[39] I thank Wolfram Richter for pointing out this effect to me. It is formalised with the help of a simple Hotelling framework in Appendix C.3 and the somewhat unexpected result is that d'Aspremont et al.'s (1979) principle of maximum (spatial) differentiation remains to be at work although there is a force towards colocation. More precisely, suppose profits are stochastic and there are firm-specific shocks. In case of a negative shock firms may have to dismiss workers. Suppose workers are risk-averse and demand a risk-premium if their employer locates in isolation and thus provides no insurance against unemployment. Then a large firm should be more prone to agglomeration because it has more workers on the wage bill that demand a risk premium.

[40] I thank Guido Friebel for his helpful comments on an early version of the model and I also appreciate his help for the revised version.

mentioned evidence for the U.S. (Holmes and Stevens, 2002) and Italy (Lafourcade and Mion, 2003). Apart from that, there remains the observation discussed in section 4.2, namely the tendency of superior firms to seek isolation. Our model is not only about the effect of firm size but also about the effect of different innovative capabilities on agglomeration.

There are many studies that suggest that small and large firms exhibit different innovative behaviour. It seems that small firms hold a disproportionate share of major innovations (Scherer 1980, Rosen 1991) and adopt new technologies more quickly than large firms (Kelley and Helper 1999) which is probably because they have a relatively greater incentive for rapid and for product innovation (Cohen and Klepper 1996). Moreover, large firms are more efficient in utilising knowledge created in their own laboratories while small firms seem to have comparative advantage in exploiting knowledge spillovers from university laboratories (Acs et al. 1994).

Taking a micro-perspective, Sah and Stiglitz (1988) show that, when considering new projects, organisations require a minimum consensus level which depends on how much the organisation has at stake. As Friebel and Gianetti (2005) remark, it is natural that large firms have more at stake than smaller and younger firms. This would explain why large firms generally adopt more centralised and bureaucratic structures (Child 1973). Similarly, Zenger (1994) presents survey evidence that small firms attract more talented R&D personnel because individuals are more likely to be rewarded within the organisation of a small firm. According to Friebel and Gianetti (2005), large companies respond differently to the competition for talent. Some decentralise by breaking up units and creating spin-offs while others continue to offer job security. Their model suggests that it is part of their comparative advantage to maintain their centralised organisation at the cost of attracting less creative workers and staying less innovative.

4.4.2 The model

Suppose workers are heterogeneous with respect to how "creative" they are and let them be represented by an equally distributed continuum of mass 1, $\phi \in [0,1]$.

"Creativity" shall be understood as the probability with which workers produce a valuable idea in the process of research. There are two industries; one consisting of *two large* firms and the other consisting of *two small* firms. Large firms engage in multiple projects (or more generally: have assets) which produce (exogenous) earnings. By contrast, small firms have no (or fewer) assets, for example because they run only a single project. In particular, large firms offer researchers a fixed salary w_L independent of the outcome of the R&D project (due to their size and diversification of projects) and are "conservative" and "bureaucratic" in the sense that they do not offer any additional share in profits. Small firms can offer only a share in profits w_S contingent on the employee producing a valuable idea. This means they pay a bonus if the employee is successful. One can argue that this becomes possible because in a small organisation the outcome can be better attributed to a particular worker[41] while a variable compensation scheme with monitoring and a performance review is too costly for a large firm (with many employees).[42]

In each industry firms engage in a patent race, but they all compete for workers in a common labour market. Suppose that in each industry firms engage in some type of collective wage bargaining so that they can appropriate parts of the (expected) surplus of R&D.

The following game takes place.

1. In each industry the footloose firm decides whether to colocate with its (fixed) rival or to separate. The fixed large and small firm are assumed to have already chosen their location.
2. Small and large firms each offer (jointly) a wage contract W_L, W_S and there is a worker (from the common labour pool) who is indifferent between working for a large firm and a small firm (ϕ^*),

[41] I thank Christian Bayer for this comment and his other suggestions about the model.

[42] While this is certainly a strong assumption we believe it is not completely unrealistic. Letting large firms offer variable payment in addition to a fixed one would render the model mathematically intractable.

$$W_L = w_L$$
$$W_S = \begin{cases} 0 & \text{if worker produces no idea} \\ w_S & \text{if worker produces idea} \end{cases} \qquad (4.9)$$

All other workers strictly prefer to work for a particular type of firms. Then each firm is randomly matched with a worker from the respective set of workers.

3. If firms decided to colocate, workers exchange knowledge and this mutually increases their creativity (knowledge spillovers).
4. In each industry stochastic R&D takes place, determining whether a firm successfully makes the innovation or not.

The "learning function", $\Psi_i(\phi)$, which specifies "knowledge spillovers" plays a crucial role. Assume that it has the following simple form

$$\Psi_i(\phi) = \begin{cases} l_i\phi & \text{if } \phi < l_i^{-1} \\ 1 & \text{else} \end{cases}$$
$$l_i = \begin{cases} \mu & \text{if firms of type } i \text{ cluster} \\ 1 & \text{else} \end{cases} \qquad (4.10)$$
$$\mu > 1, i \in \{S, L\}$$

which means that firms' workers increase their creativity ϕ by the constant factor $\mu > 1$ when spillovers occur (subject to $0 \le \phi \le 1$). The function l_i indicates whether firms of type *i* cluster. If they do, μ is the factor by which knowledge increases.

Firms undertake R&D given the expected creativity of their researcher. If a single firm wins the race, it earns a monopoly profit π_M, if both innovate, they both earn oligopoly profits $\pi_D = b\pi_M$. Make the following

Assumption 4.3. $\pi_M = 1$ *and* $b = 0$.

The first assumption is without loss of generality because it only scales profits. The second one is justified when firms face Bertrand competition in the product market so that being the duopolist is no better than not innovating at all.[43]

The game is solved backwards.

Stage 4. In each industry, firms undertake R&D given the indifferent worker ϕ^*, expected creativity $E\phi_L^*, E\phi_S^*$ and wage offers w_L^*, w_S^*.

Stage 3. In each industry, workers are allocated to firms according to where they earn most. For given offers by a small and large firm, there is a worker of creativity ϕ^* who is indifferent between working for either of them. In order to keep the model tractable, make the following

Assumption 4.4. *Workers are risk-neutral and their utility function is* $u(x) = x$.

Then comparing expected utility from working with a small firm with that from working with a large firm leads to

$$r(\phi) = \underbrace{\Psi_S(\phi)u(w_S)}_{\substack{\text{expected utility from} \\ \text{salary of small firm}}} - \underbrace{u(w_L)}_{\substack{\text{expected utility from} \\ \text{salary of large firm}}} \overset{!}{=} 0 \tag{4.11}$$

where $\Psi(\phi)_{S,L}$ is the learning function which increases the level of creativity when learning (through spillovers) takes place.

The following Lemma states the subgame equilibrium.

Lemma 4.1. *The indifferent worker is characterised by* $\phi^* = \Psi_S^{-1}\left(\frac{w_L}{w_S}\right)$, *and the large and small firm's expected creativity is* $E\phi_L = \frac{1}{2}\phi^*$ *and* $E\phi_S = \frac{1}{2}(1+\phi^*)$, *respectively.*

Proof. *See Appendix C.4.1.*

[43] This assumption is mainly for ease of exposition. Numerical calculations show that our results do not change when $0 \le b < 0.5$ which is often done in the literature.

Stage 2. Taking into account the indifferent worker, the small and the large firms each offer a contract and maximise expected profits according to

$$\begin{aligned}
&\max_{w_S} E\pi_S = E\phi_S(\phi^*)[(1-E\phi_S(\phi^*))(1-w_S)-E\phi_S(\phi^*)w_S] \\
&\max_{w_L} E\pi_L = E\phi_L(\phi^*)(1-E\phi_L(\phi^*))-w_L \\
&\text{s.t. } w_S, w_L > 0.
\end{aligned} \tag{4.12}$$

The result is stated in the following

Lemma 4.2. *The wage-setting subgame equilibrium is*

$$\begin{aligned}
w_S^* &= \begin{cases} \frac{1}{4} & \textit{if no firm colocates} \\ \frac{1}{8}\mu(4+\mu^3-A) & \textit{if only large firms colocate} \\ \dfrac{1}{8\mu^3}(6\mu^2-2\mu+1-B) & \textit{if only small firms colocate} \\ \frac{1}{4}+\frac{3}{8}\mu-\frac{1}{8}C & \textit{if all firms colocate} \end{cases} \\
w_L^* &= \begin{cases} \frac{1}{8} \\ -\mu^3(\frac{3}{8}+\frac{1}{16}\mu^3)+A(\frac{1}{8}+\frac{1}{16}\mu^3) \\ -\dfrac{1}{32\mu^4}(6\mu^2-2\mu+1-B)(2\mu^2-2\mu+1-B) \\ -\frac{1}{32}(2+3\mu-C)(3\mu-2-C) \end{cases}
\end{aligned} \tag{4.13}$$

where

$$\begin{aligned}
A &= \sqrt{\mu^3(2+\mu)(2-\mu)^2} \\
B &= \sqrt{16\mu^2-8\mu^3-4\mu+4\mu^4+1} \\
C &= \sqrt{4-4\mu+9\mu^2}.
\end{aligned}$$

Proof. *See Appendix C.4.2.*

Stage 1. When colocating, firms are subject to knowledge spillovers which enhance their worker's creativity. But this means there is both an advantage and a disadvantage because spillovers increase the probability of innovating of *both* firms. Hence it is not clear a priori whether expected profits always increase with colocation. Note that here the focus of the analysis is on pairs of symmetric firms, i.e. on the agglomeration *within* industries.

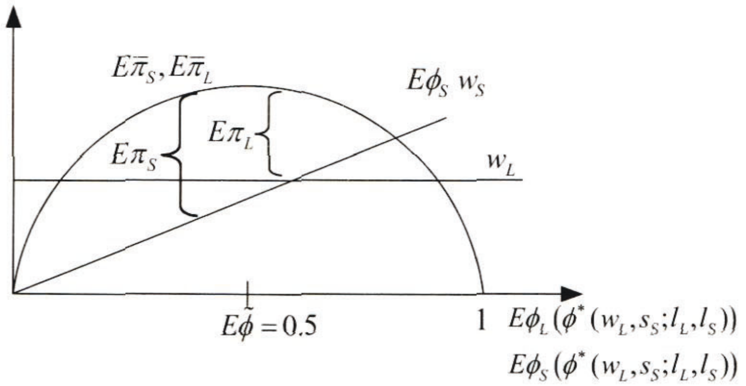
Taking the location decision of the firms of the other industry as given, in each industry the footloose firm compares profits of separation and colocation.

Proposition 4.3. *In equilibrium large firms hire less creative workers and colocate, and small firms hire more creative workers and separate.*
Proof. *See Appendix C.4.3.*

The intuition behind this result is as follows. Recall from equation (4.12) the expression for expected profits and denote by $E\overline{\pi}_S = E\phi_S(\phi^*)(1 - E\phi_S(\phi^*))$ and $E\overline{\pi}_L = E\phi_L(\phi^*)(1 - E\phi_L(\phi^*))$ firms' expected revenue from the innovation excluding the wage payment, i.e. the expected monopoly profit of the innovation. Figure 4.3 illustrates the results.

Expected monopoly profits increase with expected creativity for $E\phi < \frac{1}{2}$ and decrease for $E\phi > \frac{1}{2}$. Hence there is a critical level of expected creativity, $E\tilde{\phi} = \frac{1}{2}$, such that for given wages $\partial E\pi(E\phi)/\partial E\phi < 0, \forall \phi > \tilde{\phi}$.[44] Now, any interior solution is characterised by positive wage offers. Hence $\phi^* = w_L/(l_S w_S) > 0$ and $E\phi_S = \frac{1}{2}(1 + \phi^*) > \frac{1}{2}$ (Lemma 4.1).

Figure 4.3: Expected profits for different levels of expected creativity



[44] The same argument applies when $0 < b < 0.5$.

This means that for any subgame equilibrium of the location decision small firms' equilibrium expected creativity is greater than $\frac{1}{2}$ so that $\partial E\pi_S(E\phi_S^*)/\partial E\phi_S < 0$. Consequently mutually improving one's creativity does not pay and separation with no spillovers is the best option.

This result is due to the way R&D competition between firms is modelled. If two small firms colocate, they individually improve their creativity but this translates into a disadvantage when the rival's effect on expected profits is taken into account. Mutually improving creativity reduces for each firm the probability of being the monopolist.[45]

For large firms the opposite effect applies. Their equilibrium expected creativity is lower than $\frac{1}{2}$ so that $\partial E\pi_S(E\phi_L^*)/\partial E\phi > 0$ holds and mutual learning pays.

4.4.3 Discussion

While the concrete specification of the R&D model with "creativity" is motivated by Friebel and Gianetti's (2004) work, it is inspired by a more general research question from the economics of interaction and learning. If there exist spatially bounded knowledge flows through voluntary (market) mechanisms such as cooperation or labour poaching (and if they are important), the location decision becomes equivalent to the question under which conditions mutual learning pays for competing rivals. Then analysing firms' location decision simply adds a preliminary stage to the models of the literature on interaction and learning (for example, Jovanovic and Rob 1989, Blume 1993, Ellison 1993, Glaeser 1999). These models typically consider economic agents located on a (two dimensional) grid who interact with their neighbours. Usually, agents have different options of action such as imitating behaviour, playing best-responses or simple random action (such as in Blume 1993 and Ellison 1993).

An important question is how "knowledge" and the process of learning are modelled. Our model takes "learning" as a simple process in which identical agents

[45] This is not offset by the increased probability of being a duopolist, if $0 < b < 0.5$.

improve their knowledge by a constant factor (subject to an upper constraint). But what does this process look like when different agents interact? In Jovanovic and Rob's (1989) model there is vertical knowledge (ideas) and agents learn from each other due to stochastic meetings. But how much they learn depends not only on how much they "try" but also on the difference in what they know. If agents know the same things, they cannot learn from each other.

All these models can predict rich spatial patterns of behaviour (or knowledge diffusion) which can even be interpreted in an urban context as in Glaeser (1999) who examines learning *within* firms and *across* firms. The model presented here is by far less sophisticated but it incorporates the location decision and provides a clear answer. In the simple case with two symmetric players and a "pay-off" function of the form $\phi(1-\phi)$, where ϕ reflects each player's "ability" or "effort", *mutually* improving ability (ϕ) pays only for those types for which $\phi < \frac{1}{2}$. As regards firm characteristics, ϕ has been associated with size via worker's creativity.

In some cases it could be appropriate to model the R&D process of this model as a Tullock contest in which (mainly) relative efforts count. But the focus has been on pairs of *symmetric* firms, and with a Tullock-type effort function a *mutual* and *symmetric* increase in efforts has no effect on the individual winning probability since it wipes out.

