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Labor Pooling in R&D Intensive Industries

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Labor Pooling in R&D Intensive Industries

Heiko Gerlach, Thomas Rønde, and Konrad Stahl

Zentrum für Europäische
Wirtschaftsforschung GmbH

Centre for European
Economic Research

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Non-technical Summary

Clusters play a central role in the spatial organization of some of the world's most dynamic and R&D intensive industries. Inspired by the exceptional performance of Silicon Valley and other leading high-tech clusters, local, regional and national governments have spent billions of dollars to promote the formation of similar clusters. Yet overall success rates were low, indicating that the forces behind these agglomeration processes are more subtle than thought of heretofore.

In this paper, we take a step forward by linking firms' R&D investment incentives to their local economic environment, and then analyze how this, in turn, affects firms' location decisions. The questions addressed are: is there a relationship between agglomeration and the R&D intensity chosen and the type of R&D projects undertaken? Does the industry wide R&D portfolio change with the degree of agglomeration? What are the consequences of all this on firms' incentives to agglomerate and on the welfare benefits from agglomeration?

Towards deriving answers to these questions, we extend Marshall's labor pooling argument by introducing stochastic demand shocks arising from firms' R&D decisions. We show that upon agglomeration, firms tend to invest more in R&D and to choose R&D projects of higher risk as compared to spatially separated firms. Most interestingly, ex-ante identical firms generically choose asymmetric R&D strategies to avoid joint success and thus to reduce labor market competition. This contributes to a higher variance of R&D efforts in agglomerations.

Turning to the welfare implications, our analysis shows that the agglomeration of firms is always the preferred industry outcome. The welfare superiority of a cluster relative to dispersed locations stems from two sources. First, successful innovations are implemented by more workers (a 'labor productivity effect'). Second, R&D programs are collectively better organized (an 'R&D portfolio effect'). The latter effect is the result of firms' endogenous choice of R&D strategy, and it represents a benefit of labor pooling that has not been discussed heretofore.

Finally, we test the central prediction of the theory regarding the variance of R&D expenditures of firms in agglomerations and of firms in separate locations using firm level panel data from R&D intensive industries in Germany.

Das Wichtigste in Kürze

Clusterbildung - d.h. die räumliche Konzentration von Unternehmen der gleichen Branche - ist oftmals ein zentrales Kennzeichen von Sektoren, die sich durch eine besonders hohe Dynamik und FuE-Intensität auszeichnen. Angeregt durch die außergewöhnliche Entwicklung der Elektronik- und Softwareindustrie im Silicon Valley sowie durch andere Hightech-Cluster, haben sowohl lokale und regionale als auch nationale Regierungen große Beträge zur Förderung der Herausbildung ähnlicher Cluster in ihren Regionen ausgegeben. Der Erfolg blieb jedoch weitgehend aus, was darauf hindeutet, dass die Kräfte, die hinter sektoralen Agglomerationsprozessen stehen, wohl komplexer sind als von vielen gedacht.

Die vorliegende Arbeit untersucht die Anreize für Unternehmen, in Forschung und Entwicklung (FuE) zu investieren in Abhängigkeit von ihrem lokalen Umfeld und analysiert wird, wie dadurch die Standortentscheidung von Unternehmen beeinflusst. Die Forschungsfragen lauten: Existiert eine Beziehung zwischen Clustern (d.h. der Agglomeration von Unternehmen der gleichen Branche innerhalb einer Region) und der FuE-Intensität sowie der Art der FuE-Tätigkeit von Unternehmen? Ändert sich das FuE-Portfolio eines Sektors mit dem Ausmaß der Clusterbildung? Welche Auswirkungen haben Cluster und die Art und Intensität der sektoralen FuE-Tätigkeit auf die Anreize für Unternehmen, sich in Clustern anzusiedeln and was sind die Wohlfahrtseffekte von sektoralen Agglomerationen?

Zur Beantwortung dieser Fragen erweitern wir das traditionelle Argument des Arbeitkräftepoolings von Marshall durch die Einführung von stochastischen Nachfrageshocks, die sich aus den FuE-Entscheidungen der Unternehmen ergeben. Wir zeigen, dass zusätzlich zum Arbeitkräftepooling-Effekt Unternehmen tendenziell mehr in FuE investieren und risikoträchtigere FuE-Projekte verfolgen als Unternehmen, die außerhalb von Agglomerationen angesiedelt sind. Unternehmen, die ex-ante identisch sind, wählen asymmetrische FuE-Strategien, um gemeinsamen Erfolg und damit direkten Wettbewerb im Arbeitsmarkt zu entgehen. Dadurch kommt es zu einer höheren Varianz der FuE-Aufwendungen in Agglomerationen.

Unsere Analyse zeigt, dass Clusterbildung das von den Unternehmen bevorzugte Ergebnis ist. Die höheren Wohlfahrtseffekte von Clustern im Vergleich zu einer zerstreuten Ansiedlung von Unternehmen rührt seinerseits aus Produktivitätseffekten, da Innovationen von mehr Arbeitskräften genutzt werden können, und andererseits einer besseren kollektiven Organisation der FuE-Aktivitäten in Form eines ausgewogeneren FuE-Portfolios. Zweitgenannter Effekte resultiert aus den endogenen Entscheidungen der Unternehmen über ihre FuE-Strategie und spiegelt einen Nutzen des Arbeitskräfte-Poolings wider, der in dieser Form in der Literatur noch nicht diskutiert wurde.

Eine der zentralen Aussagen des theoretischen Modells, nämlich die höhere Varianz der FuE-Aufwendungen von Unternehmen in Agglomerationen im Vergleich zu Unternehmen an isolierten Standorten, wird mit Hilfe von Paneldaten zu Unternehmen in forschungsintensiven Industrien in Deutschland getestet.

Labor Pooling in R&D Intensive Industries*

Heiko Gerlach
University of Auckland
h.gerlach@auckland.ac.nz

Thomas Rønde
Copenhagen Business School, CEPR, and ZEW
thr.ino@cbs.dk

Konrad Stahl
University of Mannheim, CEPR, CESifo, and ZEW
kos@econ.uni-mannheim.de

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Abstract

We investigate the interplay between firms' R&D decisions and labor market competition, and how this influences equilibrium location choices and welfare. Firms engage in risky R&D activities and thus create stochastic product and implied labor demand. Spatial agglomeration is more likely in situations where the innovation step is large and the probability for a firm to be the only innovator is high. When firms agglomerate, they tend to invest more in R&D compared to spatially dispersed firms. Agglomeration is welfare maximizing, because expected labor productivity is higher and firms choose a more efficient, diversified portfolio of R&D projects at the industry level. The latter aspect is ascertained by data from German firms in R&D intensive industries. (JEL: L13, O32, R12)

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1 Introduction

Clusters play a central role in the spatial organization of some of the world's most dynamic and R&D intensive industries. The best known example is Silicon Valley that during the nineties was home to 20 per cent of the world's 100 biggest electronics and software companies (*Business Week*, August 5, 1997). Other well-known examples are the biotech cluster in La Jolla (California), the neuroscience cluster in Oxford (UK) and the automotive industry cluster in the Stuttgart region (Germany). Audretsch and Feldman (1996) provide evidence showing that firms in R&D intensive industries more than other firms tend to cluster their innovative as well as their productive activities.

The success of some of these clusters has been remarkable. In spite of ups and downs in employment during the nineties of the last century, the employment growth rate in Silicon Valley outpaced with an impressive 15 per cent the U.S. national employment growth rate, and the mean income was 50 per cent higher than the national figure (Audretsch, 1998).

The exceptional performance of Silicon Valley and other leading high-tech clusters has promoted a worldwide interest in their replication. Billions of dollars were spent by local, regional and national governments to promote the formation of such high-tech clusters. Yet overall success rates were low, indicating that the forces behind these agglomeration processes are more subtle than thought of heretofore.

In this paper, we intend to take a step forward by linking firms' R&D investment incentives to their local economic environment and then analyze how this, in turn, affects firms' location decisions. To do so, we elaborate the labor pooling argument proposed first by Alfred Marshall in his *Principles* (1920) and formalized afterwards by Krugman (1991a). Our model unveils a new benefit of labor pooling and offers novel, empirically verifiable predictions. The central prediction, that the variance of firms' R&D efforts is larger in agglomerations, is shown to be consistent with data from German firms in R&D intensive industries.

We consider a simple setup where two firms supply to a competitive world market. Firms have access to a common technology that allows them to produce a basic quality, but undertake risky R&D to improve on their product quality. The R&D shocks translate into stochastic product, and therefore labor demands. Confronted with location decisions before the outcome of these shocks becomes known, the firms decide to either locate separately in small labor markets, or, followed by their labor pool, to jointly locate in a large labor market. Firms may prefer separate locations in spite of the smaller labor supply, in order to enjoy monopsony power in the labor markets and to avoid the competition for laborers that arises under agglomeration.