It would be very interesting to empirically determine—presumably with the help of case studies—what type of knowledge and learning is involved in what field of business and technology. With these insights it could become possible to estimate precise "learning functions" which in turn would be a reasonable ground for the discussion of "knowledge spillovers". Then incorporating firms' (agents') sequential location decision in models with explicit spatial interaction and studying evolutionary behaviour and equilibrium outcomes seems to be a promising, albeit demanding, task for future research. It could help to reconcile conceptual, qualitative approaches to the nature of knowledge and its dissemination (see Martin and Sunley 2003, Morgan 2004, Malmberg and Maskell 2004 for a survey) with the more rigorous empirical and theoretical work discussed in chapters 2, 3 and 4 above.

4.5 Conclusion

The models in this section have demonstrated that heterogeneous firms may have different incentives to cluster. There is some empirical evidence for this issue and as intuitive as it may appear, this issue has been given surprisingly little attention in theory so far. For sufficiently different firms the equilibrium in a location decision game depends on the (exogenous) order in which decisions are made. In the labour poaching framework, when firms differ with respect to the value their knowledge has for the rival, the "low-quality" firm would like to colocate with the "high-quality" firm but not vice versa.

In the R&D set-up, firms with fixed payment hire less capable workers and benefit from colocation while firms with variable payment hire more creative workers and prefer separation. We have argued that the structure of payment reflects firm size so that the model can explain why on average large firms agglomerate while small ones rather do not. Even if there is some doubt whether the link between firm size and the payment system is clear, there remains the difference in innovative behaviour which, in the model, is the endogenous level of "creativity" (and which, of course, could also have been established exogenously).

We have introduced asymmetry among firms in order to study firms' location decision in the more general case. Compared to chapter 3 a more distinguished picture emerges now. In chapter 3 we found that for perfectly symmetric firms there is a strong force against colocation making firms separate in equilibrium (with an interior solution). As regards the (possible) *outcome* of a location game, the results of this chapter weaken the overall conclusion of chapter 3. Both models presented here show that when firms are heterogeneous collocation becomes *possible*. While the labour poaching model in chapter 3 has a symmetric equilibrium with spatial separation, there does not necessarily exist an equilibrium (in pure strategies) anymore when firms are asymmetric. Hence whether one observes colocation or not depends on the outcome of the anti-coordination game or (perhaps more realistically) on the order in which choices are made. This means when firms are heterogeneous, colocation is ultimately possible (and observable) even in the presence of incentives to separate.

However, as regards the *existence of incentives to separate* for individual firms, the results in this chapter reinforce the insight from chapter 3. Even when asymmetry is introduced, there remains in both models the incentive for one type of firms to locate apart from rivals. In the labour-poaching framework it is the "high-quality" firm which wants to avoid to cluster with the "low-quality" firm. In the R&D set-up it is the small/more innovative firm that, unlike the large/less innovative firm, wants to separate from its counterpart. It has been the aim of this chapter to show that such forces continue to exist in the presence of asymmetries and again to take the models as a potential explanation for the empirical results in chapter 2.

Despite the caveat about firm size there follows an important message for policy makers who try to lure firms into clusters. If it is correct that firms care about how much they contribute to and benefit from a "community" in a cluster, the issue of adverse selection arises. The simple R&D model presented here suggests that it is only the less innovative firms that benefit from "spillovers" and hence colocate. This is especially important for young firms and potential spin-outs in knowledge-intensive industries because valuable ideas are their key asset. Our model suggests that firms with more able workers are concerned about exchanging knowledge with equally capable rivals. This means that in the field of high-tech business firms engaged in a head-to-head patent race could refrain from colocation in order not to narrow their prospects.

Hence policy makers may want to make sure that cluster initiatives really attract those firms that are more innovative and capable of surviving in the long run. Moreover, the results of the model presented in chapter 3 suggest that only firms in less competitive industries want to colocate. This additional hypothesis will be discussed in the next chapter.

5 The relationship between agglomeration and competition

5.1 Introduction

In chapter 1 a model of location choice was presented in which "knowledge spillovers" occur through mutual labour poaching and in which the degree of spillovers is determined endogenously in equilibrium. One important insight from this model (and from Combes and Duranton 2001, 2003) is that for profit-maximising firms there is not only a benefit of agglomeration. Rather, in equilibrium firms may choose to separate and thus avoid localised spillovers because colocation implies too costly a level of poaching and protective wages. In both models the degree of product market competition determines how strong the competition for "inputs", i.e. key workers, is and whether colocation becomes worthwhile and hence occurs in equilibrium. A broader interpretation of the condition for colocation is that the degree of competition has a negative impact on the geographic concentration of an industry.

In this chapter this hypothesis is tested in a regression analysis using data on the geographic and industrial concentration of German and U.S. manufacturing industries. The analysis of U.S. manufacturing industries builds on Rosenthal and Strange's (2001) seminal regression analysis and is extended by variables relevant to the issue of competition. In both cases we find support for our hypothesis. Stronger competition, measured by the Herfindahl concentration index of sales, indeed implies a lower degree of agglomeration, measured by Ellison and Glaeser's (1997) index of geographic concentration in both countries. This result shows that Porter's (1990, 1998) concept of "clusters" and "local rivalry" is not as distinct from the traditional approach focusing on pure "knowledge spillovers" as is often argued. We will discuss how the results make it possible to reconcile these two approaches.

5.2 Model and hypothesis

The empirical analysis is based on a re-interpretation of our labour poaching model presented in chapter 1, which in turn can be interpreted as a (stylised) explanation for the main result of chapter 2, namely that high-tech industries agglomerate little in absolute and relative terms. In that model knowledge spillovers are incorporated in a precise way and a distinction is made between product market competition and competition for inputs. It is assumed that firms operate in a nation-wide market and that there is no particular local competition in the goods market. However, when colocating, firms "compete" for local inputs, namely valuable knowledge, since they are subject to labour poaching. Knowledge is incorporated in "key employees" (e.g. engineers, managing directors) and may flow between firms through labour poaching if firms locate close to each other.

In both models the degree of product market competition determines whether firms cluster in equilibrium. In the Cournot model the condition for colocation reads

$$\frac{\alpha}{\beta}\frac{n-1}{\left(n+1\right)^2} > T \qquad (5.1)$$

where α, β are the parameters of the linear demand function, T the training costs for poached workers and n the number of firms. The expression on the left-hand-side is readily interpretable as the degree of product market competition. Both a smaller market (lower α) and a steeper demand curve (higher β) clearly imply stronger competition. For $n \geq 4$ the expression decreases with the number of firms, n, so that a greater number of firms also implies stronger competition as measured by this expression.

One interpretation of the condition for agglomeration is that, all else equal, industries with stronger product market competition avoid agglomeration while those with weaker competition do cluster.[46] Hence the empirical test carried out in this chapter is whether competition has a negative impact on observed agglomeration.

As has been noted by Cohen and Levin (1989), market concentration, demand structure and technological opportunity and appropriability all together determine the degree of competition. There are a few studies that look at the degree of competition of particular industries in such detail, like Graddy (1995) at the Fulton fish market, Nevo (2001) at the ready-to-eat cereal industry, Nickel (1996) at selected UK manufacturing firms and Wolfram (1999) at a duopoly in the British electricity spot market. Appelbaum (1982) proposes to estimate firms' equilibrium conjectural elasticity of demand to assess oligopoly power and he applies his framework to four selected industries. Usually these studies employ price-cost data at the firm level together with other detailed information about demand. Unfortunately such detailed measures are not available on a systematic basis and for all manufacturing industries so that one has to be content with proxy variables.

In this study competition is measured by the Herfindahl index of concentration of sales. A higher Herfindahl index implies stronger industrial concentration and—leaving aside entry conditions—most likely weaker competition.

A caveat is that imports may function as a substitute for goods produced in the domestic market. A high portion of imports in an industry's shipments could indicate that competition is actually lower than what concentration of domestic industry suggests.[47] As Utton (1978) has empirically shown, taking international trade into account may indeed make substantial differences when analysing industrial concentration. However, we do not use an additional trade-related variable for two reasons. First, the percentage of imports in an industry's shipments is probably only a

[46] A strict interpretation would suggest that there is a critical level of competition below which there is strong agglomeration and above which firms disperse. We took Hansen's (2000) two-regime threshold estimator based on a re-sampling bootstrap and carefully experimented with the data. Both for Germany and the U.S. one finds a threshold that divides the sample into a small group with only few observations and a large one that contains the majority of the observations. In most cases all explanatory variables, including the measure of competition, turn insignificant in the small sub-sample which is presumably because of the very small number of observations included. Overall, the results do not appear to be very conclusive and are therefore omitted here. Additionally, the poaching model is only partial and probably too stylised to take its prediction about corner solutions literally.

[47] I thank Thomas Bittner for this comment.

very crude measure of international competition. Second, it not only reflects international competition but also simply how important trade is for firms of the industry. This in turn is much determined by trade costs which we capture already with the help of a precise measure of transportation costs derived from trade data because new economic geography models predict that these have a strong impact on agglomeration. Yet, as an alternative to the Herfindahl index we also use a simpler concentration ratio.

The model estimated is

$$\gamma = \alpha + \beta_1 H + \beta_2 H^2 + \delta^T \mathbf{X} + \varepsilon$$

where γ is EG's index of geographic concentration, H is industrial concentration (the Herfindahl index or concentration ratio; not to be confused with the concentration of employment which is used for calculating the index γ) and $\mathbf{X}$ a vector of industry characteristics reflecting theoretical agglomeration forces. Hereby it is assumed that the training cost, T, are the same across industries. Note that due to standardisation in the model T must be read as a percentage of original production cost. It is reasonable to presume that training costs are roughly the same fraction of production costs. Industries producing a complex product and hence employing workers with very specialised skills should have higher training costs. But a complex product is also likely to be more costly to produce so that the ratio should be fairly the same.

Additionally, theoretical and empirical work about innovation/growth and industrial concentration suggest that there is an inverted U-shape relationship between concentration and innovation (Scherer 1967, Smulders and van de Klundert 1995, Aghion et al. 2002, Munisamy et al. 2004). To be able to capture such an effect the quadratic term is included.

5.3 Empirical test

5.3.1 Data for Germany

For the case of Germany, we repeat a baseline version of the regression in chapter 2. Concentration of sales data are taken from the report of the *Monopolkommission* and pertain to the year 2001.[48] In the empirical analysis in chapter 2 we did not find direct evidence for labour market pooling. This time we therefore use an industry's share of R&D personnel instead of the high-tech dummies in order to account for other types of "knowledge spillovers" not captured by our poaching model. Again, it is assumed that if any additional spatially bounded knowledge spillovers exist between plants, they make a single plant and consequently the whole industry the more innovative the more concentrated it is. Accordingly, one can expect that plants optimise their location with respect to spillovers to the extent that innovative capacity is crucial for their industry which is basically Arrow's (1962) argument that knowledge spillovers are relatively more important in research-intensive industries.

Note that one important message from the labour poaching model is that labour market pooling and knowledge spillovers (through labour mobility) are hard to separate. Although we found no direct evidence for labour market pooling, an industry with a high share of researchers still might cluster because it benefits from knowledge spillovers as well as from pooling specialised workers. This is why, strictly speaking, the share of R&D personnel must be interpreted as capturing both knowledge spillovers and potential labour market pooling.

5.3.2 Data for the U.S.

For the U.S., we are able to use the complete data set which Rosenthal and Strange (2001) compiled for their regression analysis.[49] We replicate their main regressions and add alternative proxies for the degree of competition. The most important proxy is the Herfindahl index of concentration of sales but as an alternative

[48] I thank Emir Dzinic for helping me to extract the data and making them readable for the computer.
[49] I am grateful to Stuart Rosenthal who kindly provided the data.

we employ a simple concentration ratio, namely the eight largest firms' share of an industry's total sales (*CR8*). All data were published by the US Census Bureau and pertain to the year 1992. We do not use data from 1997 because in that year the US Census Bureau replaced the SIC classification system by the new NAICS system and our other data are available only in the SIC system. There is a bridge between the two systems but the changes were substantial, and in both directions there are ambiguous relations.

From Rosenthal and Strange we got Ellison and Glaeser's index of agglomeration for the 459 four-digit U.S. manufacturing industries at the zipcode, county and state level. Following them, two variables are used to proxy for input sharing: *Manufactured inputs per $ of shipment* and *Non-manufactured inputs*. Both were obtained from the 1992 US Bureau of Economic Analysis Input-Output tables.

Labour market pooling is separately measured by three different variables. The first is *Net productivity*, equal to the value of shipments less the value of purchased inputs all divided by the number of workers in the industry. This measure was obtained from the NBER. The second is the ratio $Management\ workers/(Management + Production\ workers)$ which captures the share of supervisory and support labour in production. The final variable measures workers' education, specifically the percentage of workers with *Doctorates*, *Master's Degrees*, and *Bachelor's Degrees*. It was obtained from the Consumer Population Survey (CPS).

The variable for "knowledge spillovers" is *Innovations per $ of shipment* where innovations are defined as the number of new products advertised in trade magazines in 1982, the only year for which such data were readily available. Although this variable pre-dates the agglomeration measures by 18 years, Rosenthal and Strange argue that it seems likely that most industries for which innovation was important in 1982 would continue to place importance on innovation in the 1990s. To allow for the possibility that innovativeness has different effects on agglomeration depending on the size of the firms that innovate, the authors partition the variable into *Innovations at firms with fewer than 500 employees* and *Innovations at firms with more than 500 employees*. Of course, there is some doubt whether industries that were innovative 18 years ago remain to be so today.[50] Product life cycles that cause whole industries to decline (and to revive) may blur the relationship between an industry's degree of innovativeness and spatial concentration. However, there are no other data at the four-digit industry level available which is why these data were already used by Audretsch and Feldman (1996).

To control for the importance of natural advantages, the variable *Natural resources is* employed.[51] *Inventories per $ of shipment* are used as a proxy for the per mile cost of shipping. Rosenthal and Strange argue that industries producing highly perishable products face high product shipping costs per unit distance and therefore will seek to locate close to their markets and hence tend to disperse.

5.3.3 Regression results

While OLS estimation is probably the most intuitive approach there is obviously the need for a robustness check with the help of an Ordered Probit estimation because γ is an index. As in our earlier regression analysis in chapter 2, the index is continuous so that it needs to be discretised. The results reported in Table 5.1 and Table 5.2 pertain to a discretisation using eleven quantiles (thus yielding a uniform distribution). As an additional robustness check, the estimations for Germany are repeated with the bootstrap method on the one hand and for the more aggregate planning region level on the other hand. For the U.S., they are done for the zip-, county- and state level with OLS and Ordered Probit.