We first look at a situation where innovations are the result of an exogenous R&D process.

We show that agglomeration in a cluster only occurs if, after the realization of the R&D shocks, firms are likely to end up in an asymmetric situation where one of the firms pulls significantly ahead in the R&D race. If this outcome arises *ex-post*, the leading firm is able to enjoy the large labor supply at relatively low wages, because competition in the labor market from the lagging firm is weak. By contrast, if firms market products of similar qualities, most of their profits are dissipated by labor market competition. Labor pooling has thus two opposing effects on profits. It allows the leading firm to expand its production, which increases expected profits and constitutes the agglomerative force in our model. At the same time, competition in the labor market dilutes profits, which works against agglomeration.

We then endogenize firms' R&D investment and thereby, implicitly, the labor demand shocks. Interestingly, upon agglomeration, *ex-ante* identical firms generically choose asymmetric R&D strategies to avoid joint success and to reduce labor market competition. This contributes to a higher variance of R&D efforts in agglomerations.

The welfare analysis shows that within our framework agglomeration of firms is always the preferred industry outcome. The superiority of a cluster relative to dispersed locations in terms of welfare stems from two sources. Firstly, successful innovations are applied over a larger base of workers due to a deeper labor pool (a 'labor productivity effect'). Secondly, agglomeration in a cluster allows for a better organization of R&D programs within the industry (an 'R&D portfolio effect'). The latter effect is the result of firms' endogenous choice of R&D strategy, and it represents a benefit of labor pooling that has not been discussed heretofore. The intuition is that if the firms locate together in a cluster and both experience R&D success, one of the innovations represents wasteful duplication of R&D efforts. The asymmetric equilibrium strategies that reduce the likelihood of joint success increase thus the efficiency of the R&D portfolio at the industry level by reducing duplication. Since there are clear cut parameter regimes under which in equilibrium firms choose separate locations, there is too much locational separation relative to the welfare optimum.

In his Principles, Marshall (1920) argued that firms enjoy a number of benefits when locating in a cluster.[1] Firstly, the high demand for intermediate inputs allows upstream suppliers to achieve a higher degree of specialization, leading to a more efficient division of labor within the industry and lower prices due to decreasing marginal cost (Stigler, 1951; Krugman, 1991b). Secondly, firms inside a cluster can share information and knowledge which reflects itself as technology spillovers. There is ample empirical evidence suggesting that firms' productivity increases due to technology spillovers with increasing geographical proximity (Acs et al., 1994; Almeida and Kogut, 1999; Jaffe et al., 1993; summarized in

[1] See Duranton and Puga (2004) for an excellent survey of the microeconomics of clusters.

Audretsch and Feldman, 2004). Recently, a number of authors have analyzed spillover driven clustering from a theoretical perspective (Combes and Duranton, 2005; Fosfuri and Rønde, 2004; Saint-Paul, 2003).

Thirdly and finally, the concentration of firms attracts a 'deep' pool of laborers, which is the benefit from clustering we focus on in this paper. Marshall argued that firms have incentives to locate in the same region when they face imperfectly correlated stochastic labor demands. Firms blessed with high output and labor demand can draw workers at low cost from a large local labor market pool. Labor pooling thus provides firms with a more elastic labor supply and workers with more job security. Although labor pooling probably is the agglomeration benefit that has received the least attention in the literature, empirical work suggests that it plays an important role for firms' location decisions. Indeed, Rosenthal and Strange (2002) regress the Ellison-Glaeser index of spatial industry concentration (Ellison and Glaeser, 1997) on proxies for the three above mentioned agglomeration benefits and find that the evidence is strongest for the labor pooling argument. Dumais et al. (2002) reach a similar conclusion in their study of the dynamics of agglomeration processes.

Marshall's labor pooling argument was first formalized in a model by Krugman (1991a, Ch. 2 and App. B). He analyzed location equilibria in a model with two locations and n firms who produce under decreasing returns to scale and face exogenous firm-specific productivity shocks. The analysis shows that large clusters provide greater labor pooling benefits than smaller clusters, because the labor market is 'deeper'. The firms' individual labor demands affect the equilibrium wage less in a deep market, which allows the most productive firms to capture a larger share of the labor force. This results in higher profits and welfare, and provides a push towards full agglomeration by firms and workers. Apart from Krugman (1991a), Stahl and Walz (2001) is the only other formal model of labor pooling known to us. Stahl and Walz introduce both firm-specific and sector-specific (exogenous) shocks and analyze whether firms locate together with firms belonging to the same or to a different sector. There is also a small literature on firms' location decisions relative to localized labor markets. However, Topel (1986), Baumgardner (1988), or more recently Picard and Toulemonde (2000) all focus on issues different from ours, such as workers' migration incentives, the division of labor as changing with labor market size, and asymmetric agglomeration as the result of minimum wages, respectively.

The remainder of the paper is organized as follows: In Section 2, we present our baseline model of labor pooling with exogenous R&D strategies. At the end of this section, we relate in more detail our setup and results to Krugman's labor pooling model. In Section 3, we endogenize R&D investment decisions and derive and characterize the equilibria of the game. Section 4 contains our empirical analysis, in which, by combining German data from various sources, we show that indeed R&D expenditures of firms vary significantly more in agglomerations than under separation even after controlling for the most important confounding effects. We conclude by discussing implications of our analysis and possible extensions. All relevant proofs are relegated to the first Appendix.

2 A Simple Model of Labor Pooling

2.1 The Model Set-Up

There are two firms 1 and 2, and two locations. The firms produce with a one-to-one production function, so that L_i units of labor employed by firm i at wage w_i result in the identical output quantity y_i. With respect to their output, the firms are price takers in a world market. The price obtained depends on the quality of the product. For simplicity, we assume that the price p_i fetched by firm i is equal to the quality of its product q_i.[2] The firms' marginal production cost net of wages is normalized to zero, and fixed costs are sunk.

The firms are initially endowed with a technology to produce a good of quality v. They may benefit from the stochastic outcome of their R&D effort that for the moment is costless. If the R&D project is successful, the product's quality is increased to $v + \Delta$, with $\Delta > 0$. If it is unsuccessful, the firm has to produce the initial quality. In this section, we assume the simplest possible R&D process, with exogenous and independent success probability ρ for each firm.

In specifying labor supply, we follow the simple approach taken by Krugman (1991a). There is an economy wide mass of L identical workers with industry-specific skills. Before accepting a job, laborers are perfectly mobile between the two locations. However, once settled in one region, the costs of migration become prohibitive.[3] The workers are risk-neutral and choose the location maximizing their expected wage. The opportunity wage outside the industry for the workers is $\overline{u} < v$, i.e. industry production is efficient with the initial product quality.

The firms simultaneously choose their location. We consider two alternative outcomes of the location subgame: the outcome in which firms locate together is dubbed 'agglomeration', and the outcome in which firms locate separately is dubbed 'separation'. If the firms agglomerate, they compete in wages for the skilled workers in the region. Firms simultaneously

[2] This price would also be obtained if the two firms were monopolists in their respective market and $N \geq L$ consumers endowed with a utility function of $U = q - p$ would buy at most one unit of the good.

[3] Introducing non-prohibitive *ex-post* migration costs would not affect the qualitative nature of our results.

set wages and workers choose either the firm offering the higher wage, or take the outside opportunity. In case of a tie at a wage that is preferred to the outside option, workers split equally across the firms. If the firms choose separate locations, they behave as monopsonists in their respective local labor market.

The timing of the game is as follows: 1) firms choose their location, 2) workers locate, 3) R&D outcomes are realized, 4) firms set wages and workers are hired, and 5) production takes place and profits are realized. Our timing reflects that location decisions involve a longer term commitment relative to R&D decisions, which in turn are less flexible than allocation decisions involving wages.

2.2 Equilibrium Analysis

Suppose that firms have chosen separate locations. As each firm is a monopsonist in its local labor market, workers are paid a wage that matches their outside opportunity $\overline{u}$, and this independently of the R&D outcome. Therefore, *ex-ante*, workers are indifferent between settling in the two regions, and the expected local labor supply is $L/2$. Then, firm i's expected profits under separation are

$$\begin{aligned} E(\pi_i^S) &= \rho(v+\Delta-\overline{u})\frac{L}{2}+(1-\rho)(v-\overline{u})\frac{L}{2} \\ &= \frac{L}{2}(v-\overline{u}+\rho\Delta). \end{aligned} \tag{1}$$

Obviously, the firms' profits increase in the number of workers available, as well as in the expected product quality net of the minimum wage, $\overline{u}$.

Suppose now that firms have agglomerated in one region. The wage resulting from firms' competition in the labor market depends on the outcome of the R&D process of both firms.