The regression results for Germany (Table 5.1) and the U.S. (Table 5.2, Table 5.3 and Table 5.4) suggest that industrial concentration has a significant impact on agglomeration at almost all geographic levels, in both countries and with OLS, Ordered Probit and the bootstrap approach. More specifically, the relationship appears to be an inverted-U one but it is important to note that nearly all observations lie on the increasing segment of the parable (Germany: approx. 90%, U.S.: approx. 95%), indicating that higher concentration (lower competition) probably has a non-

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[50] I thank Michael Roos for discussing this with me.

[51] Two other variables, namely *Energy costs* and *Water costs* are dropped because in most cases they are insignificant.

monotonous but positive (negative) effect on agglomeration as broadly predicted by the model.[52]

As regards the other variables, the results largely confirm our earlier and Rosenthal and Strange's results. In particular, natural advantages, transportation costs, manufactured inputs and the variables for labour market pooling have the anticipated and mostly significant positive effect on agglomeration. Interestingly, also in the U.S. more innovative industries seem to be less agglomerated which is in line with the earlier results for Germany in chapter 2. Observe that Rosenthal and Strange's original regressions also exhibit a very low R^2. The results are robust as Ordered Probit estimation produces very similar results. When the *CR8* concentration ratio is used there is still a significant positive—albeit no quadratic—effect on agglomeration.

In sum, we take this as some first evidence that there is a negative and presumably non-monotonous relationship between the degree of competition and spatial agglomeration of firms.

[52] The maximum of the estimated parable is approx. $H = 0.167$ for Germany and $H = 2.15$ for the U.S. The few observations that lie on the decreasing segment could be outliers so that there is actually a monotonous relationship. This would be in line with the results of the regression involving the concentration ratio *CR8* (Table 5.4).

Table 5.1: Regression results for Germany

	OLS		Ordered Probit		Bootstrap	
	County level	PR level	County level	PR level	County level	PR level
Constant	0.0125***	0.0265***			0.0125**	0.0265**
	(0.0033)	(0.0057)			(0.0038)	(0.0067)
Herfindahl	0.1149***	0.1576***	8.3917**	10.9753***	0.1149**	0.1576**
	(0.0458)	(0.0785)	(4.4544)	(4.4934)	(0.0517)	(0.0855)
Herfindahl^2	-0.3422***	-0.4944***	-25.1497**	-31.8225***	-0.3422**	-0.4944**
	(0.1449)	(0.2482)	(14.2211)	(14.3021)	(0.1543)	(0.2785)
Employment	-0.0350***	-0.0533***	-2.7217**	-3.7740***	-0.0350**	-0.0533**
	(0.0143)	(0.0246)	(1.4026)	(1.4164)	(0.0099)	(0.0227)
Extractive industry	0.0459***	0.0753***	2.7200***	2.9445***	0.0459	0.0753
	(0.0126)	(0.0215)	(1.3193)	(1.3308)	(0.0303)	(0.0432)
Transportation costs	-0.0012***	-0.0019***	-0.0737***	-0.0786***	-0.0012**	-0.0019**
	(0.0004)	(0.0006)	(0.0354)	(0.0356)	(0.0008)	(0.0011)
Service inputs	0.0888***	0.0790	3.1006	3.0018	0.0888	0.0790
	(0.0379)	(0.0649)	(3.6155)	(3.6154)	(0.0798)	(0.1238)
Manufactured inputs	-0.0368**	-0.0885***	-4.2415***	-6.1700***	-0.0368**	-0.0885**
	(0.0214)	(0.0366)	(2.0869)	(2.1048)	(0.0206)	(0.0347)
R&D intensity	-0.0304**	-0.0439	-2.0198	-1.7365	-0.0304**	-0.0439**
	(0.0163)	(0.0279)	(1.5721)	(1.5767)	(0.0150)	(0.0244)
Adjusted R^2	0.29	0.22				

Notes: Standard errors in brackets. * denotes significant at 10%, ** at 5%, *** at 1% level.

Table 5.2: OLS regression results for the U.S.

	Zipcode level			County level			State level		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Constant	-0.0085 (0.0072)	0.0007 (0.0077)	-0.0012 (0.0071)	-0.0107 (0.0097)	0.0093 (0.0105)	0.0097 (0.0096)	-0.0384*** (0.0180)	-0.0086 (0.0190)	-0.0189 (0.0175)
Herfindahl	0.0146*** (0.0061)	0.0179*** (0.0066)	0.0173*** (0.0066)	0.0168*** (0.0082)	0.0208*** (0.0091)	0.0200*** (0.0090)	0.0391*** (0.0153)	0.0531*** (0.0164)	0.0497*** (0.0164)
Herfindahl^2	-0.0033 (0.0025)	-0.0045** (0.0027)	-0.0043 (0.0027)	-0.0042 (0.0033)	-0.0046 (0.0037)	-0.0043 (0.0037)	-0.0085 (0.0061)	-0.0129** (0.0067)	-0.0120** (0.0067)
Natural resources	-0.0029 (0.0142)	-0.0073 (0.0153)	-0.0056 (0.0150)	-0.0120 (0.0191)	-0.0094 (0.0208)	-0.0101 (0.0204)	0.0950*** (0.0355)	0.0819*** (0.0378)	0.0911*** (0.0372)
Inventories	0.0205 (0.0208)	0.0154 (0.0219)	0.0160 (0.0219)	0.0396 (0.0279)	0.0197 (0.0299)	0.0212 (0.0297)	0.1499*** (0.0518)	0.1330*** (0.0541)	0.1361*** (0.0542)
Innovations from small firms	-0.4363 (0.8137)	-0.5082 (0.8999)	-0.5398 (0.8976)	-1.3884 (1.0918)	-1.5989 (1.2282)	-1.5416 (1.2192)	-3.1169 (2.0288)	-3.2149 (2.2262)	-3.3912 (2.2216)
Innovations from large firms	0.7085 (0.7528)	0.9358 (0.7971)	0.8929 (0.7970)	0.5410 (1.0101)	0.9429 (1.0878)	0.8596 (1.0824)	-1.2284 (1.8769)	-0.6433 (1.9718)	-0.8635 (1.9725)
Manufactured inputs	0.0144 (0.0130)	0.0042 (0.0136)	0.0061 (0.0133)	0.0221 (0.0174)	0.0000 (0.0185)	0.0008 (0.0181)	0.1095*** (0.0323)	0.0796*** (0.0335)	0.0892*** (0.0330)
Non-Manufactured inputs	-0.0107 (0.0193)	-0.0219 (0.0228)	-0.0229 (0.0229)	-0.0320 (0.0259)	-0.0571** (0.0311)	-0.0626*** (0.0311)	-0.0833** (0.0482)	-0.1133*** (0.0564)	-0.1182*** (0.0566)
Netproductivity	0.0000*** (0.0000)			0.0001*** (0.0000)			0.0002*** (0.0000)		
Bachelor		-0.0104 (0.0205)			0.0159 (0.0280)			-0.0577 (0.0508)	
Phd.			0.0329 (0.0672)			0.1898*** (0.0912)			0.1544 (0.1662)
Adjusted R^2	0.04	0.02	0.03	0.09	0.03	0.04	0.11	0.10	0.09

Notes: Standard errors in brackets. * denotes significant at 10%, ** at 5%, *** at 1% level.

Table 5.3: Ordered Probit regression results for the U.S.

	Zipcode level			County level			State level		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Herfindahl	1.6275***	1.7037***	1.6786***	1.1804***	1.2201***	1.2008***	0.9056***	1.0553***	1.0164***
	(0.2422)	(0.2537)	(0.2525)	(0.2377)	(0.2478)	(0.2468)	(0.2362)	(0.2470)	(0.2459)
Herfindahl²	-0.4395***	-0.4518***	-0.4439***	-0.3214***	-0.3172***	-0.3100***	-0.2310***	-0.2615***	-0.2504***
	(0.0961)	(0.1022)	(0.1020)	(0.0940)	(0.0996)	(0.0995)	(0.0938)	(0.0993)	(0.0992)
Natural resources	1.0327**	1.0339**	1.0821**	0.0329	0.0211	0.0235	1.5706***	1.5805***	1.6699***
	(0.5425)	(0.5641)	(0.5549)	(0.5381)	(0.5593)	(0.5502)	(0.5431)	(0.5636)	(0.5548)
Inventories	3.5124***	3.0767***	3.1110***	3.4625***	2.9074***	2.9572***	3.8081***	3.3225***	3.3704***
	(0.8112)	(0.8278)	(0.8280)	(0.7985)	(0.8123)	(0.8128)	(0.8094)	(0.8239)	(0.8242)
Innovations from small firms	-29.8047	-19.3295	-19.9522	-67.7873***	-61.4806**	-60.3461**	-69.3860***	-65.0567**	-66.3078***
	(30.9378)	(32.9445)	(32.8508)	(31.5042)	(33.4549)	(33.3464)	(31.1625)	(33.5653)	(33.4798)
Innovations from large firms	-8.3432	2.3164	0.5631	3.9284	13.1465	10.7999	1.8019	9.4082	6.5624
	(28.7467)	(29.5797)	(29.5911)	(28.8604)	(29.7022)	(29.7114)	(28.8614)	(29.7612)	(29.7934)
Manufactured inputs	0.8316**	0.3509	0.4144	0.5407	0.0212	0.0586	1.6703***	1.3010***	1.4072***
	(0.4925)	(0.5009)	(0.4931)	(0.4929)	(0.4999)	(0.4924)	(0.4934)	(0.5000)	(0.4929)
Non-Manufactured inputs	-1.2638**	-2.8654***	-2.9282***	-1.8812***	-3.1752***	-3.3076***	-1.5537***	-2.2110***	-2.3015***
	(0.7320)	(0.8456)	(0.8483)	(0.7351)	(0.8469)	(0.8504)	(0.7333)	(0.8422)	(0.8452)
Netproductivity	0.0027***			0.0032***			0.0031***		
	(0.0008)			(0.0009)			(0.0009)		
Bachelor		-0.2074			0.2789			-0.4412	
		(0.7543)			(0.7565)			(0.7566)	
Phd.			2.3389			4.6171**			3.2534
			(2.4856)			(2.4853)			(2.4765)
Log likelihood	-1029.94	-960.35	-959.95	-1046.79	-979.06	-977.39	-1048.10	-979.30	-978.60

Notes: Standard errors in brackets. * denotes significant at 10%, ** at 5%, *** at 1% level.

Table 5.4: Regression Results for the U.S., concentration ratio

	OLS			Ordered Probit		
	Zipcode level	County level	State level	Zipcode level	County level	State level
Constant	-0.0041 (0.0084)	-0.0343 (0.0211)	-0.0245 (0.0235)			
CR8	-0.0176 (0.0234)	0.0015 (0.0588)	0.0084 (0.0644)	2.7966*** (0.9166)	2.4210*** (0.9021)	2.1215*** (0.9000)
$CR8^2$	0.0326 (0.0217)	0.0362 (0.0545)	0.0277 (0.0592)	-0.9530 (0.8410)	-1.2700 (0.8290)	-1.2800 (0.8310)
Natural resources	-0.0022 (0.0143)	0.0994*** (0.0358)	0.0915*** (0.0391)	1.0506** (0.5416)	0.1230 (0.5377)	1.6358*** (0.5424)
Inventories	0.0225 (0.0209)	0.1531*** (0.0525)	0.1507*** (0.0574)	3.3206*** (0.8134)	3.3228*** (0.8020)	3.6842*** (0.8123)
Innovations from small firms	-0.5210 (0.8133)	-3.4903** (2.0413)	-4.3684** (2.2262)	-37.7360 (30.8089)	-77.2594*** (31.4100)	-78.7861*** (31.0767)
Innovations from large firms	0.9056 (0.7526)	-0.7836 (1.8890)	-1.0722 (1.9713)	5.5742 (28.6955)	13.1933 (28.8047)	8.1533 (28.7917)
Manufactured inputs	0.0181 (0.0131)	0.1160*** (0.0328)	0.0979*** (0.0357)	0.8629** (0.4954)	0.5297 (0.4961)	1.6219*** (0.4963)
Non-Manufactured inputs	-0.0129 (0.0194)	-0.0911** (0.0486)	-0.1011** (0.0531)	-1.6017*** (0.7322)	-2.1341*** (0.7350)	-1.7740*** (0.7332)
Netproductivity	0.0000*** (0.0000)			0.0027*** (0.0008)		
Adjusted R^2	0.04	0.10	0.09			
Log likelihood				-1036.42	-1054.23	-1054.45

Notes: Standard errors in brackets. * denotes significant at 10%, ** at 5%, *** at 1% level.

5.4 Discussion

This result is important insofar as it adds to the literature that has analysed the relationship between innovation and industrial concentration but left out the spatial dimension (Scherer 1967, Smulders and van de Klundert 1995, Gopinath et al. 2004).

More importantly, the result shows that Porter's (1990, 1998) approach to agglomeration namely his concept of "clusters" and "local rivalry" is not as distinct from the traditional approach focusing on "knowledge spillovers" as is sometimes argued as, for example, in Beal and Gimeno (2001). By finding empirical support for a clear hypothesis about the relationship between agglomeration and "competition", this analysis makes it possible to reconcile Porter's view and the traditional approach which perceives spillovers as a "black box".

The labour poaching model, on which this empirical test builds, considers the location decision and hence the degree of local competition (for inputs) as endogenous and as determined by the exogenous degree of nation-wide (product market) competition. Porter (1990, 1998) proposed a different (and much adopted) approach to agglomeration, which we already sketched in the introduction in chapter 1. Porter takes a cluster, i.e. the agglomeration of "related" firms, as given and argues that the primary benefits of agglomeration arise from *local rivalry* itself, rather than from pure knowledge spillovers. According to him, the benefits depend on "inter-firm interaction" such as increased motivation and a "desire to look good" due to peer pressure and effective mutual control in a "cluster". In sum, clusters both facilitate innovation and cooperation and intensify rivalry.

Our theoretical and empirical results show that Porter's concept needs to be improved in several ways. First, as argued in chapter 3, possible channels for "knowledge spillovers" are labour turnover, local spin-offs, reverse engineering, sub-contracting, cooperation etc. of which the first one is perhaps the most important one. However, any of them constitutes an example of "inter-firm interaction" in the sense of Porter (1998). Thus, his focus on "inter-firm interaction" can be reconciled with the concept of knowledge spillovers if one goes beyond a "black-box" concept and conceives of a precise way of how exactly knowledge flows between firms.