Lemma 1 *Consider the labor market equilibrium when firms agglomerate.*
i) If both firms produce at the same quality $q \geq v$*, then the equilibrium wages are* $w_i^* = w_j^* = q$*. Firms make no profit.*
ii) If firm i *produces at quality* $v+\Delta$ *and firm* j *at quality* v*, then the equilibrium wages are* $w_i^* = v+\varepsilon$ *and* $w_j^* = v$*, respectively. All workers supply to firm* i*. Firm* i*'s profit per worker is* Δ*, and firm* j *makes no profit.*

Hence under agglomeration the firms' competition for labor shifts rents to the workers. No matter whether both firms have innovated or not, all profits are competed away in the labor market when product qualities are symmetric. By contrast, when only one firm innovates, the successful firm drives the low quality firm out of the market and employs all available workers at a wage above the workers' outside opportunity. The expected profits of firm i under agglomeration are therefore

$$E(\pi_i^A) = \rho(1-\rho)\Delta L. \tag{2}$$

Profits increase in the probability that only one firm is successful, $\rho(1-\rho)$, in the size of the labor pool, and in the innovation step. Workers in the cluster receive a wage of $v + \Delta$ if both firms innovate and of v otherwise. Their expected wage of $v + \rho^2\Delta$ always exceeds the opportunity wage they would earn in the other location. Therefore, all workers with industry-specific skills prefer to co-locate with the two agglomerating firms.

In the first stage of the game, firms simultaneously choose their location on the basis of expected profits. Comparing (1) and (2), the Nash equilibrium in locations is summarized in

Proposition 1 *Agglomeration is the unique location outcome if $\rho < 1/2$ and*

$$\Delta \geq \widetilde{\Delta} \equiv \frac{v - \overline{u}}{\rho(1-2\rho)}. \tag{3}$$

Otherwise, separation is the unique outcome.

The profits of a firm can come from two sources: the basic product quality available at the industry level and firm specific product innovation. Under separation, both the basic product quality and the innovation contribute to expected profits. Under agglomeration, however, successful innovation is the only source of rents, because the profits that could accrue from the basic product quality are competed away in the labor market. Hence, a necessary condition for agglomeration to be the preferred option is that the expected profits from successful innovation efforts must be greater than under separation, which is guaranteed by the minimum condition on Δ.

Explaining the location trade-off in a different way, agglomeration has two opposing effects on profits. On the one hand, it induces the formation of a large labor pool. Therefore, the firm with the higher product quality can expand its production more than under separation, which increases expected profits. This is the agglomerative force. On the other hand, wages increase via tougher competition for workers. Wage competition under agglomeration thus constitutes the deglomerative force in the model.

Keeping these two forces in mind, the comparative statics of the model are easily understood. Under agglomeration a firm is only able to hire workers at a profitable rate if it pulls ahead in the R&D race and makes its workers more productive than the rival's. Consequently, agglomeration is more profitable if the innovation step, i.e. the productivity advantage of the winning firm, is large. Agglomeration is also more likely if the R&D hazard rate is neither too low (which would render innovation unlikely) nor too high (which would render likely simultaneous innovation by both firms). The $\Delta-$threshold of Proposition 1 takes its minimum value at a hazard rate of 1/4, and separation equilibrium always obtains for $\rho \geq 1/2$. This relationship is illustrated in Figure 1. Finally, wage competition under agglomeration destroys all rents to firms from the initial technology. Thus, separation becomes the more attractive the higher is $v - \overline{u}$. This can also be seen from Figure 1 where the region of the parameter space for which agglomeration is the equilibrium outcome is smaller for the higher value of $v - \overline{u}$.

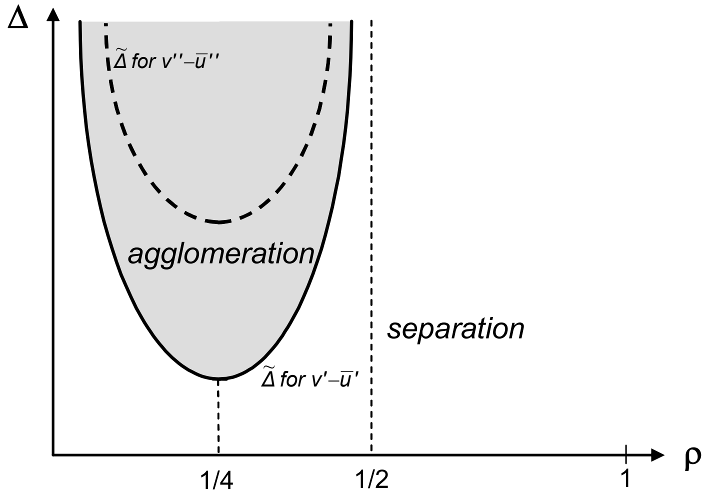

Figure 1: *Location equilibrium with exogenous R&D success probabilities for two different values of* $v - \overline{u}$, $(v - \overline{u})' < (v - \overline{u})''$.

Turning to a welfare comparison, we have that expected social surplus, the sum of workers' rents and firms' profits, is maximized when firms agglomerate. Under agglomeration all available labor produces the higher quality good if at least one of the firms is successful in R&D. Under separation this is possible only if both firms are successful. Agglomeration has therefore the advantage over separation that workers are always put to their most productive use. We will refer to this agglomeration benefit as the '*labor productivity effect*'. The welfare implication of the location equilibrium in Proposition 1 is straightforward. There is (weakly) too little agglomeration in equilibrium.

Our benchmark model represents essentially a simplified version of Krugman's labor pooling model. First, we assume two rather than n firms. The locational choice is therefore reduced to either full agglomeration or separation. Second, the firms operate under constant rather than decreasing returns to scale in our model, which leaves labor pooling as the only source of profits under agglomeration. Finally, R&D shocks have a two-point distribution instead of the uniform distribution assumed by Krugman. Only in the labor market do we consider a slightly more complicated set-up by assuming imperfect rather than perfect competition. The simplifying assumptions are advantageous both in terms of presentation and further analysis. First and foremost, they provide us with a framework that lends itself to model endogenous R&D and to explore the interaction between location and innovation. At the same time the assumptions highlight the importance of firm-level asymmetries for labor pooling, an issue fairly hidden in Krugman's model.

Albeit simpler, the benchmark model contains most of the central effects at play in Krugman's model. In both models the agglomerative force is the 'labor productivity effect': labor pooling increases expected productivity and profits by allowing the more productive firms to expand their output. Unlike our analysis, Krugman finds full agglomeration as the unique equilibrium outcome. Ellison and Fudenberg (2003) point out that the apparent lack of a deglomerative force is due to Krugman's treatment of firms as price takers in the labor market. Once the firms take into account that their location decision affects local wages through the labor market competition, a deglomerative force similar to the one in our model is introduced. Ellison and Fudenberg show that this results in a multiplicity of equilibria where equilibria with full agglomeration and equilibria with firms and workers in both possible locations coexist.

As to the Krugman model, notice finally that it has a scale effect of agglomeration not present in our model with only two firms. In the Krugman model the benefit from labor pooling increases in the size of the agglomeration for a given ratio of workers to firms. The intuition is that the realized productivity of an individual firm has a smaller impact on the average productivity in larger agglomerations with more firms. Since the local wage is determined by the average productivity, the covariance between individual firm productivity and wage is reduced. As a result, firms blessed with a high productivity shock will expand production more. This leads to higher firm productivity as well as profits in larger agglomerations with many firms and workers; an effect that pushes towards full agglomeration in equilibrium.

Before extending our model to endogenous R&D decisions, we should remark that the benchmark model can be reinterpreted as a dynamic R&D model with catching-up in technology. Consider an infinite horizon model in discrete time where firms and workers choose their locations at the beginning of the game. Innovations occur in discrete jumps (maximally one per period) along a 'quality ladder' à la Grossman and Helpman (1991) of the type $q_i = (1+\Delta)q_{i-1}$. If one firm pulls ahead in a period, the laggard catches up before the beginning of the next period. That is, firms start the following period with equal qualities. It can be shown that such a dynamic R&D race produces the same threshold $\widetilde{\Delta}$ as in Proposition 1.

3 Endogenous R&D Investment

In the benchmark model firms' location decisions were driven by exogenous shocks. These shocks were referred to as innovations, but they could equally well be interpreted as demand shocks. In this and the following section we take seriously the former interpretation, and endogenize the shocks by explicitly modeling firms' R&D investment. This allows us to bring together two aspects heretofore not considered together, namely the choice of location, and research strategy. The aim is to analyze the interplay between labor market competition and R&D decisions and how this, in turn, influences equilibrium location choices and welfare conclusions.

3.1 Model with R&D Investment

In the baseline model, R&D was characterized by two exogenous parameters, ρ, the probability of a successful innovation, and Δ, its size. Without alluding to specific examples it is difficult to say whether R&D investment affects ρ, Δ, or both. We therefore start from a fairly general R&D technology and then look at two focal, parameterized examples.