Secondly, the labour poaching model treats agglomeration of firms as endogenous and shows that it is especially the very local "inter-firm interaction" which may make firms avoid a "cluster". This means that taking a broader perspective than Porter, by explicitly considering firms' location decision and by taking labour poaching as an element of "inter-firm interaction", challenges the common reasoning: it may not be that agglomeration is "beneficial" for firms because of intensified local rivalry (e.g. for inputs), as Porter argues, but rather conversely that some industries agglomerate *despite* the negative effect of intensified local rivalry.

Finally, Porter's work on clusters has been criticised for being vague and only descriptive (see the survey of Martin and Sunley 2003 and Morgan 2004). In particular, it is not clear which role competition plays in a cluster:

> *"Clusters promote both competition and cooperation. [...] Yet there is also cooperation, much of it vertical, involving companies in related industries and local institutions. Competition can coexist with cooperation because they occur on different dimensions and among different players." (Porter 1998, p. 79).*

Cooperation between firms that are no direct rivals, for example because they belong to different industries, is realistic. However, cooperation between direct rivals will be rare and usually confined to non-core activities such as joint purchase. First of all, there must be a surplus from collaboration. Secondly, the partners must find an agreement on how to share this surplus. Incomplete contracts, the strategic interaction leading to prisoner dilemma-like situations or simply competition regulations may make such agreements very difficult to enforce.

The labour poaching model is very clear about what types of competition are at work. A distinction is made between product market competition which is assumed to take place at a nation-wide level, hence with no spatial dimension, and input market competition, which becomes effective only under colocation. In sum, the degree of product market competition, which is taken as an exogenous industry characteristic, determines how strong competition for inputs (knowledge) is and hence whether or not firms agglomerate in equilibrium. The results from the regression analysis suggest that there is indeed a negative relationship between the degree of competition and agglomeration.

There are a two related empirical studies which distinguish between the effect of spillovers and local rivalry and which thereby pick up Porter's line of arguments. Beal and Gimeno (2001) contrast several hypotheses grounded in the "knowledge spillovers" approach and Porter's approach, respectively, and test them with the help of panel data analysis for the U.S. pre-packaged software industry. One important hypothesis of the "pure spillovers" perspective is that agglomeration is *negatively* associated with firm commitment to innovation due to the temptation for firms to free-ride on the innovative efforts of rivals. By contrast, the main hypothesis of Porter's approach says that in a cluster increased competition and peer pressure *increase* the commitment of firms to innovation. The authors find support for the spillovers perspective but no evidence for Porter's one. In particular, localised "knowledge spillovers" seem to increase firm innovative output but decrease firm-level commitment to R&D. Accordingly, Porter's hypothesis that agglomeration should be positively associated with firm commitment to innovation is declined.

In a similar study Buch and Lipponer (2004) analyse if German banks have a tendency to agglomerate when they establish foreign subsidiaries through FDI. Once they control for country-fixed effects there is evidence for a dominant negative competition effect which makes firms avoid colocation.

The predictions of our labour poaching model and the results of the empirical test carried out in this chapter are in line with these findings.

5.5 Conclusion

The location decision models presented in chapter 3 have specified "spillovers" as knowledge flows between firms due to labour poaching. Both, Combes and Duranton's model (Bertrand competition) and our model (Cournot competition), show that there is a downside associated with such spillovers which stems from the fact that sharing knowledge makes the rival more competitive. Depending on the degree of product market competition, profit-maximising firms may find it too costly to colocate (and protect themselves against poaching with the help of high wages) so that they choose not to cluster. This paper has tested the hypothesis that competition—measured by industrial concentration—has a negative impact on spatial agglomeration, in a regression analysis for German and U.S. manufacturing industries. We find evidence for this effect and it seems to be robust with respect to the estimation method and the level of geographic aggregation. More precisely, the relationship between industrial concentration and spatial agglomeration appears to be positive but non-monotonous. Industries which exhibit low industrial concentration and hence strong competition tend to be less agglomerated. In the model, the explanation is that (local) competition for inputs, such as strategic knowledge incorporated in key employees, intensifies with product market competition and makes firms avoid colocation.

This result is important because it helps to bring together two different and important approaches to the phenomenon of agglomeration of firms. The first concentrates on knowledge spillovers as an externality making firms cluster in space. The second goes back to Porter (1990, 1998) and focuses on inter-firm interaction such as intensified rivalry and cooperation. We have argued that these two perceptions are not as distinct as it may seem. In particular, in chapter 3 we have criticised that in many models "knowledge spillovers" are treated as a black-box while possible channels through which knowledge may leak out of a firm or research institute are in fact labour turnover, local spin-offs, reverse engineering, sub-contracting, cooperation etc., all of which constitute examples for inter-firm interaction in the sense of Porter. The theoretical models of chapter 3 and the empirical analysis carried out in this chapter help to clarify Porter's approach and to reconcile it with the concept of pure "knowledge spillovers". While Porter takes agglomeration as given and postulates that there are advantages (such as "intensified rivalry"), the more complete approach pursued here makes the location decision endogenous. By doing so, the line of argument is reversed: some industries agglomerate *despite* the negative effect of intensified local rivalry, such as the strategic interaction in labour poaching.

A theoretical study of the interplay of *all* potential benefits and disadvantages from clustering including congestion costs, labour poaching, input sharing and transportation costs appears to be a complex task, however, and is left for future work.

6 Concluding remarks

The aim of this dissertation has been to look at firms' incentive for agglomeration from a micro-perspective. This focus was motivated by the fact that Marshall's (1920) agglomeration externalities between firms are empirically relevant, that new economic geography models in the spirit of Krugman (1990a, b) do not leave much room for such firm-level phenomena and that this very issue has been given little attention in theory yet.

The empirical results in chapter 2 have been disappointing in that there is no evidence for spatially bounded knowledge spillovers. More precisely, German high-tech manufacturing industries do not agglomerate much in absolute and relative terms. We used Ellison and Glaeser's (1997) index of geographic concentration and have shown, both, by exploring the data and with the help of a regression analysis, that there is no general relationship between high-tech related business and the degree of agglomeration. At the same time we confirmed earlier empirical studies which present evidence for "market linkages" postulated by new economic geography models (transportation costs, internal increasing returns to production) and Marshall's (1920) sharing of inputs. These results are striking as common wisdom in regional policy (and even regional economics) takes it for granted that knowledge spillovers (between high-tech firms) exist, are ubiquitous and unambiguously stimulate agglomeration.

In chapter 3 we have offered an explanation for the empirical results. It has been shown that there may exist very strong forces against colocation when firms take into account that mutual spillovers make their rivals more competitive. In our model with Cournot competition and homogeneous goods firms never want to colocate except with corner solutions. We have criticised that in most work in industrial organisation and regional economics spillovers are treated as a "black box" while in fact labour poaching is an important channel of knowledge diffusion which is why we followed Combes and Duranton (2001) by explicitly modelling knowledge spillovers this way.

Chapter 4 extended this analysis to heterogeneous firms. There is empirical evidence that both, small firms and firms with "superior" resources, agglomerate less than large firms and firms with "inferior" resources. As regards firm size, our empirical results in chapter 2 give support to this observation. It is intuitive that different firms contribute to and benefit from a "cluster" to a different extent. Consequently we have introduced firm heterogeneity in the labour poaching model and shown that for sufficiently different firms the equilibrium of the location decision game depends on the order in which decisions are made. The "low-quality" firm would like to colocate with the "high-quality" firm but not vice versa.

In order to give a potential explanation involving firm size, we have proposed a simple patent race model in which firm size is reflected by different payment systems (fixed vs. variable) which endogenously render small firms more innovative than large firms. As a consequence, small firms—contrary to large firms—only lose from mutual knowledge spillovers and hence do not cluster. Assuming that smaller firms are more innovative seems to be justifiable on the ground of the empirical evidence. Although the link between firm size and payment structure is perhaps not so clear, there remains the argument that only less capable, i.e. less innovative, firms benefit from agglomeration.

A similar result emerges from the analysis in chapter 5. There we related an industry's degree of competition, measured by the concentration of sales, and its degree of agglomeration in a regression analysis using data for Germany and the U.S. (by extending Rosenthal and Strange's 2001 regression). The labour poaching model presented in chapter 3 broadly predicts that more competitive industries tend to agglomerate less in order to avoid costly competition for inputs. There is evidence for this effect in our data and it seems to be robust with respect to the estimation method and the level of geographic aggregation. More precisely, the relationship between competition and spatial agglomeration appears to be negative and non-monotonous. The conclusion is that firms in less competitive industries colocate more often. These results are new to the literature and without doubt further empirical and theoretical research on this topic is warranted.

As preliminary as the results are, they still make it possible to reconcile Porter's (1990) indistinct concept of "local rivalry" in "clusters" with the traditional one treating technological spillovers as a "black box". We have argued that in fact knowledge spillovers work through various channels all of which are voluntary and/or operate through markets. Labour poaching is perhaps the most important one and it is a prominent example of "inter-firm interaction" in the sense of Porter. The labour poaching model suggests that this very interaction between firms can make them separate so that Porter's line of argument needs to be revised: some industries agglomerate *despite* the negative effect of intensified local rivalry.

As regards advice for policy, public intervention would in general be desirable if market forces did not lead to the optimal (desired) outcome, i.e. the optimal degree of agglomeration and "knowledge spillovers". However, our argument has been that there are no (or much fewer) externalities involved in the transmission of knowledge through channels such as labour poaching (than a pure spillover concept suggests). Concerning the *efficiency* of labour poaching and agglomeration, the empirical and theoretical work presented in this thesis does not allow to make specific policy recommendations or evaluate particular policy initiatives. Yet, as regards the *effectiveness* of regional policy, it recommends caution.

Our empirical study about the agglomeration of German manufacturing industries is a top-down one. But using Ellison and Glaeser's index, which builds on a statistical model and takes into account industrial concentration, allows for more systematic statements than is possible in case studies which are widely used in regional science. The results do not suggest that there is *no* agglomeration of (high-tech) firms at low spatial levels at all, but that on average, across the whole country these industries exhibit only little agglomeration. This implies that politicians[53] who think that high-tech industries are especially prone to clustering because of "knowledge spillovers" should act with caution. Obviously there is no such effect.

Similarly, the models we offered as an explanation are better suited to advise caution rather than any particular action. The new economic geography literature provides a variety of models that make welfare analysis in a general equilibrium model possible but, as noted, even these models are too stylised to give proper advice for public intervention. We deliberately focused on partial models with an emphasis on firms' incentives for agglomeration. In the labour poaching model firms behave too aggressively and separate in equilibrium leading to too little "knowledge spillovers". Firms face a prisoner's dilemma when deciding about poaching and protective wages. There is a moderate level that maximises welfare but each firm has an incentive to deviate and behave predatorily.

This result is well-known in industrial economics but it is new in the spatial context. It is at best unclear how the government could (or should) intervene because any additional regulation would affect workers' right of job mobility or firms' freedom of movement. Still, politicians inspired by Porter should take into account that there is a downside associated with "spillovers" stemming from the strategic interaction of firms. Again, our results suggest that firms do not agglomerate *because*, but, if at all, *in spite of* intensified local rivalry. Politicians should also recognise that different firms may have different incentives for agglomeration. Our models suggest that there is some type of adverse selection as less capable firms and firms in less competitive industries benefit most from agglomeration. Hence special care should be taken when costly support programmes spend taxpayers' money in order to lure young, innovative and prospering firms into "clusters".

Apparently these considerations played no role in the formulation and implementation of European cluster projects at the end of the 1990s and "[i]t is

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[53] Consider, for example, current policy efforts in poor German cities such as Dortmund (Dortmund Project), or past initiatives such as BioRegio and InnoRegio. See also the references given in the Introduction and in section 2.1.

impossible to resist the conclusion that the policy tail is wagging the analytical dog and wagging it so hard indeed that much of the theory is shaken out."[54]

Now that these programmes, in particular the German BioRegio and InnoRegio initiative, have terminated it remains to be seen if politicians were too precipitant and if the target regions are able to give birth to a successful and long-living cluster.

[54] Lovering (1999, p. 390) in a critical evaluation of a U.K. regional policy programme.

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A Appendix to chapter 2

Table A.1: Industries contained in the hand-compiled industry groups

Group	contains NACE 3
High-tech	233, 242, 244, 296, 300, 321, 322, 333, 353
Medium-tech	241, 243, 246, 291, 293, 294, 295, 311, 314, 315, 316, 323, 331, 334, 341, 343, 352
R&D-intensive Chemicals	233, 241, 242, 243, 244, 246
R&D-intensive Manufacture of Machinery	291, 293, 294, 295, 296
R&D-intensive Manufacture of Electrical Machinery and Apparatus	311, 314, 315, 316
R&D-intensive Automobiles	341, 343, 352, 353
R&D-intensive Electronic, Optical and Communication Equipment	300, 321, 322, 323, 331, 332, 333, 334

B Appendix to chapter 3

B.1 Proof of Proposition 3.1 (Duopoly)

The proof shows that (i) for any market size leading to optimal wages of zero and (ii) any market size inducing an interior poaching solution, profits under colocation are smaller than profits in isolation, so that colocation is never a subgame equilibrium; and (iii) that for the full poaching solution there is a $\tilde{w}$ that divides the continuum of (symmetric) wage equilibria into a part that leads to colocation and one that leads to separation.

(i) Suppose $1 < \alpha \leq \underline{\alpha} = -P_4/P_5$. Then the condition $w^* \geq 0$ is binding, and solving for c^*, q^* and p^* one gets $q^* = \frac{1}{3\beta}(\alpha - 1 + \lambda^*)$, $p^* = \frac{1}{3}(\alpha + 2 - 2\lambda^*)$ and $c^* = 1 - \lambda^*$. In contrast, if firms separate $\overline{q} = (\alpha - 1)/(3\beta)$ and $\overline{p} = \frac{1}{3}(\alpha + 2)$ and $\overline{c} = 1$.

Then the difference in market revenue between clustering (implying the sub-game equilibria of stage 2 – 4) and isolation (with no poaching) is

$$\begin{aligned}\Delta MR &= (p^* - c^*)q^* - (\bar{p} - \bar{c})\bar{q} \\ &= \frac{1}{9\beta}(\alpha - 1 + \lambda^*)^2 - \tfrac{1}{9}\tfrac{1}{\beta}(\alpha - 1)^2 \\ &= \frac{1}{9\beta}(2(\alpha - 1)\lambda^* + \lambda^{*2}) > 0\end{aligned} \quad \text{(B.1)}$$

which implies a benefit of clustering. It simply reflects that producing with lower variable costs is more profitable. However, the cost of poaching are the (fixed) training costs $T\lambda^{*2}$ so that the overall difference in profits is

$$\Delta\pi = \Delta MR - T\lambda^{*2} = \frac{1}{9\beta}\lambda^*\left(\underbrace{2(\alpha - 1) + \lambda^*(1 - 9T\beta)}_{z_1}\right) \quad \text{(B.2)}$$

Rearranging λ^* from equation (3.7) to $\lambda^* = 2(\alpha - 1)/(9T\beta - 2)$, it is straightforward to show that $z_1 < 0 \Leftrightarrow 2 + 2(1 - 9T\beta)/(9T\beta - 2) < 0$ is true for any T, β. Hence firms prefer separation.