Returning to the specification of a general R&D technology, let firm i choose an R&D intensity ϕ_i resulting in a probability of success $\rho(\phi_i)$ and an innovation size $\Delta(\phi_i)$. Both $\rho(\phi_i)$ and $\Delta(\phi_i)$ are C^2-functions. Let $\rho(\cdot)$, $\Delta(\cdot) > 0$ for $\phi_i > 0$ and $\rho'(\cdot)$, $\Delta'(\cdot) \geq 0$ with at least one strictly positive slope. The cost of employing ϕ_i is specified by the increasing C^2-function $g(\phi_i)$ where $g(0) = g'(0) = 0$ and $g''(\cdot) > 0$. It is assumed that $g(\cdot)$ is sufficiently convex so that the profit function of firm i is concave for $\phi_i < \phi_j$ and for $\phi_i > \phi_j$, and that corner solutions are excluded.[4]

3.2 Equilibrium Analysis

Towards an analysis of this extended model, suppose that in the first stage of the game the firms have chosen separate locations. The expected profit of firm i is now given by

$$\pi^S(\phi_i) = \rho(\phi_i)(v - \overline{u} + \Delta(\phi_i))L/2 + (1 - \rho(\phi_i))(v - \overline{u})L/2 - g(\phi_i).$$

[4] By this we suppose that the profit function is piecewise concave but not necessarily globally concave.

The optimal research intensity $\phi^{S,*}$ solves the first-order condition

$$\rho'(\phi^{S,*})\Delta(\phi^{S,*})L/2 + \rho(\phi^{S,*})\Delta'(\phi^{S,*})L/2 - g'(\phi^{S,*}) = 0. \tag{4}$$

Suppose now instead that firms have chosen to agglomerate. In this case, equilibrium wages in the labor market depend on the outcome of the stochastic R&D processes. A firm can draw all workers from the labor pool if its R&D project is the only successful one in the industry. With $\Delta'(\phi) > 0$ the firm investing more aims for a higher product quality and employs all skilled laborers in the event that both firms' R&D projects are successful. Therefore, the expected profit of any firm i can be written as:

$$\pi_i^A(\phi_i,\phi_j) = \rho(\phi_i)(1-\rho(\phi_j))\Delta(\phi_i)L - g(\phi_i) + \begin{cases} 0 & \text{if } \phi_i \leq \phi_j, \\ \rho(\phi_i)\rho(\phi_j)(\Delta(\phi_i)-\Delta(\phi_j))L & \text{otherwise.} \end{cases}$$

Without loss of generality, suppose that $\phi_i \leq \phi_j$. The first-order condition for the low-investment firm i is

$$(1-\rho(\phi_j^{A,*}))\left[\rho'(\phi_i^{A,*})\Delta(\phi_i^{A,*}) + \rho(\phi_i^{A,*})\Delta'(\phi_i^{A,*})\right]L - g'(\phi_i^{A,*}) = 0, \tag{5}$$

while for the high-investment firm j it is

$$\left[\rho'(\phi_j^{A,*})\Delta(\phi_j^{A,*}) + \rho(\phi_j^{A,*})\Delta'(\phi_j^{A,*}) - \rho'(\phi_j^{A,*})\rho(\phi_i^{A,*})\Delta(\phi_i^{A,*})\right]L - g'(\phi_j^{A,*}) = 0. \tag{6}$$

It is easy to verify that the firms' R&D investment choices are strategic substitutes.[5] Specifically, an increase in one firm's R&D investment reduces the marginal value of the other firm's investment by decreasing the probability of having the only successful R&D project. Also, for the higher investment firm j, investment by firm i decreases profits by reducing firm j's efficiency advantage in case both firms are successful.

The following proposition characterizes the R&D equilibrium under agglomeration.

Proposition 2 *Suppose that $g(\cdot)$ is sufficiently convex, and consider the equilibrium in R&D investment strategies $(\phi_i^{A,*}, \phi_j^{A,*})$ when firms agglomerate.*
(i) If $\Delta'(\phi^{A,*}) = 0$, then there exists a unique, symmetric, pure-strategy equilibrium, $\phi_i^{A,*} = \phi_j^{A,*} = \phi^{A,*}$ in which the equilibrium investment satisfies

$$(1-\rho(\phi^{A,*}))\rho'(\phi^{A,*})\Delta(\phi^{A,*})L - g'(\phi^{A,*}) = 0. \tag{7}$$

(ii) If $\Delta'(\phi^{A,*}) > 0$, then there exists a generically unique pure-strategy equilibrium with $\phi_i^{A,*} < \phi_j^{A,*}$ in which the equilibrium investment levels satisfy (5) and (6).

[5] Check that for two firms with $\phi_i \leq \phi_j$ it holds that $\partial^2\pi_i^A(\phi_i,\phi_j)/(\partial\phi_i\partial\phi_j) = \partial^2\pi_j^A(\phi_i,\phi_j)/(\partial\phi_j\partial\phi_i) = -\rho'(\phi_j)(\rho'(\phi_i)\Delta(\phi_i) + \rho(\phi_i)\Delta'(\phi_i)) < 0$.

The equilibrium in investment strategies conditional upon firms' agglomeration exhibits some interesting properties. Specifically, as long as $\Delta(\cdot)$ is a strictly increasing function, the *ex-ante symmetric* firms choose *asymmetric* R&D investments. The reason is that the marginal return to R&D investment increases discretely as a firm's investment becomes larger than its competitor's. The firm then produces a higher quality than its competitor when both firms are successful and wins the labor market bid for skilled laborers, which in turn increases the marginal return to R&D.[6] This induces firms to optimally differentiate their R&D strategies. The high investment firm benefits from a higher probability and a higher innovation step, which provides it with full access to the labor pool in case of joint R&D success. By contrast, the low investment firm is better off saving on R&D expenditures, even if it only gains access to the entire labor pool in situations where it is the sole innovator. Notwithstanding this optimal differentiation of R&D strategies, it is easy to show that, in equilibrium, the high investment firm j has higher expected profits than firm i.[7] Finally, it is worth emphasizing that Proposition 2 implies both generic existence and uniqueness (modulo firm identity) of a pure-strategy R&D equilibrium even within a fairly general functional form setup of the R&D technology.[8]

The empirical implication of our analysis of the firms' R&D decision is that the variance of R&D expenditures is higher under agglomeration than that under separation. In section 4 we test this hypothesis using German data on firm-level R&D expenditures in R&D intensive industries.

Now consider the determination of equilibrium location choices. In our baseline model firms' expected profits under agglomeration are identical, since ρ and Δ are the same for both firms. This yields a simple solution to the locational choice problem in the first stage of our game, as firms always agree on whether to locate jointly or separately. With endogenous R&D investment, firms generically differentiate their R&D strategies as described in Proposition 2. This leaves us with two pure-strategy equilibria in the agglomeration subgame which are identical in every aspect except for the identity of the firm with the higher investment level,

[6] Note, however, that the firm's payoff remains continuous at this investment level, because the profit margin (price - wage) reflects the difference in product quality.

[7] Verify that $\partial \pi_i^A(\phi_i, \phi_j)/\partial \phi_j < 0$. Using this, the fact that $\phi_i^{A,*} < \phi_j^{A,*}$, and a revealed preference argument, we have that $\pi_i^A(\phi_i^{A,*}, \phi_j^{A,*}) < \pi_i^A(\phi_i^{A,*}, \phi_i^{A,*}) = \pi_j^A(\phi_i^{A,*}, \phi_i^{A,*}) \leq \pi_j^A(\phi_i^{A,*}, \phi_j^{A,*})$.

[8] In order to show this, we link the equilibrium and welfare analysis via the first-order conditions. We show that if $g(\cdot)$ is sufficiently convex, there exists a unique solution to the welfare problem, implying that a unique equilibrium in pure strategies exists. Note that existence of a Nash equilibrium (at least in mixed strategies) could be guaranteed without assumptions on $g(\cdot)$, by just imposing an upper limit on ϕ_i. This makes the strategy set compact and the existence theorem of Glicksberg (1952) would apply.

and thus, higher equilibrium profits. With the usual equilibrium selection criteria like Pareto dominance or risk dominance we are unable to distinguish between these two equilibria.

As long as both firms prefer either agglomeration or separation no matter which equilibrium is played, we can continue to assume that the firms reach their preferred location outcome. However, asymmetric profit levels under agglomeration introduce the possibility that the high investment firm prefers agglomeration whereas the low investment firm prefers separation.

This issue can be dealt with in several ways. First suppose that firms know their (relative) R&D investment level in an agglomeration before choosing location, i.e. they know which equilibrium would be played. In this case if say firm i prefers agglomeration whereas firm j prefers separation, then firms end up in a mixed strategy equilibrium in location. In such an equilibrium each firm randomizes 50:50 across the locations, and agglomeration occurs in equilibrium with probability 1/2. A second alternative is to assume that there is uncertainty concerning the equilibrium of the agglomeration subgame. The two equilibria are equally likely to arise, and the firms do not know which equilibrium is the relevant one when choosing locations. The firms' expected profits are thus symmetric and the location choice can be analyzed as before.[9] Formally, the assumption is that firms under agglomeration use a public randomization device, i.e. firms condition their R&D on a public signal (for example, media coverage of one of the firms) that selects one of the two equilibria with probability 1/2. Then, agglomeration is the unique equilibrium outcome if and only if

$$\pi_i^A(\phi_i^{A,*}, \phi_j^{A,*}) + \pi_j^A(\phi_j^{A,*}, \phi_i^{A,*}) \geq 2\pi^S(\phi^{S,*}). \quad (8)$$

It is not crucial for our analysis how the location outcome is determined when the firms disagree on the location choice *ex-post*. Indeed, the following propositions are formulated in such a way that they do not rely on the specific assumption made here. Rather than choosing one of the assumptions, we will use the examples to illustrate the equilibrium outcome for the two assumptions discussed above.

The next proposition compares equilibrium investments under separation and agglomeration and further characterizes the location equilibrium.

Proposition 3 *Compare R&D investments and expected profits from innovation under the two location choices:*
(i) In a symmetric equilibrium, $\rho(\phi^{A,*}) < 1/2$ *is a necessary and sufficient condition for both*

[9] This approach reflects the idea that location decisions are longer-term than R&D decisions. At the location stage there is thus uncertainty not only concerning R&D outcomes but also concerning how R&D competition will take place.

firms to invest more in and to earn higher profits from R&D under agglomeration than under separation.
(ii) In an asymmetric equilibrium with $\phi_i^{A,*} < \phi_j^{A,*}$, $\rho(\phi_j^{A,*}) < 1/2$ is a sufficient condition for both firms to invest more in and to earn higher profits from R&D under agglomeration than under separation.
(iii) Consider an equilibrium where firm j earns higher expected profits from R&D under agglomeration than under separation. Furthermore, firm j earns weakly higher profits from R&D under agglomeration than firm i does. Then, there exist two threshold levels ψ_i and ψ_j such that firm i (firm j) prefers agglomeration if and only if $v-\overline{u} < \psi_i$ ($v-\overline{u} < \psi_j$), $\psi_j \geq \psi_i$ and $\psi_j > 0$. Separation and agglomeration are the equilibrium outcomes for $v-\overline{u} \geq \psi_j$ and for $v-\overline{u} < \psi_i$, respectively.
(iv) Consider an equilibrium where both firms earn higher profits from R&D under separation than under agglomeration. Then, separation is the equilibrium outcome.

Points *(i)* and *(ii)* of the proposition reflect the trade-off between innovating for a labor pool of half the size under separation versus the dissipation of rents from innovation under agglomeration due to labor market competition. A firm invests more in R&D under agglomeration and has higher expected profits from innovation if the equilibrium hazard rate of its competitor is less than 1/2. A low hazard rate of the competitor stimulates own investment in R&D, because the rents from successful innovation are less likely to be competed away in the labor market. Though the conditions $\rho(\phi^{A,*}) < 1/2$ and $\rho(\phi_j^{A,*}) < 1/2$ refer to endogenous rather than exogenous parameters,[10] it is clear that these conditions hold in equilibrium when it is not feasible or too expensive to increase the hazard rate beyond 1/2, i.e. $\lim \rho(\phi) < 1/2$ as $\phi \to \infty$, or $g(\phi) \to \infty$ as $\phi \to \rho^{-1}(1/2)$. This will be illustrated in more detail in Example I below.

As detailed in the discussion of the baseline model in section 2, expected profits under separation are composed of the certain profits from the basic technology and the expected profits from innovation. Under agglomeration innovation is the only source of profits. Thus, for agglomeration to be preferred, the profits from innovation must not only be greater under agglomeration than under separation, but the basic technology must also not be too profitable. Point *(iii)* and *(iv)* of Proposition 3 give precision to this argument. Point *(iii)* and *(iv)* characterize the location choices, except when firm j prefers agglomeration but firm i prefers separation. Using the notation of Proposition 3, the firms prefer different location outcomes when $\psi_i \leq v-\overline{u} < \psi_j$. As explained above, this case can arise when the firms are

[10] We have formulated them this way in order to preserve the comparability of the results with those derived in the other model versions.

not equally likely to obtain the role as the high investment firm under agglomeration. We return to this issue in example II that consider asymmetric equilibria in the agglomeration subgame.

3.3 Welfare

We now turn to the welfare properties of the equilibrium characterized in the previous section. Under separation the firms operate as monopsonists and appropriate all local rents. From this it follows directly that conditional upon locational separation, the equilibrium R&D intensities maximize total welfare.

The welfare analysis is more involved under agglomeration because there are competing effects at play. Firms no longer capture all rents accruing from their R&D investment, as some of these rents go to the workers in the form of higher wages. This tends to reduce incentives to invest in R&D below the welfare maximizing level. At the same time, however, there is a strategic effect at play. A firm does not internalize the negative effect its R&D investment has on the competitor's profits, which pushes towards overinvestment in R&D. *A priori*, it is unclear how these effects play out and whether there is underinvestment or overinvestment in R&D.

Aggregate welfare is specified by

$$W^A(\phi_i, \phi_j) = \left[v - \overline{u} + \rho(\phi_j)\Delta(\phi_j) + \rho(\phi_i)(1 - \rho(\phi_j))\Delta(\phi_i)\right] L - g(\phi_i) - g(\phi_j).$$

Suppose that $W^A(\phi_i, \phi_j)$ is globally concave in ϕ_i and ϕ_j for $\phi_i \leq \phi_j$, which holds if $g(\cdot)$ is sufficiently convex. Then it is easy to verify that the first-order conditions characterizing the welfare maximizing R&D intensities are identical to (5) and (6). Hence the R&D intensities chosen by the firms in equilibrium are welfare maximizing, i.e. the two effects leading to underinvestment and overinvestment, respectively, cancel out each other. More precisely, the expected contribution of firm i to social welfare is $E[Max\{q_i - q_j, 0\}L - g(\phi_i)]$, which is equal to firm i's expected profit. Therefore, the firm has the correct incentive to invest in quality improvement. Although interesting, we do not wish to over-emphasize this result as it clearly represents a knife's edge case. Changes in the specification of the model, for example in the mode of competition in labor or output markets, could affect the relative strength of the two opposing effects. As a result, equilibrium R&D investments would no longer be welfare optimal.

The next proposition summarizes the welfare analysis of R&D investments and assesses the efficiency of location choices.

Proposition 4 *Suppose that $g(\cdot)$ is sufficiently convex such that the welfare function is globally concave in ϕ_i and ϕ_j for $\phi_i \leq \phi_j$. Then*
(i) conditional upon locations, firms choose the welfare maximizing R&D intensities,
(ii) welfare is maximized when firms agglomerate.

Towards assessing the efficiency of the location equilibrium, it is useful to decompose the welfare difference between agglomeration and separation into two effects, an *R&D portfolio effect* and a *labor productivity effect*,

$$W^A(\rho_i^{A,*}, \rho_j^{A,*}) - W^S(\rho^{S,*}, \rho^{S,*}) = \underbrace{W^A(\rho_i^{A,*}, \rho_j^{A,*}) - W^A(\rho^{S,*}, \rho^{S,*})}_{\text{R\&D portfolio effect}} + \underbrace{W^A(\rho^{S,*}, \rho^{S,*}) - W^S(\rho^{S,*}, \rho^{S,*})}_{\text{Labor productivity effect}}$$

The labor productivity effect captures the welfare benefit of agglomeration for given R&D strategies. As discussed in section 2.2, this effect is positive because under agglomeration the firm with higher product quality can expand production by hiring all workers. The R&D portfolio effect represents an additional welfare benefit of agglomeration that arises because labor pooling allows for a more efficient, diversified R&D portfolio at the industry level.[11] To the best of our knowledge, the R&D portfolio effect is novel to the labor pooling literature.

The major difference between the equilibrium R&D strategies under the two locational choices is that firms choose asymmetric R&D investments under agglomeration, but symmetric R&D investments under separation. To see why asymmetric investments lead to a more efficient R&D portfolio, suppose that firms would choose symmetric investment levels. Then, if both firms were successful, the R&D investment of one of the firms would be wasted, i.e. would not contribute to welfare. Notice that this is not the case under separation as the firms do not share a common pool of workers. Keeping total investments constant but allocating them asymmetrically reduces the problem of wasteful R&D duplication under agglomeration. The investment of the low quality firm is still wasted if the high quality firm is successful. However, since the low quality firm invests less compared to the situation of symmetric investments, that waste is reduced. Of course, this argument provokes the question of why it would not be efficient to allocate all investment to one firm to avoid duplication altogether. The reason is that there are decreasing returns to R&D investment at the firm level. Thus the allocation of R&D investment trades off the cost of asymmetric R&D investments due to decreasing returns to scale, against the cost of wasteful duplication of R&D efforts.[12]

[11] Since in equilibrium firms choose the welfare maximizing R&D investments, we have immediately that $W^A(\rho_i^{A,*}, \rho_j^{A,*}) \geq W^A(\rho^{S,*}, \rho^{S,*})$.