(ii) Now consider $\underline{\alpha} < \alpha \leq \bar{\alpha} = 9T\beta$ so that $w^* > 0$ which lowers λ^*, c.p. Repeating the exercise from above, one gets

$$\Delta\pi = \frac{1}{9\beta}\left(\underbrace{2(\alpha - 1)\lambda^* + \lambda^{*2}(1 - 9T\beta) - 9\beta w^*}_{z_2}\right). \quad \text{(B.3)}$$

Inserting the expression for λ^* and w^* into (B.3) and rearranging shows that z_2 can be expressed as $z_2 = (k\alpha^2 + l\alpha + m)/r^2$ whereby

$$\begin{aligned}k &= (9T\beta - 4)(243T^2\beta^2 - 189T\beta + 28) \\ l &= -65610T^4\beta^4 + 87480T^3\beta^3 - 38070T^2\beta^2 + 5904T\beta - 256 \\ m &= 177147T^5\beta^5 - 255879T^4\beta^4 + 129033T^3\beta^3 - 29241T^2\beta^2 + 3744T\beta - 256 \\ r &= P_6/\beta = 162T^2\beta^2 - 117T\beta + 16.\end{aligned}$$

Note that z_1 and z_2 intersect at $\alpha = \underline{\alpha}$ so that $z_2(\underline{\alpha}) < 0$; and that $\partial z_2/\partial^2\alpha = 2\beta^2 k/P_6^2 > 0$ so that z_2 is convex in market size, α. Instead of showing that the second root of z_2 is always greater than $\overline{\alpha}$, it is shown that its *minimum* is associated with an α greater than $\overline{\alpha}$. Since the second root of z_2 must be greater than the minimum it is thereby proofed that the difference in profits cannot break even with $1 < \alpha < \overline{\alpha}$. The first derivative of z_2 w.r.t. α is

$$\frac{\partial z_2}{\partial \alpha} = \frac{2\beta^2}{P_6^2}((9T\beta - 4)(243T^2\beta^2 - 189T\beta - 189)\alpha \\ -32805T^4\beta^4 + 43740T^3\beta^3 - 19035T^2\beta^2 + 2952T\beta - 128)$$

and

$$\frac{\partial z_2}{\partial \alpha} = 0 \Leftrightarrow \alpha_0 = \frac{32805T^4\beta^4 - 43740T^3\beta^3 + 19035T^2\beta^2 - 2952T\beta + 128}{(9T\beta - 4)(243T^2\beta^2 - 189T\beta + 28)}.$$

The expression $\alpha_0 - 9T\beta$ can be nicely factorised to

$$\alpha_0 - 9T\beta = \frac{(81T^2\beta^2 - 63T\beta + 8)P_6}{\beta(9T\beta - 4)(243T^2\beta^2 - 189T\beta + 28)} \tag{B.4}$$

where each factor can be shown to be positive (for all *T*, β satisfying Assumption 3.1) so that $\alpha_0 > 9T\beta$. Thus, the global minimum and hence the second root of z_2 is always associated with a market size that involves full poaching (and a continuum of equilibria of w^*), and the difference in profits will always be negative for a market size smaller than $9T\beta$. Hence firms prefer separation.

(iii) With $\alpha \geq \overline{\alpha}$ one has $\lambda^* = 1$ and $w_i^*, w_j^* \in [0, \underline{w}]$, $\underline{w} = \frac{4}{9}\alpha/\beta - 2T$. Then it is easy to show that

$$\Delta\pi(w^*) > 0 \Leftrightarrow z_2(w^*) > 0 \Leftrightarrow w^* < (2\alpha - 1)/(9\beta) - T = \tilde{w}$$

so that $\tilde{w}$ divides the continuum of equilibria into a lower and an upper part such that at all wage combinations that lie in the former make clustering mutually profitable and all wage combinations that lie in the latter make separation mutually profitable. If $\alpha < \frac{1}{2}(9T\beta - 1)$, one has $\tilde{w} > \underline{w}$ so that firms prefer colocation regardless of the wage combination they choose. ◊

B.2 Derivation of the Equilibrium (Oligopoly)

The first-order conditions for all firms give the system of best responses

$$q_i^{BR} = \frac{\alpha - 1 + \lambda_i - \beta \sum_{k \neq i} q_k}{2\beta}$$
$$\vdots$$
$$q_j^{BR} = \frac{\alpha - 1 + \lambda_j - \beta \sum_{k \neq j} q_k}{2\beta}$$

in which each equation has got the common term $(\alpha - 1)/(2\beta)$ and a specific one (λ_i). Using the recursion formula $1/(1-(n-1)x)$ for the common term, $(1-(n-2)x)/((x+1)(1-(n-1)x))$ for each equation's own specific term and $x/((x+1)(1-(n-1)x))$ for the specific term of the other equations (with n the number of equations and $x = -\frac{1}{2}$ being the slope of the best response function) gives

$$q_i^* = \frac{\alpha - 1 + n\lambda_i - \sum_{k \neq i} \lambda_k}{(n+1)\beta}.$$

The same tedious but straightforward steps lead to the expression of the equilibrium in the poaching and wage-setting subgame.

In particular, solving stage 1 for n firms gives the familiar

$$q_i^* = \frac{(\alpha - 1 + n\lambda_i - (n-1)\lambda_{-i})}{(n+1)\beta} \tag{B.5}$$

for output quantities and

$$\begin{aligned} \lambda_i^{BR} &= \min\left[\max\left[0, \frac{\left(n(\alpha - 1 - (n-1)\lambda_{-i}) - \frac{(n+1)^2(n-1)}{2}\beta w_{-i}\right)}{(n+1)^2 T\beta - n}\right], 1\right] \\ \lambda^* &= \frac{2n(\alpha-1)((n+1)T\beta - n) + \beta n(n+1)w_i - \beta\left((n+1)^2 T\beta - n^2\right)(n+1)w_{-i}}{2((n+1)T\beta - n)\left((n+1)^2 T\beta - n\right)} \end{aligned} \tag{B.6}$$

for the best response and equilibrium in the poaching subgame. Equilibrium wages consist of lengthy expressions

$$w^* \in \begin{cases} \{0\} & 0 \le \alpha < \underline{\alpha} \\ \left\{\dfrac{n-1}{n+1}\dfrac{P_4 + \alpha P_5}{P_6}\right\} & \underline{\alpha} \le \alpha < \overline{\alpha} \\ [0, \underline{w}] & \overline{\alpha} \le \alpha \end{cases} \tag{B.7}$$

whereby

$$\begin{aligned} P_4 &= 2\left(-T^3\beta^3(n+1)^5 + T^2\beta^2(n+1)^3(n^2+2n-1) - T\beta n^3(n+1)\right) \\ P_5 &= 2\left(T^2\beta^2(n+1)^4 - T\beta n^2(n+3)(n+1) + n^3\right)) \\ P_6 &= \beta\left(T^2\beta^2 n(n+1)^4 - T\beta(n+1)^2(n^3+2n^2-2n+1) + n^4\right) \\ \underline{\alpha} &= \frac{T^2\beta^2(n+1)^4 - T\beta(n^2+2n-1)(n+1)^2 + n^3}{T^2\beta^2(n+1)^4 - T\beta n^2(n+3)(n+1) + n^3}(n+1)\beta \\ \overline{\alpha} &= \frac{(n+1)^2}{n-1}T\beta \\ \underline{w} &= \left(\frac{2\alpha n}{\beta(n+1)^2} - 2T\right). \end{aligned} \tag{B.8}$$

As in the case of duopoly, the wage equilibrium is unique and symmetric for a certain range of market size. Knowing this, the condition for interior poaching, $0 < \lambda^* < 1$, can be expressed in terms of wages as

$$\begin{aligned} &\left.\begin{aligned} \lambda^*(w^*) < 1 &\Leftrightarrow w^* > \underline{w} \\ \lambda^*(w^*) > 0 &\Leftrightarrow w^* < \overline{w} \end{aligned}\right\} \underline{w} < w^* < \overline{w} \\ &\overline{w} = \frac{2n(\alpha-1)}{(n+1)^2\beta}. \end{aligned} \tag{B.9}$$

Also as in the case of duopoly, $w^* < \overline{w}$ is always true for positive market size,

$$\begin{aligned} w^*(\alpha) \le \overline{w} &\Leftrightarrow \frac{AB}{C} < 0 \\ &\Leftrightarrow \alpha > -\frac{(n-1)(n+1)^4T^2\beta^2 - (n^3+n^2-2n+1)(n+1)^2T\beta + n^4}{(n+1)^2T\beta - n^2} \\ A &= -2\left((n+1)^2T - n\right) \\ B &= \left((n-1)(n+1)^4T^2\beta^2 + (-n^3-n^2+2n+\alpha-1)(n+1)^2T\beta - n^2(\alpha-n^2)\right) \\ C &= \left(n(n+1)^4T^2\beta^2 - (n^3+2n^2-2n+1)(n+1)^2T\beta + n^4\right), \end{aligned}$$

but $w^*(\alpha) > \underline{w}$ only for $\alpha < \overline{\alpha} = (n+1)^2T\beta/(n-1)$. For market size greater than $\overline{\alpha}$ there is full poaching, $\lambda^* = 1$, and any wage combination consistent with full poaching is an equilibrium. Hence there is a continuum of equilibria $w^* \in [0, \underline{w}]$ with $\underline{w}$ being the maximum (symmetric) wage level leading to full poaching.

Wages are positive only from a certain market size $\underline{\alpha}$ on, i.e. in small markets firms do not engage in protective wages. Calculations show that $\underline{\alpha} > 1$ for all valid combinations of T and β and that $\bar{\alpha} > \underline{\alpha}$.

The second-order condition for the wage-setting requires

$$T\beta > \frac{2n^2 + 5n - 1 + \sqrt{4n^4 + 4n^3 + 5n^2 - 10n + 1}}{4(n+1)^2} \qquad \text{(B.10)}$$

which reduces to $T\beta > \left(\sqrt{97} + 17\right)/36 \approx \frac{3}{4}$ for $n = 2$ as stated in Assumption 3.1. The expression on the right hand side converges to 1, so that this condition becomes $T > \frac{1}{\beta}$ when $n \to \infty$. Table 1 gives a feel for this condition. A casual comparison with the corresponding condition in CD's model (SCE) shows that in effect the restrictions imposed on T are of the same scale.

Table B.1: The lowest valid value for T due to the second-order condition of the wage-setting subgame

n	$\beta = 0.5$	$\beta = 1$	$\beta = 1.5$	$\beta = 2$
2	1.492	0.746	0.497	0.373
4	1.747	0.873	0.582	0.437
6	1.832	0.916	0.611	0.458
8	1.874	0.937	0.625	0.469
10	1.900	0.950	0.633	0.475
20	1.950	0.975	0.650	0.487
30	1.967	0.983	0.656	0.492

Nevertheless, when clustering, the increase in operating profit is still more than compensated by the total cost of poaching so that the terms of the trade-off do not change with more than two firms (see Appendix B.3).

B.3 Proof of Proposition 3.2 (Oligopoly)

The proof for an arbitrary number of firms is similar to that of the duopoly.

(i) Suppose $1 < \alpha \leq \underline{\alpha}$. The condition $w^* \geq 0$ is binding and solving for c^*, q^* and p^* one gets $q^* = (\alpha - 1 + \lambda^*)/((n+1)\beta)$, $p^* = (\alpha + n - n\lambda^*)/(n+1)$ and $c^* = 1 - \lambda^*$. In contrast, $\overline{q} = (\alpha - 1)/((n+1)\beta)$, $\overline{p} = (\alpha + n)/(n+1)$ and $\overline{c} = 1$ if firms separate. Then the difference in market revenue between clustering (implying the sub-game equilibria of stage 2 – 4) and isolation (with no poaching) is

$$\begin{aligned}\Delta MR &= (p^* - c^*)q^* - (\overline{p} - \overline{c})\overline{q} \\ &= \frac{(\alpha - 1 + \lambda^*)^2 - (\alpha - 1)^2}{(n+1)^2 \beta} \\ &= \frac{2(\alpha - 1)\lambda^* + \lambda^{*2}}{(n+1)^2 \beta}\end{aligned} \qquad \text{(B.11)}$$

which implies a benefit of clustering. It simply reflects that producing with lower variable costs is more profitable net of the strategic interaction between firms. However, the cost of poaching are the (fixed) training costs $T\lambda^{*2}$ so that the overall difference in profits is

$$\Delta\pi = \Delta MR - T\lambda^{*2} = \frac{1}{(n+1)^2 \beta}\left(\underbrace{2(\alpha - 1)\lambda^* + \lambda^{*2}(1 - (n+1)^2 T\beta)}_{z_1}\right). \qquad \text{(B.12)}$$

Inserting λ^* from equation (B.6) with $w^* = 0$ gives $\lambda^* = n(\alpha - 1)/((n+1)^2 T\beta - n)$, and it is straightforward to show that

$$z_1 < 0 \Leftrightarrow T\beta > \frac{n}{(n+1)^2(2-n)}$$

is true for any T, β if $n > 2$. Thus, if markets are small and firms do not engage in protective wages, separation is more attractive than clustering. Observe that here

$$\frac{\partial z_1}{\partial^2 \alpha} = -2n \frac{(n-2)(n+1)^2 T\beta + n}{((n+1)^2 T\beta - n)^2} < 0$$

and

$$\frac{\partial z_1}{\partial n} = -2 \frac{(\alpha - 1)^2 T\beta(n+1)((2n-1)(n+1)^2 T\beta - n^3)}{((n+1)^2 T\beta - n)^3} > 0$$

so that the disadvantage of clustering accelerates with market size but declines with the number of firms.