[12] Put differently, starting from a situation of symmetric investments, a small reallocation of investments

While the welfare optimality of R&D investments rests on the specific assumptions made here, this appears not to be the case for the two effects underlying Proposition 4 (ii). The labor productivity effect relies on the more productive firm hiring more workers than the less productive firm under agglomeration. All reasonable specifications of labor market competition would yield this outcome, so this effect is clearly robust to different specifications of the model. The R&D portfolio effect arises, because firms have an interest in avoiding situations where joint R&D success cannibalizes the profits from innovation. Joint success is also undesirable from the point of view of social welfare, because it entails wasteful duplication of R&D efforts. As public and private interests are aligned on this matter, it seems likely that the R&D portfolio effect will remain positive for minor changes in the model.

In order to gain additional insights into the link between R&D strategies and location decisions, we have constructed two examples involving specific functions for $\rho(\cdot)$, $\Delta(\cdot)$, and $g(\cdot)$ so that the model could be solved in closed-form. We consider the two extreme cases, one where R&D investment increases only ρ, and another where it only increases Δ.

3.4 Example I: Endogenous Hazard Rate

In this example, we consider a setup where firms choose the probability of achieving an innovation of constant size Δ. In particular, suppose that $\rho(\phi) = \phi$ and $g(\phi) = \gamma\phi^2/2$ where γ measures the marginal cost of R&D. We assume that $\gamma > \Delta L/2$, to exclude corner solutions. The equilibrium is derived in the same manner as above, so details are left out.

Since investment does not increase the innovation step, there is a symmetric equilibrium also when firms choose to agglomerate. The investment in R&D per firm is $\phi^{S,*} = \Delta L/2\gamma$ and $\phi^{A,*} = \Delta L/(\Delta L + \gamma)$ under separation and agglomeration, respectively. This results in equilibrium profits

$$\begin{aligned} \pi_i^S(\phi^{S,*}) &= \frac{(v-\overline{u})L}{2} + \frac{\Delta^2 L^2}{8\gamma}, \\ \pi_i^A(\phi^{A,*}, \phi^{A,*}) &= \frac{\gamma\Delta^2 L^2}{2(\Delta L + \gamma)^2}. \end{aligned}$$

In this example, the location decision can be treated as in the benchmark model. Comparing profits under agglomeration and separation, we find that firms agglomerate in the first stage if and only if

$$\pi_i^A(\phi^{A,*}, \phi^{A,*}) \geq \pi_i^S(\phi^{S,*}) \Leftrightarrow \psi_j = \psi_i \equiv \psi = \frac{\Delta^2 L(\gamma - \Delta L)(3\gamma + \Delta L)}{4\gamma(\gamma + \Delta L)^2} \gtrless v - \overline{u}. \qquad (9)$$

from one firm to the other will result in a second-order reduction in R&D efficiency due to decreasing returns to scale but in a first-order reduction in R&D duplication. Therefore, the welfare maximizing R&D investments are asymmetric under agglomeration.

In Figure 2 equation (9) is plotted in (γ, Δ)-space. Notice that in this example the condition $\rho(\phi^{A,*}) < 1/2$ from Proposition 3 (i) is equivalent to $\gamma > \Delta L$. This implies that for all parameter values above the $\gamma = \Delta L$-line, firms invest more in R&D under agglomeration than under separation, and the profits from innovation are higher when firms cluster. However, this must be weighed against the profits obtained under separation from producing the baseline product.

Since we can explicitly determine the relevant equilibrium values, it is easier to see the connection to the benchmark model of section 2 than in the more general setup. In particular, firms agglomerate also in this example if two conditions are met: i) $\rho(\phi^{A,*})$ is intermediate between 0 and 1/2, and ii) Δ is sufficiently large compared to $v - \overline{u}$. The first condition is violated if the marginal cost of R&D, γ, is either too low or too high.

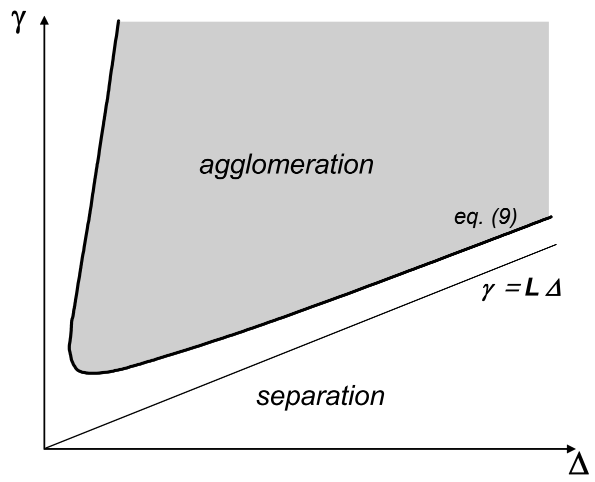

Figure 2: *Location equilibria with endogenous hazard rate.*

3.5 Example II: Endogenous Innovation Size

Suppose now that firms choose the innovation step so that $\Delta(\phi) = \phi$ whereas the probability of success is constant, $\rho(\phi) = \rho$. Let the marginal cost of adding to the innovation size be quadratic as in the previous example.

With separate locations both firms choose the R&D intensity $\phi^{S,*} = \rho L/2\gamma$. The equilibrium profits are

$$\pi_i^S(\phi^{S,*}) = \frac{(v - \overline{u})L}{2} + \frac{\rho^2 L^2}{8\gamma}.$$

Under agglomeration equilibrium R&D intensities are asymmetric since $\Delta(\phi)$ is increasing in ϕ. Solving the first-order conditions, we find $\phi_i^{A,*} = (1-\rho)\rho L/\gamma$ and $\phi_j^{A,*} = \rho L/\gamma$. The more R&D intensive firm j, which produces the highest quality, increases its investment with higher success probability ρ. By contrast, the less R&D intensive firm i invests the most when the probability of being successful alone is maximized, i.e. at $\rho = 1/2$. Note also that firm j invests as much in R&D as the two firms together under separation. The resulting profits under agglomeration are

$$\pi_i^A(\phi_i^{A,*}, \phi_j^{A,*}) = \frac{(1-\rho)^2 \rho^2 L^2}{2\gamma},$$
$$\pi_j^A(\phi_i^{A,*}, \phi_j^{A,*}) = \frac{\rho^2 L^2 (1 - 2\rho(1-\rho))}{2\gamma}.$$

Suppose that the firms know the equilibrium outcome under agglomeration. Then, firm i prefers agglomeration if and only if

$$v - \overline{u} \leq \frac{\rho^2 L}{4\gamma}\left(3 - 8\rho + 4\rho^2\right) =: \psi_i, \tag{10}$$

and firm j prefers agglomeration if and only if

$$v - \overline{u} \leq \frac{\rho^2 L}{4\gamma}\left(3 - 8\rho + 8\rho^2\right) =: \psi_j. \tag{11}$$

If the equilibrium under agglomeration is determined after the locations are chosen, and the two equilibria are equally likely to be played, the firms agglomerate if and only if

$$v - \overline{u} \leq \frac{\rho^2 L}{4\gamma}\left(3 - 8\rho + 6\rho^2\right) =: \psi. \tag{12}$$

The equilibrium outcome is depicted in $(v - \overline{u}, \rho)$-space in Figure 3. Firm i makes highest profits under agglomeration if and only if $v - \overline{u}$ is below ψ_i in (10). Notice that this can only occur for $\rho < 1/2$ where agglomeration results in higher profits from R&D. The high investment firm always earns higher profits from R&D under agglomeration. Since expected profits are increasing more rapidly in ρ under agglomeration than under separation, the threshold value of $v - \overline{u}$ below which firms agglomerate, ψ_j in (11), is also increasing in ρ.

For values of $v - \overline{u}$ above ψ_j (the white area) and below ψ_i (the dark grey area), the firms agree on separation and agglomeration, respectively. In the rest of the parameter space (the light grey area), firm j earns more profits under agglomeration but firm i earns less. Here, as discussed above, the outcome depends on the specific assumptions made at the location stage. If the firms know which equilibrium will be played under agglomeration, simultaneous location choices result in a mixed strategy equilibrium where agglomeration is the outcome with a probability 1/2. If instead the firms are equally likely to become the high investment firm under agglomeration, there is separation above the dotted line in Figure 3, representing ψ in (12), and agglomeration below.

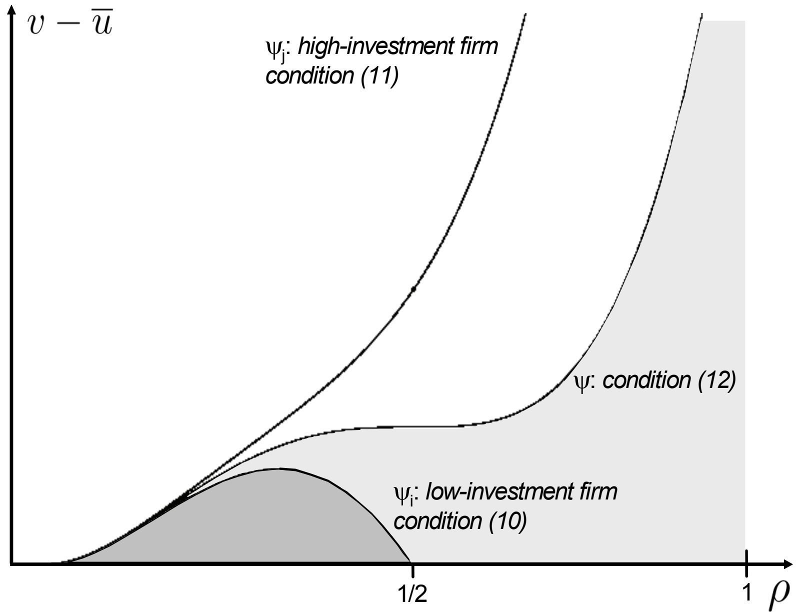

Figure 3: *Location equilibria with endogenous innovation size*

4 The Variance of R&D Expenditures by Location: Evidence from German Firms

In the previous section, we have demonstrated that local labor market competition for skilled workers induces firms to choose a more diversified R&D portfolio at the industry level. If this is true then, ceteris paribus, it should hold that the variance of R&D expenditures of firms in agglomerations is higher than the variance of R&D expenditure of firms in separate locations. In this section, we test this relationship using firm level panel data from R&D intensive industries in Germany. In what follows, we first describe the construction of the data set and compare different definitions of agglomeration and separation. We then discuss potential confounding factors and explain how we deal with them in our analysis. Finally, we run a two-step fixed effect estimation and test for heteroskedasticity with respect to firms in agglomerations and in separations.

We primarily make use of two data sets for Germany, namely the Mannheim enterprise panel (MUP) and the Mannheim innovation panel (MIP), both located at the Centre for European Economic Research, Mannheim (ZEW). The MUP is constructed from credit rating data collected by Creditreform, the largest credit rating firm in Germany. The data base is supposed to contain all firms active in Germany at a given time. The MIP is a subset of these firms selected from research intensive NACE3 industries.[13] For the purpose of our analysis, the natural locational unit is a labor market region. We use the specification developed by Eckey et al. (1991) from commuting data, which is the specification currently used in all German policy studies.

Towards defining whether a labor market region is an agglomeration or a separation, we employed the 2003 MUP data to determine for each of the research intensive NACE3 industries the number of firms per labor market region. We considered five alternative definitions of agglomeration and separation and settled on the following: first, we specify a separation to be a labor market region housing just one firm belonging to the particular NACE3 industry. We justify this narrow definition of separation as one excluding, in line with the assumptions made in our model, the swap of specialized labor across firms. Second, we deviate slightly from the theoretical model by defining a labor market region as an agglomeration if it houses two or more firms belonging to the NACE3 industry. Focusing on regions with exactly two firms would be closer to the theoretical model, but it would reduce the number of observations substantially. Instead, we establish the link between theory and empirics by requiring that the concentration of industry employment in the region exceeds a Hirschman-Herfindahl-Index (HHI) of 0.18 and that at least one per cent of the country's labor force in the industry works in the region. These two criteria are imposed in order to ensure that the labor force is concentrated in a small number of sizable firms rather than spread over many small firms of equal size. The regions classified as agglomerations are thus likely to be characterized by a high degree of imperfect competition in the labor market, a central ingredient of the theoretical model.[14] Appendix 2 contains a brief description of the two data sets, our procedure for the sample selection, a discussion of the definitions of agglomeration and separation, and summary statistics on the selected sample. Since estimations based on the alternative definitions of agglomeration and separation led to similar results, we do not report them here. Details are available upon request.

One could expect that a host of factors confounds location choice and the volume and variance of per employee R&D expenditures across firms and time. Therefore, a simple comparison of the variance of *per capita* R&D expenditures in agglomerations and separations could be misleading as long as, e.g., firm size varies across the two location types and the variance of *per capita* R&D expenditures depends on firm size.[15]

[13] For a detailed description see Rammer et al. (2005).

[14] This HHI was computed from the MUP data base. The rationale behind the cutoff value of 0.18 is that the U.S. Department of Justice considers an industry as concentrated if the HHI for turnover exceeds 0.18.

[15] As a benchmark we included the result of this simple approach in Figure 4 in the appendix. Each point in this figure represents, for a particular NACE3 industry, the (raw) standard deviation of per capita

We therefore control (i) for firm size by including a polynomial in the number of employees additional to considering *per capita* R&D expenditures, (ii) for differences across industries by including industry fixed effects, (iii) for firm age by including age dummies, (iv) for the firms' skill composition by including the fraction of employees with a higher education degree, (v) for changes over time by including a time trend, and (vi) for possible differences between East and West Germany that date back to the 1989 reunification by including a dummy for East Germany.

In accordance with our hypothesis, we then posit that once we control for all these factors any remaining, unexplained difference between the R&D variance of firms in agglomeration and separation can be attributed to the strategic R&D portfolio effect elaborated in Section 3. To capture this difference, we proceed in two steps. First we regress firms' annual per capita R&D expenditures on those control variables plus dummies for agglomeration and separation using MIP data from 1992 to 2004 and a fixed effects estimator.[16] We then calculate the residual from this estimation and regress its square on the location indicators, controlling again for the same factors. This procedure can be understood as a refined version of a test for heteroskedasticity, testing the hypothesis that the variance of *per capita* R&D expenditures is higher for firms in agglomeration than for firms in separation.[17]

Table 1 reports the results for different specifications of the first stage regression. In specifications (1) to (3) the polynomial of firm size (as measured by number of employees) is increased from third to fifth order. The first two models indicate that this polynomial is significant up to the 4th order term. By contrast, adding a fifth order term in column (3) leads to a drop in significance for all polynomial coefficients. We therefore chose the specification from (2) to control for firm size. In column (4) we report the results of this second specification with age dummies included. Firm age is highly correlated with firm size in our sample. As a result the coefficients hardly change from (2) to (4) and the age dummies are insignificant. At the same time we lose some observations because age information is not available for all firms. For these reasons, we chose to use specification (2) for the second stage of the estimation. Note that using any of the other three specifications did not make a

innovation expenditure of firms in agglomeration and separation. The dominant share of vector points is located above the 45 degree line, indicating again that firms' per capita R&D expenditures exhibit more variation in agglomerations than in separations.

[16] We used the conventional within regression estimator. For all specifications a Hausman test indicates that a random effects model is not appropriate relative to the chosen fixed effects specification.

[17] A conventional test for heteroskedasticity would test whether, in general, the variance depends on exogenous variables. Here, we would like to test whether, conditional on a set of controls, the variance is higher in agglomerations than in separations.

significant difference for our second stage results. While we are not primarily interested in the *per capita* levels of R&D expenditure, the results in Table 1 indicate that R&D expenditures increase in the firm size and in the fraction of employees with a higher education degree. The coefficient of the indicator variable for agglomeration is negative but insignificant throughout. The value of R^2 is low in all four specifications, which reflects the fact that we explain most of the variation in firms' R&D expenditure by using R&D expenditure per capita as the dependent variable.

In the second stage of our estimation we use the squared residual of specification (2) as the dependent variable and test whether and in which way the indicator variables for agglomeration and separation help to explain the variance in R&D expenditure. Table 2 contains the results for three different specifications. Column (1) contains the simplest possible specification which regresses the R&D residuals on the firms' location indicator. This yields a highly significant, positive coefficient for the agglomeration indicator variable. According to our definition of this variable, this means that firms in an agglomeration display a higher variance of R&D expenditure (as measured by the residuals) relative to firms being located neither in agglomeration nor separation. The second column additionally includes an indicator for East Germany, a time trend and industry dummies. With this specification the coefficient for separation is negative, the coefficient for agglomeration is positive and both coefficients are significantly different from zero (at the 1 % level). The regression in column (3) adds the firm size polynomial and firms' skill composition. Again, all terms of the size polynomial prove to be significant, the sign of their coefficient hint at a highly non-linear relationship between firm size and R&D residuals. The skill composition coefficient is positive and significant indicating a positive relationship between firms' human capital and the R&D residuals.

The hypothesis we want to test with these results is that the R&D expenditure residuals for firms in agglomeration are higher compared to firms in separation. Formally, we ask whether the coefficient of the indicator variable for separation is greater than or equal to the coefficient for agglomeration. Table 3, which presents the main results of this section, reports the coefficient differences and the corresponding one-sided p-test values for the three different specifications of Table 2. The first row gives the values for the full sample and shows that the null hypothesis is clearly rejected for all specifications. This result is strong support in favor of the R&D portfolio effect identified in our theoretical model.