(ii) Now consider $\underline{\alpha} < \alpha \leq \overline{\alpha}$ so that $w^* > 0$ which lowers λ^*, c.p. Repeating the exercise from above one gets

$$\Delta\pi = \frac{1}{(n+1)^2 \beta}\left(\underbrace{2(\alpha-1)\lambda^* + \lambda^{*2}(1-(n+1)^2 T\beta) - (n+1)^2 \beta w^*}_{z_2}\right). \qquad \text{(B.13)}$$

Inserting the expression for λ^* from (B.6) and w^* from (B.7) and rearranging shows that, as was in the case of duopoly, $z_2 = k\alpha^2 + l\alpha + m$ with k, l, m being lengthy polynomials containing P_4, P_5, P_6 from equation (B.8) and that $k > 0$ so that z_2 is convex in α. Note that z_1 and z_2 intersect at $\alpha = \underline{\alpha}$ so that $z_2(\underline{\alpha}) < 0$, too. Instead of showing that the second root of z_2 is always greater than $\overline{a}$, the following shows that the global minimum is reached with an α always greater than $\overline{a}$. Since that root of z_2 must be greater than the minimum, it is thereby shown that the difference in profits cannot break even with $\alpha < \overline{\alpha}$. Unfortunately, neither the expression for the minimum of z_2 nor that for the difference between it and $\overline{\alpha}$ can be factorised in a way that an analytical approach is possible (the expression for the root is even more cumbersome). The difference reads

$$\alpha_0 - \overline{\alpha} = \frac{T^4\beta^4 d_1 - T^3\beta^3 d_2 + T^2\beta^2 d_3 - T\beta d_4 + n^7(n-1)(n^2-n-1)}{(n-1)\left((n+1)^2 T\beta - n^2\right)\left(T^2\beta^2 d_5 - T\beta d_6 + n^2(2n^2-1)\right)} \qquad \text{(B.14)}$$

where

$$\begin{aligned}
d_1 &= (n^4 - 2n^3 + 2n^2 - 4n + 2)(n+1)^8 \\
d_2 &= (2n^6 - 8n^4 + 7n^3 - 11n^2 + 8n - 1)(n+1)^6 \\
d_3 &= n^8 + 4n^7 - 10n^6 - 3n^5 + 11n^4 - 17n^3 + 15n^2 - 5n + 1)(n+1)^4 \\
d_4 &= n^3(2n^6 - 10n^4 + 9n^3 - 4n^2 + n + 1)(n+1)^2 \\
d_5 &= (2n-1)(n+1)^4 \\
d_6 &= (2n-1)(n^2 + 2n - 1)(n+1)^2.
\end{aligned}$$

Calculations show that it is increasing in T, β and n and that it is always positive. Thus the global minimum and hence the root of z_2 is always at a market size that involves full poaching (and a continuum of wage equilibria), and the difference in profits is always negative for a market size smaller than $\bar{\alpha}$. Hence with an interior solution for poaching and wages, firms prefer separation.

(iii) Suppose $\alpha \geq \bar{\alpha}$. Now one has $\lambda^* = 1$, and each wage level $w_i^* \in [0, \underline{w}]$ is an equilibrium in the wage-setting subgame. As the equilibrium is no longer symmetric and unique, denote by w_{-i}^* the average wage that a firm must pay in order to poach workers from its rivals. Then

$$z_2(w_{-i}^*) > 0 \Leftrightarrow w_{-i}^* < \frac{2\alpha - 1}{(n+1)^2 \beta} - T = \tilde{w} \qquad \text{(B.15)}$$

so that for a single firm clustering is profitable only if the average wage level of all other firms is not too high, i.e. $w_{-i}^* \in [0, \tilde{w}]$. Agglomeration (of all firms) is an equilibrium if all firms find colocation worthwhile which requires the expression (B.15) to hold for all firms. This in turn means that the average wage of the whole industry must be below $\tilde{w}$. ◊

C Appendix to chapter 4

C.1 Proof of Proposition 4.1

Define by $\Delta MG = MG_j - MG_i$ the difference between the advantage of clustering of the small firm and the large one whereby $MG = \pi^{cluster} - \pi^{sep}$ is the gain in profits from clustering vs. separating. It is be shown that $\left.\frac{\partial \Delta MG}{\partial \bar{c}_j}\right|_{\bar{c}_j = 1} < 0$ and that MG is concave with $\bar{c}_j = 1$ being the only root with a strictly interior solution so that in this model the larger firm indeed has a greater incentive to cluster.

Using the best-responses from equations (3.3), (3.6) and (3.9) the subgame equilibria with colocation read

$$
\begin{aligned}
q_i^* &= \tfrac{1}{3\beta}(\alpha + \overline{c}_j + 2\lambda_i - \lambda_j - 2) \\
q_j^* &= \tfrac{1}{3\beta}(\alpha + 1 + 2\lambda_j - \lambda_i - 2\overline{c}_j) \\
\lambda_i^* &= \frac{-\beta(27T\beta - 12)w_j + 6\beta w_i + 12T\beta(\alpha + \overline{c}_j - 2) - 8(\alpha - 1)}{N_\lambda} \\
\lambda_j^* &= \frac{-\beta(27T\beta - 12)w_i + 6\beta w_j + 12T\beta(\alpha + 1) - \overline{c}_j(24T\beta - 8) - 8\alpha}{N_\lambda} \\
w_i^* &= \frac{k\alpha + 9(-486 \,|\, 963 \,|\, 636 \,|\, \frac{496}{3} \,|\, -\frac{128}{9})\overline{c}_j - 3(9 \,|\, -4)(162 \,|\, -891 \,|\, 558 \,|\, -132 \,|\, \frac{32}{3})}{N_w} \qquad \text{(C.1)} \\
w_j^* &= \frac{k\alpha - 12T\beta(27 \,|\, -18 \,|\, 2)\overline{c}_j - 9T\beta(3 \,|\, -1)(486 \,|\, -783 \,|\, 360 \,|\, -40)}{N_w} \\
&\quad N_\lambda = 2(9 \,|\, -2)(3 \,|\, -2) \\
&\quad k = (54 \,|\, -63 \,|\, 16)(81 \,|\, -60 \,|\, 8) \\
&\quad N_w = \tfrac{3}{2}\beta(54 \,|\, -63 \,|\, 16)(162 \,|\, -117 \,|\, 16)
\end{aligned}
$$

where $(\cdot \,|\, \cdot \,|\, \ldots)$ is short hand for $(T\beta)^q + (T\beta)^{q-1} + \ldots + (T\beta)^0$.

Assumption C.1. *Assume that the poaching and the wage-setting subgame equilibria are interior solutions, i.e.* $\lambda_i^*, \lambda_j^* \in]0,1[$ *and* $w_i^*, w_j^* > 0$. *More precisely, assume that the following conditions hold:*

$$
\begin{aligned}
\overline{c}_j < c_1 &= \tfrac{-\alpha(54|-63|16)+(486|-351|0|16)}{(216|-144|16)} && (\lambda_i^* < 1) \\
\overline{c}_j < c_2 &= \alpha\tfrac{(54|-63|16)}{(270|-207|32)} + \tfrac{(4374|-7047|4320|-1188|128)}{(9|-4)(270|-207|32)} && (\lambda_j^* > 0) \\
\overline{c}_j < c_5 &= \tfrac{\alpha(81|-60|8)(54|-63|16)-(9|-4)(1458|-2673|1674|-396|32)}{(4374|-8667|5724|-1488|128)} && (w_i^* > 0) \qquad \text{(C.2)} \\
T\beta &\gtrapprox 0.936 && \\
\alpha &< \overline{\alpha}^{int} = 9T\beta && (c_1 > 1) \\
\alpha &> \underline{\alpha}^{int} = 3T\beta\tfrac{(81|-63|8)}{(81|-60|8)} && (c_5 > 1)
\end{aligned}
$$

Then the effect of a variation of $\overline{c}_j$ on ΔMG can be written as the sum of three components,

$$
\frac{\partial \Delta MG}{\partial \overline{c}_j} = \frac{\partial \Delta MG^{wages}}{\partial \overline{c}_j} + \frac{\partial \Delta MG^{revenue}}{\partial \overline{c}_j} + \frac{\partial \Delta MG^{poaching}}{\partial \overline{c}_j}
$$

each of which shall be considered separately. The point of departure is the symmetric case and consequently each term will be evaluated for $\overline{c}_j = 1$.

a) A first impact on profits comes from the effect of the rival's poaching on one's own wage bill,

$$\frac{\partial MG_j^{poaching}}{\partial \overline{c}_j} = w_j \left(\underbrace{\frac{\partial \lambda_i}{\partial \overline{c}_j}}_{\substack{\text{larger incentive} \\ \text{for cost} \\ \text{reduction} \\ \text{as } q_i \text{ rises}}} + \underbrace{\frac{\partial \lambda_i}{\partial w_i} \frac{\partial w_i}{\partial \overline{c}_j}}_{\substack{\text{reaction of } i \text{ to} \\ j\text{'s increase of} \\ \text{poaching due to} \\ \text{lower eq. wages} \\ \text{(strat. substitutes)}}} \right) > 0$$

$$\frac{\partial MG_i^{poaching}}{\partial \overline{c}_j} = w_i \left(\underbrace{\frac{\partial \lambda_j}{\partial \overline{c}_j}}_{\substack{\text{lower incentive} \\ \text{for cost} \\ \text{reduction as} \\ q_j \text{ decreases}}} + \underbrace{\frac{\partial \lambda_j}{\partial w_j} \frac{\partial w_j}{\partial \overline{c}_j}}_{\substack{\text{reaction of } j \text{ to} \\ i\text{'s increase of} \\ \text{poaching due} \\ \text{to lower wages}}} \right) < 0. \tag{C.3}$$

It is positive, implying a lower wage bill, for firm *j* and negative for firm *i* because firm *i* (*j*) reacts by poaching more (less) workers. The following effects are at work. With higher cost, firm *j* reduces poaching (best response), because the marginal benefit from poaching, i.e. the cost reduction per unit times output, pertains to fewer output in equilibrium. At the same time firm *i* increases poaching (best response) because it raises output as a reaction to firm *j*'s decrease which makes poaching more worthwhile. Since own cost have a stronger impact on equilibrium output than the rival's cost, *j*'s best poaching response moves farther (inwards) than *i*'s response moves outwards so that in equilibrium firm *j* poaches less, $\partial \lambda_j / \partial \overline{c}_j < 0$, while firm *i* poaches more, $\partial \lambda_i / \partial \overline{c}_j < 0$.

In the wage-setting decision of firm *j* higher costs reduce the advantage of a less aggressive rival (in terms of poaching and output) but also decrease the disadvantage from the higher wage bill as *i* is induced to poach away more workers. The opposite is true for firm *i*. However, both best-response functions move inwards with both equilibrium wages decreasing.

Further, It can be shown that

$$\frac{\partial \lambda_i}{\partial \overline{c}_j} + \frac{\partial \lambda_i}{\partial w_i} \frac{\partial w_i}{\partial \overline{c}_j} > 0$$

which means that for firm *i* the increased incentive for cost reduction outweighs the softening effect from lower poaching by *j*. So firm *i* reacts by increasing poaching.

b) Second, there is an effect from the rival's adjustment of its wages. One has

$$\frac{\partial MG_j^{wages}}{\partial \overline{c}_j} = -\frac{\partial w_i}{\partial \overline{c}_j}\lambda_j > 0$$
$$\frac{\partial MG_i^{wages}}{\partial \overline{c}_j} = -\frac{\partial w_j}{\partial \overline{c}_j}\lambda_i > 0$$

which implies for both firms an advantage from reduced wages for a given level of poaching. This advantage is even greater for firm j than for firm i, if $(27\,|\,-36\,|\,8) > 0 \Leftrightarrow T\beta >\approx 1.05$.

c) Finally there is an effect on marginal revenue because the rival adjusts its quantity due to the change in wages and poaching. For firm j the impact also includes the direct effect of higher production cost and reads

$$\frac{\partial MG_j^{revenue}}{\partial \overline{c}_j} = \underbrace{\frac{\partial p}{\partial q_i}}_{-}\left(\underbrace{\frac{\partial q_i}{\partial \overline{c}_j}}_{\substack{+\\ i\text{'s reaction}\\ \text{to lower}\\ q_j}} + \underbrace{\frac{\partial q_i}{\partial \lambda_i}\left(\frac{\partial \lambda_i}{\partial \overline{c}_j} + \frac{\partial \lambda_i}{\partial w_i}\frac{\partial w_i}{\partial \overline{c}_j}\right)}_{\substack{+\\ \text{firm } i \text{ increases}\\ \text{poaching in}\\ \text{equilibrium}}}\right)q_j^* - \underbrace{q_j^*}_{\substack{+\\ \text{direct}\\ \text{increase}\\ \text{in marg.}\\ \text{cost}}} - \underbrace{\left(\frac{\partial p}{\partial q_i}\frac{\partial q_i}{\partial \overline{c}_j}\overline{q}_j - \overline{q}_j\right)}_{\substack{-\\ \text{losses due to lower}\\ \text{price and higher}\\ \text{marginal cost when}\\ \text{separating}}}. \tag{C.4}$$

For firm i it is

$$\frac{\partial MG_i^{revenue}}{\partial \overline{c}_j} = \underbrace{\frac{\partial p}{\partial q_j}}_{-}\left(\underbrace{\frac{\partial q_j}{\partial \overline{c}_j}}_{\substack{-\\ j\text{'s direct}\\ \text{reduction}\\ \text{of quantity}\\ \text{due to}\\ \text{higher cost}}} + \underbrace{\frac{\partial q_j}{\partial \lambda_j}\left(\frac{\partial \lambda_j}{\partial \overline{c}_j} + \frac{\partial \lambda_j}{\partial w_j}\frac{\partial w_j}{\partial \overline{c}_j}\right)}_{\substack{-\\ \text{firm } j \text{ decreases}\\ \text{poaching in}\\ \text{equilibrium}}}\right)q_i^* - \underbrace{\left(\frac{\partial p}{\partial q_j}\frac{\partial q_j}{\partial \overline{c}_j}\overline{q}_i\right)}_{\substack{+\\ \text{gain from higher}\\ \text{price and lower}\\ \text{cost of } j \text{ when}\\ \text{separating}}}. \tag{C.5}$$

Note that $q^* > \overline{q}$ because both firms have strictly lower production cost when clustering (assuming an interior symmetric equilibrium) and hence produce more than in isolation. Comparing equations (C.4) and (C.5) piecewise it follows from visual inspection that

$$\underbrace{\frac{\partial p}{\partial q_i}}_{-}(\underbrace{\frac{\partial q_i}{\partial \lambda_i}}_{+}\underbrace{(\frac{\partial \lambda_i}{\partial \overline{c}_j}+\frac{\partial \lambda_i}{\partial w_i}\frac{\partial w_i}{\partial \overline{c}_j})}_{+})q_j^* - \underbrace{\frac{\partial p}{\partial q_j}}_{-}(\underbrace{\frac{\partial q_j}{\partial \lambda_j}}_{+}(\underbrace{\frac{\partial \lambda_j}{\partial \overline{c}_j}}_{-}+\underbrace{\frac{\partial \lambda_j}{\partial w_j}\frac{\partial w_j}{\partial \overline{c}_j}}_{-}))q_i^* < 0$$

$$-q_j^* - \left(-\overline{q}_j\right) < 0$$

$$\underbrace{\frac{\partial p}{\partial q_i}}_{-}\underbrace{\frac{\partial q_i}{\partial \overline{c}_j}}_{+}\left(q_j^* - \overline{q}_j\right) - \underbrace{\frac{\partial p}{\partial q_j}}_{-}\underbrace{\frac{\partial q_j}{\partial \overline{c}_j}}_{-}\left(q_i^* - \overline{q}_i\right) < 0$$

so that

$$\frac{\partial MG_j^{revenue}}{\partial \overline{c}_j} - \frac{\partial MG_i^{revenue}}{\partial \overline{c}_j} < 0 \tag{C.6}$$

which means that in terms of market revenue the larger firm, i, benefits from j's reduction in output and the induced increase in the price while firm j looses. The "standard" effect of larger costs that would happen in isolation is amplified by the fact that firm j reduces output further due to reduced poaching while firm i increases its output due to more poaching.

In sum, the bigger firm unambiguously benefits more from clustering than the small one in terms of revenue. It loses with respect to the relative effect of poaching on the wage bill and the relative effect of wages is ambiguous.

Nevertheless the partial effects add together to a negative one:

$$\begin{aligned}\frac{\partial \Delta MG}{\partial \overline{c}_j} = \frac{\partial \Delta MG}{\partial \overline{c}_j} &= \frac{\partial \Delta MG^{wages}}{\partial \overline{c}_j} + \frac{\partial \Delta MG^{revenue}}{\partial \overline{c}_j} + \frac{\partial \Delta MG^{poaching}}{\partial \overline{c}_j} \\ &= -\frac{2}{3}\frac{\left(972\,|-1917\,|1320\,|-368\,|\,\tfrac{304}{9}\right)\alpha + \left(243\,|-54\,|-228\,|120\,|-\tfrac{128}{9}\right)}{(18\,|-13\,|\,\tfrac{16}{9})(6\,|-7\,|\,\tfrac{16}{9})} \\ &< 0\end{aligned} \tag{C.7}$$

is decreasing in market size, α, and negative for all $\alpha > \underline{\alpha}^{int}$. Hence $\partial \Delta MG / \partial \overline{c}_j$ is negative for the symmetric case, $\overline{c}_j = 1$, so that a marginal increase in $\overline{c}_j$, i.e. a slight deviation from symmetry implies a stronger incentive to cluster for the large firm.

In general, on has

$$\Delta MG(\overline{c}_j) = -\tfrac{1}{3}(\overline{c}_j - 1)\left[\frac{3(9\,|\,{-4})(27\,|\,{-27}\,|\,4)(\overline{c}_j - 2\alpha)}{\beta(162\,|\,{-117}\,|\,16)(54\,|\,{-63}\,|\,16)} + \frac{(21870\,|\,{-34749}\,|\,18603\,|\,{-4032}\,|\,304)}{\beta(162\,|\,{-117}\,|\,16)(54\,|\,{-63}\,|\,16)}\right] \tag{C.8}$$

which is concave in $\overline{c}_j$ and there exists another root at

$$c_0 = 2\alpha + \frac{9(-810\,|\,1287\,|\,{-689}\,|\,\frac{448}{3}\,|\,{-\frac{304}{27}})}{(9\,|\,{-4})(27\,|\,{-27}\,|\,4)} \tag{C.9}$$

If the denominator is positive it is increasing in α and

$$c_0(\alpha) > 1 \Leftrightarrow \alpha > \frac{(10935\,|\,{-17010}\,|\,8775\,|\,{-1800}\,|\,128)}{3(9\,|\,{-4})(27\,|\,{-27}\,|\,4)} > \overline{\alpha}^{int} \tag{C.10}$$

so that any root right to $\overline{c}_j = 1$ implies a corner solution. If the denominator is negative this implies market size to be negative which cannot be the case. Thus $\overline{c}_j = 1$ is the only root of ΔMG with an interior solution. It follows that the large firm always likes agglomeration better than the small one. ◊

C.2 Proof of Proposition 4.2

a) A large firm prefers to cluster with an asymmetric, i.e. smaller rival. Consider the difference between i's profits when clustering with a symmetric rival (with production cost $\overline{c} = 1$) and its profits when clustering with asymmetric rival ($\overline{c}_i = 1, \overline{c}_j > 1$)

$$\Delta\pi_i(\overline{c}_j) = \pi_i^{asym}(\overline{c}_j) - \pi_i^{sym} = \frac{k\overline{c}_j + l\alpha + m}{N}$$

$$k = 729(9\,|\,{-4})(6804\,|\,{-17172}\,|\,17165\,|\,{-\tfrac{25916}{3}}\,|\,\tfrac{61856}{27}\,|\,{-\tfrac{24448}{81}}\,|\,\tfrac{11264}{729})$$
$$l = 2\cdot 729(1296\,|\,{-3438}\,|\,3611\,|\,{-\tfrac{17176}{81}}\,|\,\tfrac{14320}{27}\,|\,{-\tfrac{17696}{243}}\,|\,\tfrac{2816}{729})$$
$$m = -19683(1944\,|\,{-6516}\,|\,9546\,|\,{-\tfrac{23825}{3}}\,|\,\tfrac{109664}{27}\,|\,{-\tfrac{104528}{81}}\,|\,\tfrac{178688}{729}\,|\,{-\tfrac{54784}{2187}}\,|\,\tfrac{20480}{19683})$$
$$N = \beta(162\,|\,{-117}\,|\,16)^2(54\,|\,{-63}\,|\,16)^2$$

which is convex with roots $c = 1$ and $c = c_0(\alpha)$. It can be shown that $\partial c_0(\alpha)/\partial\alpha < 0$ and $c_0(\alpha = \underline{\alpha}^{int}) < 0$ so that for all $\alpha, \overline{c}_j$ fulfilling (C.2) on has $\Delta\pi_i > 0$ which means that a large firm prefers to cluster with a smaller firm.

b) A small firm prefers to cluster with a symmetric rival. First note that for the case of the symmetric duopoly with production cost $\overline{c} > 1$ another necessary condition for a strict interior solution is $\overline{c} < c_5^{sym} = \alpha - \frac{(3|-2)(9|-2)^2}{(81|-60|8)}$. Similarly to (a), the difference of j's profits is

$$\Delta\pi_j(\overline{c}_j) = \pi_j^{asym}(\overline{c}_j) - \pi_j^{sym}(\overline{c}_j) = \frac{k\overline{c}_j + l\alpha + m}{N}$$

$$k = -2187(9|-2)(1944|-5940|7602|-\tfrac{15857}{3}|\tfrac{19426}{9}|-\tfrac{41996}{81}|\tfrac{8192}{2187})$$
$$l = 2\cdot 243(3|-2)(324|-684|539|-\tfrac{1774}{9}|\tfrac{8100}{9}|-\tfrac{17696}{243}|\tfrac{512}{243})$$
$$m = 2\cdot 19683(1944|-6408|8880|-\tfrac{20195}{3}|\tfrac{82112}{27}|-\tfrac{67620}{81}|\tfrac{98636}{729}|-\tfrac{8576}{729}|\tfrac{8192}{19683})$$
$$N = \beta(162|-117|16)^2(54|-63|16)^2.$$

It can be shown that $\overline{c}_j < c_5^{sym}$ of the symmetric case is the binding condition for $\alpha < \alpha'$ and that $\overline{c}_j < c_5$ from the assumptions in (C.2) is the binding condition for $\alpha > \alpha'$, $\underline{\alpha}^{int} < \alpha' < \overline{\alpha}^{int}$. In any case $\Delta\pi_i(\overline{c}_j)$ is convex and has a root $c_0(\alpha) > 1$ which can be shown to be larger than c_1 and c_5^{sym}. Hence $\Delta\pi_i(\overline{c}_j)$ is negative for all $\alpha, \overline{c}_j$ satisfying the assumptions for an interior solution, and a small firm prefers to colocate with a symmetric rival. ◊

C.3 Labour market pooling and firm size in a Hotelling framework

Suppose there are two firms which must choose their location on a line segment of length 1. Thereafter nature decides for each firm whether it goes bankrupt or survives (probability α, think, for example, of firms undertaking product R&D). Assume that Bertrand competition takes place when both firms survive (i.e. both firms successfully complete their R&D) and that a monopolist would earn exogenous monopoly profits π_M. Assume further that workers share profits with firms (for example because of negotiations by strong unions) and in addition demand a risk premium depending on the distance between firms. Let σ reflect how risk-averse workers are and let c denote the labour requirement for the production of one unit of goods. With quadratic transportation costs workers' compensation (e.g. with firm i) reads

$$\begin{aligned} wages &= \tfrac{1}{2} p_i q_i + RP_i \\ RP_i &= q_i c\sigma t\left(x_j - x_i\right)^2 \end{aligned} \tag{C.11}$$

and firm i's expected profits are given by

$$E\pi_i = \alpha^2 q_i\left(\tfrac{1}{2} p_i - c\sigma t\left(x_j - x_i\right)^2\right) + \alpha\left(1-\alpha\right)\pi_M. \tag{C.12}$$

There is a two-stage game in which firms first choose their location by balancing centrifugal forces (Bertrand competition) and centripetal forces (workers' risk premium). Thereafter they set prices (if they did not go bankrupt). Assume that labour supply is infinite and completely inelastic.

Surprisingly, d'Aspremont et al.'s (1979) principle of maximum (spatial) differentiation is at work in this set-up, too, although there is a force towards colocation. Taking into account that equilibrium prices are

$$\begin{aligned} p_i^*\left(x_i, x_j\right) &= \tfrac{1}{3} t\left(x_j - x_i\right)\left(2 + 6c\sigma\left(x_j - x_i\right) + x_j + x_i\right) \\ p_j^*\left(x_i, x_j\right) &= \tfrac{1}{3} t\left(x_j - x_i\right)\left(4 + 6c\sigma\left(x_j - x_i\right) - x_j - x_i\right) \end{aligned} \tag{C.13}$$

one gets

$$\begin{aligned} \pi_i\left(x_i, x_j\right) &= \tfrac{1}{36}\left(x_j + x_i + 2\right)^2\left(x_j - x_i\right)t \\ \pi_j\left(x_i, x_j\right) &= \tfrac{1}{36}\left(x_j + x_i - 4\right)^2\left(x_j - x_i\right)t \end{aligned} \tag{C.14}$$

and hence

$$\begin{aligned} \frac{\partial \pi_i\left(x_i, x_j\right)}{\partial x_i} &= \tfrac{1}{36} t\left(x_j + x_i + 2\right)\left(x_j - 3x_i - 2\right) < 0 \\ \frac{\partial \pi_j\left(x_i, x_j\right)}{\partial x_j} &= \tfrac{1}{36} t\left(x_j + x_i - 4\right)\left(3x_j - x_i - 4\right) > 0 \end{aligned} \tag{C.15}$$

so that firm i will always locate at $x_i^* = 0$ and firm j at $x_j^* = 1$ (maximum product differentiation).[55] Observe that in equation (C.14) profits depend neither on firm size (c) nor on the degree of risk-aversion (σ).

However, it is easy to show in a different framework (e.g. with two regions instead of a linear city or with an explicit labour supply function) that unit labour requirement, c, which is interpreted as firm size, determines firms' location decision and makes them locate close to each other, ceteris paribus.

C.4 Proofs of section 4.4

C.4.1 Proof of Lemma 4.1.

If $\Psi(\phi) = l_S \phi$ then setting $r(\phi^*) \overset{!}{=} 0$ from equation (4.11) yields

$$\phi^* = \Psi_S^{-1}\left(\frac{w_L}{w_S}\right) = \frac{w_L}{l_S w_S} \tag{C.16}$$

and it is easy to see that $\partial r(\phi^*)/\partial\phi > 0$ so that all workers right of ϕ^* prefer to join a small firm.

Large firms are randomly matched with a worker from the interval $[0, \phi^*]$ and small firms with a worker from the interval $[\phi^*, 1]$. Hence the large and small firms' expected creativity is

$$E\phi_L = \frac{\int_0^{\phi^*} x\,dx}{\int_0^{\phi^*} 1\,dx} = \tfrac{1}{2}\phi^*, \quad E\phi_S = \frac{\int_{\phi^*}^{1} x\,dx}{\int_{\phi^*}^{1} 1\,dx} = \tfrac{1}{2}(1+\phi^*), \tag{C.17}$$

respectively.

[55] The same line of argument is used in Varian (1999) p. 620.

C.4.2 Proof of Lemma 4.2.

An interior equilibrium is a solution $w_S^*, w_L^* > 0$ with $0 < E\phi_S^*, E\phi_L^* \leq 1$ of the maximisation program in (4.12):[56]

$$\begin{aligned} \frac{\partial E\pi_S(w_S)}{\partial w_S} &= \frac{1}{2w_S^3}(w_L w_S(l_S - 1) + w_L^2 - w_S^3 l_S) \overset{!}{=} 0 \\ \frac{\partial E\pi_L(w_L)}{\partial w_L} &= \frac{1}{2w_S^2 l_S^2}(l_S w_S(l_L - 2l_S w_S) - l_L^2 w_L)) \overset{!}{=} 0 \end{aligned} \quad \text{(C.18)}$$

Solving these equations for all four possible cases of the location decision gives the result stated. Observe that the second-order condition is satisfied since

$$\begin{aligned} \frac{\partial E\pi_S(w_S)}{\partial w_S} &= -\frac{w_L}{2w_S^4}(3w_L + 2w_S(l_S - 1)) < 0 \\ \frac{\partial E\pi_L(w_L)}{\partial w_L} &= -\frac{l_L^2}{2w_S^2 l_S^2} < 0. \end{aligned} \quad \text{(C.19)}$$

C.4.3 Proof of Proposition 4.3.

Define by

$$\begin{aligned} \Delta\pi_S &= \pi_S^{cluster} - \pi_S^{sep} \\ \Delta\pi_L &= \pi_L^{cluster} - \pi_L^{sep} \end{aligned}$$

the incentive to colocate for the small and large firm respectively. Use the expression for wages and the indifferent worker in equilibrium as given by equation (4.13). $\Delta\pi > 0$ indicates that firms prefer colocation and $\Delta\pi < 0$ indicates that firms prefer to separate. Because of cumbersome expressions for the equilibrium terms there is no manageable analytic proof. Consider therefore the calculations shown in the following Tables and Figures. The parameter μ, which indicates the effectiveness of knowledge spillovers, is chosen to be of the range $[1, 1.4]$. A value of 1.4 means that firms' stock of knowledge increases by 40%. In light of the estimated effects of agglomeration on profits and innovation (see the discussion of the empirical literature in section 2.2) this appears to

[56] There always exists the corner solution $w_S^* = 1$, $w_L^* = 0$ in which the large firm does not produce at all and the small firm makes negative expected profits.

be already a high value. Higher values are certainly not realistic. NaN denotes a parameter constellation in which there is no interior equilibrium.

Figure C.1: Small firms' profits with colocation minus profits with separation (large firms do not cluster)

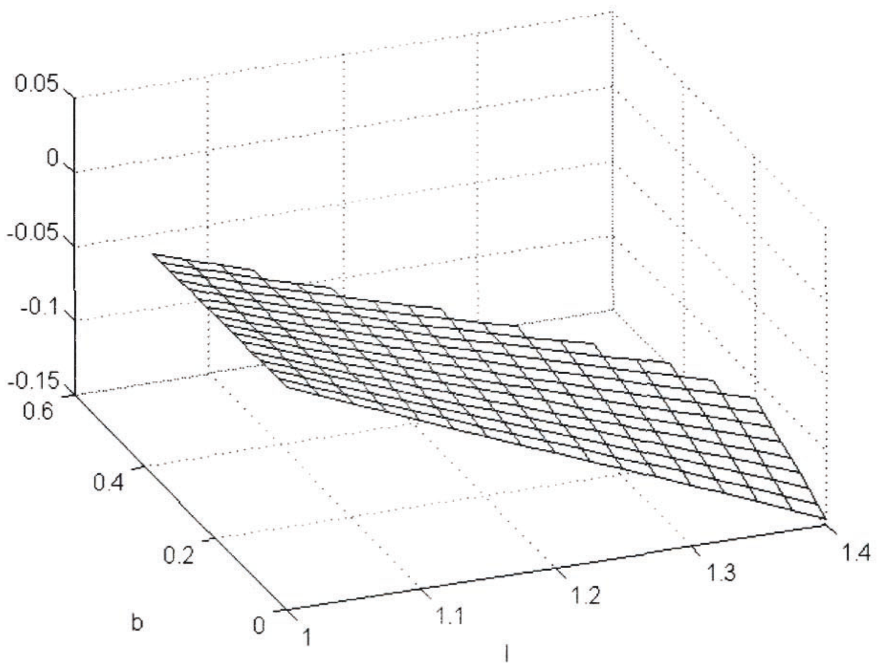

Table C.1: Small firms' profits with colocation minus profits with separation (large firms do not cluster)

	μ								
b	1	1.05	1.1	1.15	1.2	1.25	1.3	1.35	1.4
0.000	**0.000**	**-0.019**	**-0.037**	**-0.055**	**-0.073**	**-0.091**	**-0.109**	**-0.128**	**-0.147**
0.050	0.000	-0.018	-0.035	-0.052	-0.069	-0.086	-0.103	-0.120	-0.138
0.100	0.000	-0.017	-0.034	-0.050	-0.066	-0.081	-0.097	-0.113	-0.129
0.150	0.000	-0.016	-0.032	-0.047	-0.062	-0.077	-0.092	-0.106	-0.121
0.200	0.000	-0.016	-0.031	-0.046	-0.059	-0.073	-0.087	-0.100	-0.114
0.250	0.000	-0.016	-0.030	-0.044	-0.057	-0.070	-0.082	-0.094	NaN
0.300	0.000	-0.015	-0.029	-0.043	-0.055	-0.067	NaN	NaN	NaN
0.350	0.000	-0.015	-0.029	NaN	NaN	NaN	NaN	NaN	NaN
0.400	0.000	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
0.450	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

Figure C.2: Small firms' profits with colocation minus profits with separation (large firms cluster)

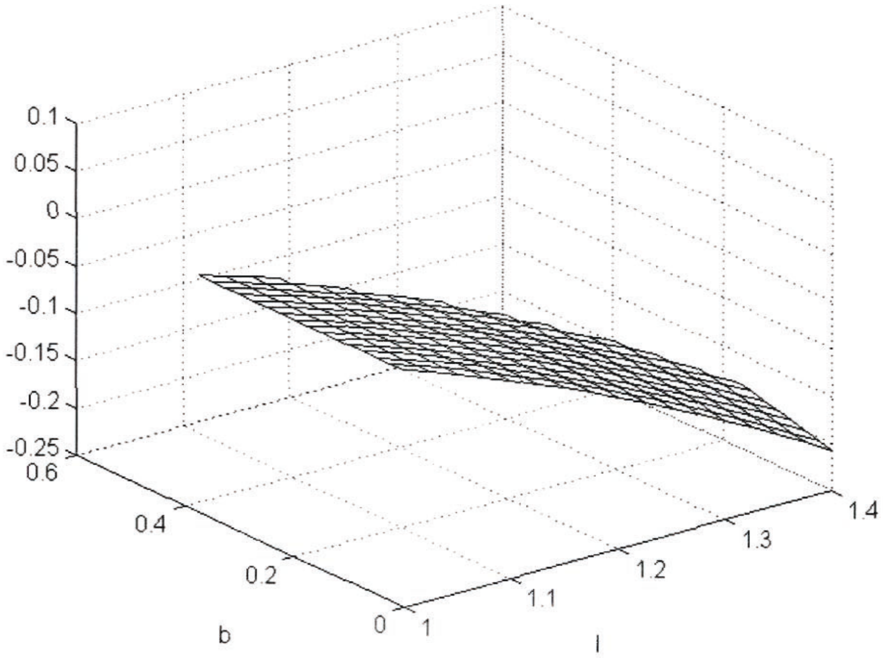

Table C.2: Small firms' profits with colocation minus profits with separation (large firms cluster)

	μ								
b	1	1.05	1.1	1.15	1.2	1.25	1.3	1.35	1.4
0.000	0.000	-0.020	-0.041	-0.065	-0.090	-0.117	-0.146	-0.176	-0.207
0.050	0.000	-0.019	-0.040	-0.062	-0.087	-0.113	-0.140	-0.169	-0.199
0.100	0.000	-0.018	-0.038	-0.060	-0.084	-0.109	-0.135	-0.163	-0.192
0.150	0.000	-0.018	-0.037	-0.058	-0.081	-0.105	-0.130	-0.157	-0.185
0.200	0.000	-0.017	-0.036	-0.057	-0.079	-0.102	-0.126	-0.152	NaN
0.250	0.000	-0.017	-0.035	-0.055	-0.077	-0.099	-0.123	NaN	NaN
0.300	0.000	-0.017	-0.035	-0.055	-0.076	-0.098	NaN	NaN	NaN
0.350	0.000	-0.017	-0.035	NaN	NaN	NaN	NaN	NaN	NaN
0.400	0.000	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
0.450	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

Figure C.3: Large firms' profits with colocation minus profits with separation (small firms do not cluster)

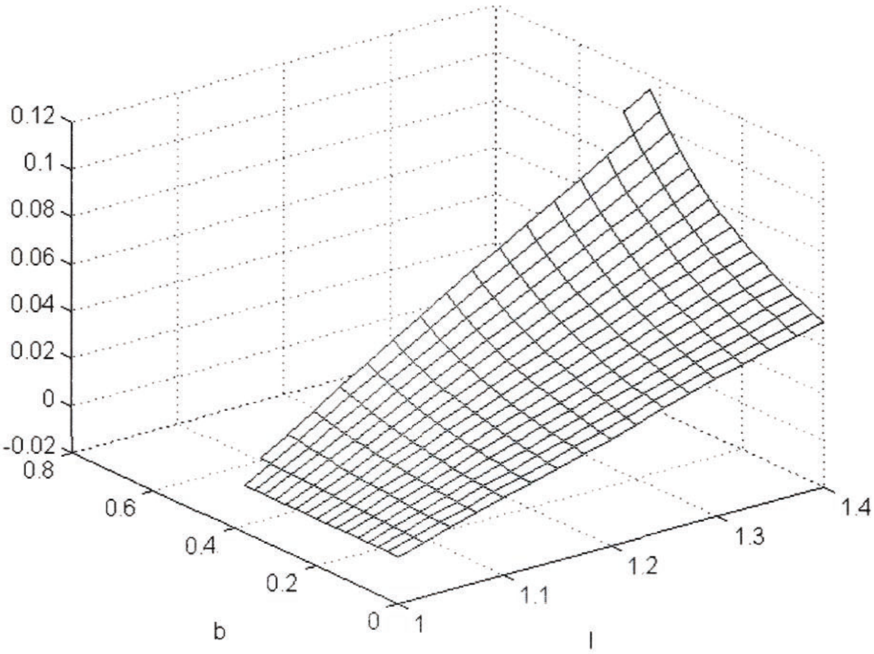

Table C.3: Large firms' profits with colocation minus profits with separation (small firms do not cluster)

	μ								
b	1.000	1.050	1.100	1.150	1.200	1.250	1.300	1.350	1.400
0.000	**0.000**	**0.006**	**0.013**	**0.019**	**0.025**	**0.032**	**0.038**	**0.044**	**0.050**
0.050	0.000	0.007	0.014	0.020	0.027	0.034	0.041	0.047	0.054
0.100	0.000	0.007	0.015	0.022	0.030	0.037	0.044	0.051	0.058
0.150	0.000	0.008	0.016	0.024	0.032	0.040	0.048	0.056	0.063
0.200	0.000	0.009	0.018	0.026	0.035	0.044	0.052	0.061	0.069
0.250	0.000	0.010	0.019	0.029	0.039	0.048	0.058	0.067	0.076
0.300	0.000	0.011	0.022	0.032	0.043	0.054	0.064	0.074	0.084
0.350	0.000	0.012	0.024	0.036	0.048	0.060	0.072	0.083	0.094
0.400	0.000	0.014	0.027	0.041	0.055	0.068	0.081	0.094	0.107
0.450	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

Figure C.4: Large firms' profits with colocation minus profits with separation (small firms cluster)

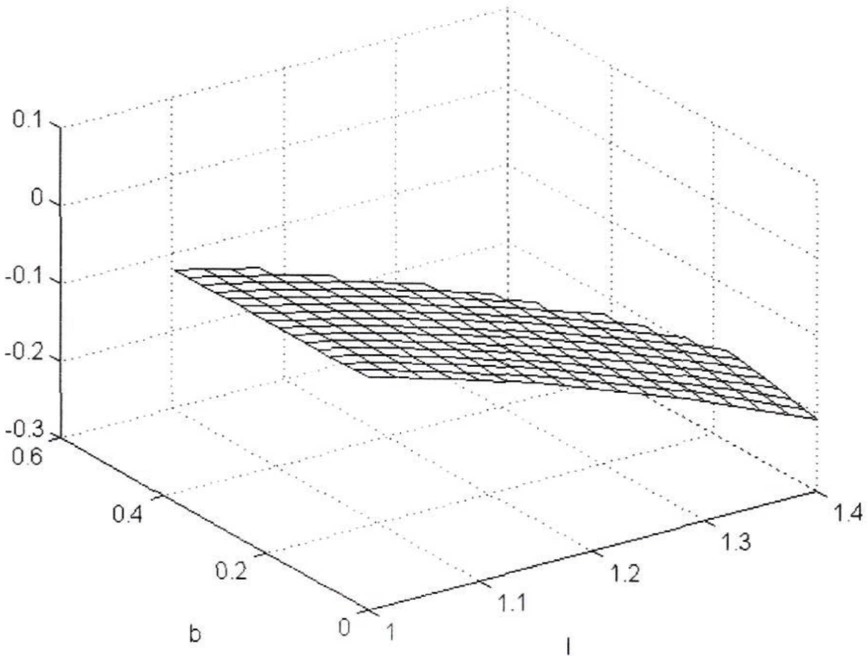

Table C.4: Large firms' profits with colocation minus profits with separation (small firms cluster)

	μ								
b	1	1.05	1.1	1.15	1.2	1.25	1.3	1.35	1.4
0.000	NaN	0.006	0.011	0.015	0.018	0.021	0.024	0.026	0.028
0.050	NaN	0.006	0.012	0.016	0.020	0.023	0.026	0.028	0.030
0.100	NaN	0.007	0.012	0.017	0.021	0.025	0.028	0.030	0.033
0.150	NaN	0.007	0.014	0.019	0.023	0.027	0.030	0.033	0.035
0.200	NaN	0.008	0.015	0.021	0.025	0.030	0.033	0.036	NaN
0.250	NaN	0.009	0.016	0.023	0.028	0.033	0.037	NaN	NaN
0.300	NaN	0.010	0.018	0.025	0.031	0.036	NaN	NaN	NaN
0.350	NaN	0.011	0.020	NaN	NaN	NaN	NaN	NaN	NaN
0.400	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
0.450	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

Table C.5: Equilibrium expected creativity of small firms (large firms cluster)

	l								
b	1	1.05	1.1	1.15	1.2	1.25	1.3	1.35	1.4
0.000	0.750	0.771	0.792	0.814	0.836	0.858	0.880	0.903	0.926
0.050	0.768	0.788	0.809	0.831	0.852	0.874	0.896	0.918	0.941
0.100	0.788	0.808	0.829	0.850	0.871	0.892	0.914	0.936	0.958
0.150	0.811	0.831	0.851	0.871	0.892	0.913	0.935	0.956	0.978
0.200	0.838	0.857	0.876	0.896	0.917	0.938	0.958	0.980	NaN
0.250	0.869	0.887	0.906	0.926	0.946	0.966	0.986	NaN	NaN
0.300	0.905	0.923	0.941	0.960	0.979	0.999	NaN	NaN	NaN
0.350	0.948	0.965	0.983	NaN	NaN	NaN	NaN	NaN	NaN
0.400	1.000	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
0.450	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

Table C.6: Equilibrium expected creativity of large firms (small firms do not cluster)

	μ								
b	1	1.05	1.1	1.15	1.2	1.25	1.3	1.35	1.4
0.000	0.250	0.262	0.274	0.286	0.297	0.307	0.317	0.327	0.336
0.050	0.268	0.281	0.293	0.305	0.317	0.328	0.339	0.349	0.358
0.100	0.288	0.302	0.315	0.328	0.340	0.352	0.363	0.374	0.384
0.150	0.311	0.326	0.340	0.354	0.367	0.379	0.391	0.403	0.413
0.200	0.338	0.354	0.369	0.383	0.397	0.411	0.424	0.436	0.447
0.250	0.369	0.386	0.402	0.418	0.433	0.447	0.461	0.474	0.487
0.300	0.405	0.424	0.441	0.459	0.475	0.491	0.505	0.520	0.533
0.350	0.448	0.468	0.488	0.507	0.525	0.542	0.558	0.573	0.588
0.400	0.500	0.522	0.544	0.564	0.584	0.603	0.621	0.638	0.654
0.450	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

Ich versichere, daß ich diese Dissertation selbständig verfaßt habe. Bei der Erstellung der Arbeit habe ich mich ausschließlich der angegebenen Hilfsmittel bedient.
Die Dissertation ist nicht bereits Gegenstand eines erfolgreich abgeschlossenen Promotions- oder sonstigen Prüfungsverfahrens gewesen.

Köln, Mai 2006