We performed various robustness checks with respect to this result and report one particularly insightful test at this point. Our theory is based on labor pooling. If the results from row 1 of Table 3 are due to the R&D portfolio effect, then we would expect that the

	(1)	(2)	(3)	(4)
indicator for separation	0.001	0.001	0.001	0.001
	(0.003)	(0.003)	(0.003)	(0.003)
indicator for agglomeration	-0.003	-0.003	-0.003	-0.003
	(0.002)	(0.002)	(0.002)	(0.002)
indicator for eastern Germany	-0.005	-0.005	-0.005	-0.006
	(0.003)+	(0.003)+	(0.003)+	(0.003)+
million employees	-1.096	-1.725	-0.968	-1.741
	(0.210)**	(0.365)**	(0.579)+	(0.377)**
million employees sq.	6.942	18.492	-22.001	18.673
	(1.552)**	(5.710)**	(24.732)	(5.857)**
million employees cu.	-10.605	-67.763	449.782	-68.429
	(2.575)**	(27.318)*	(308.778)	(27.892)*
million employees qu.		77.144	-2,113.324	77.902
		(36.706)*	(1,302.273)	(37.391)*
million employees 5th order			2,745.434	
			(1,631.562)+	
fraction of empl. with higher	46.941	46.458	46.990	47.161
education ($\times 10^6$)	(18.926)*	(18.922)*	(18.922)*	(19.097)*
NACE3 indicators	yes	yes	yes	yes
year indicators	yes	yes	yes	yes
firm age dummies up to 9 years	no	no	no	yes
observations	10,115	10,115	10,115	9,969
number of firms	3,708	3,708	3,708	3,668
R-squared	0.07	0.07	0.07	0.08

standard errors in parentheses

+ significant at 10%; * significant at 5%; ** significant at 1%

Table 1: The dependent variable is the firm's annual *per capita* innovation expenditure. We controlled for firm fixed effects. The coeffiecient of the fraction of employees with a higher education degree has been multiplied by 10^6.

	(1)	(2)	(3)
indicator for separation ($\times 1,000$)	0.000	-0.577	-0.410
	(0.201)	(0.205)**	(0.203)*
indicator for agglomeration ($\times 1,000$)	0.473	0.314	0.112
	(0.093)**	(0.094)**	(0.094)
indicator for eastern Germany ($\times 1,000$)		-0.139	-0.175
		(0.075)+	(0.076)
million employees			0.218
			(0.024)**
million employees sq.			-2.477
			(0.419)**
million employees cu.			8.967
			(1.977)**
million employees qu.			-10.062
			(2.634)**
fraction employees with higher education ($\times 10^6$)			12.278
			(1.596)**
NACE3 indicators	no	yes	yes
year indicators	no	yes	yes
observations	10,115	10,115	10,115
R-squared	0.00	0.05	0.07

standard errors in parentheses

+ significant at 10%; * significant at 5%; ** significant at 1%

Table 2: Coefficient estimates obtained from an OLS regression. The dependent variable is the squared residual from the Column (2) estimate reported in Table 1. The coefficients of the first three and the last variable have been multiplied by 1000 and 10^6, respectively, as indicated in parentheses behind the variable names.

	(1)		(2)		(3)	
	diff.	p-value	diff.	p-value	diff.	p-value
full sample	0.465	0.016	0.891	0.000	0.522	0.008
≥20% higher ed.	0.688	0.012	1.636	0.000	0.904	0.026
<20% higher ed.	0.256	0.006	0.371	0.000	0.094	0.119

standard errors in parentheses

+ significant at 10%; * significant at 5%; ** significant at 1%

Table 3: Estimated difference between the variance in agglomerations and separations as well as p-values for the hypothesis that the variance of the residuals in agglomeration is smaller than or equal to the residuals in separation. The residuals were obtained from the specification in column (2) of Table 1. The columns correspond to the specifications in Table 2. The subsamples are defined by the mean fraction of employees with a higher education degree. This fraction has been calculated on the industry level across firms and time using the number of employees as weights.

results are stronger - or at least not weaker - in industries with a highly specialized labor force. We test this by comparing the results when the sample is split into two subsamples, industries with a highly specialized labor force and other industries. We follow Rosenthal and Strange (2001) and use the percentage of employees with a higher education degree as a proxy for the degree of specialization of the labor force. Rows 2 and 3 of Table 3 report, respectively, the differences and p-test values for industries with at least 20 per cent higher education employees and industries with less than that. The results are compelling. The difference between the agglomeration and separation coefficient is in all three specifications much higher for firms with a highly specialized workforce compared to the full sample (by 47.9% for (1), by 83.0% for (2) and by 73.1% for (3)). Remarkably, both subsamples have low p-test values comparable to the full sample lending additional, strong empirical support for our hypothesis.

A last issue that deserves some discussion concerns the possible endogeneity of the location decision. The theoretical analysis suggests that firms' location decision depends on their R&D technology, implying that firms in agglomerations and separations might have different R&D technologies. If so, this would influence our results, as the R&D technology affects the level and the variance in R&D expenditures. Controlling for a number of firm characteristics that can be expected to correlate with the R&D technology, such as size and skill composition of the labor force, also mitigates the endogeneity problem. Therefore, we argue that the problem is likely not to be severe in the above analysis. Taking the possible endogeneity fully into account in the estimation procedure is beyond the scope of this paper, and it is left for future research.

5 Conclusions

We have developed a model demonstrating some central trade-offs involved in the location decision of research intensive firms. A joint location induces the formation of a large labor pool for firms to draw from. This allows a firm with a successful R&D project to expand its production more than under separate locations, which works as an agglomerative force. At the same time, however, wages increase via tougher competition for workers, which is a deglomerative force.

From our analysis it emerges that firms tend to agglomerate when the equilibrium probabilities of R&D success are low. This is, for instance, the case when it is very costly to increase the success probability. We show that the *ex-ante* identical firms generically choose asymmetric R&D investments to avoid the tough labor market competition resulting from joint R&D success. This contributes to a higher variance of R&D efforts in agglomerations; a prediction shown to be consistent with data from German firms in R&D intensive industries.

Turning to welfare, agglomeration leads to two distinct advantages compared to separation. First, all labor is put to its most productive use under agglomeration but not necessarily under separation. Second, firms choose a more efficient portfolio of R&D projects under agglomeration. Whence the first effect also arises in models of exogenous productivity shocks such as Krugman (1991a), the R&D portfolio effect results from the firms' endogenous choice of R&D strategy. The effect is novel to the literature on labor pooling and represents one of the main insights of the paper.

In Gerlach et al. (2005) we study another important dimension of firms' R&D strategies, namely how ambitious a R&D project to target. A variant of the model is considered where firms strategically choose, at given research outlay, the risk-return profile of their R&D project. It shown that firms in agglomerations choose projects of different risk-return profiles. The asymmetric R&D strategies result also here in a more efficient R&D program at the industry level confirming the robustness of the R&D portfolio effect identified in this paper.

In our model firms always take the welfare maximizing R&D choices conditional upon location. Furthermore, as agglomeration in a cluster is welfare maximizing but not always the equilibrium outcome, the policy recommendation is to leave firms' R&D activities untouched, but to subsidize the formation of a cluster in situations where firms tend to stay apart; for instance in form of a tax break, or favorable land prices.[18] However, as usual, the welfare

[18]Such policies are widely used. For instance, the French government announced recently a policy initiative aimed at supporting six globally competitive clusters and no less than 61 "poles of competitiveness" (The Financial Times, 13.07.05). The financial incentives available to these "poles" are 1.5bn EUR, and the policies include subsidies to infrastructure investments but also R&D subsidies.

improving implementation of such a policy requires precise knowledge about the conditions under which such situations arise.

Appendix 1: Proofs

Proof of Proposition 2

(i) Consider first a symmetric equilibrium where $\phi_j^{A,*} = \phi_i^{A,*} = \phi^{A,*}$. Define:

$$\begin{aligned} \omega_1(\phi_i, \phi^{A,*}) &\equiv \partial\pi_i^A(\phi_i, \phi^{A,*})/\partial\phi_i \text{ for } \phi_i < \phi^{A,*}, \\ \omega_2(\phi_i, \phi^{A,*}) &\equiv \partial\pi_i^A(\phi_i, \phi^{A,*})/\partial\phi_i \text{ for } \phi_i > \phi^{A,*}. \end{aligned}$$

In equilibrium the following necessary conditions need to be satisfied:

$$\begin{aligned} \omega_1(\phi_i, \phi^{A,*}) &\geq 0 \text{ for } \phi_i \to (\phi^{A,*})_- \text{ and} \\ \omega_2(\phi_i, \phi^{A,*}) &\leq 0 \text{ for } \phi_i \to (\phi^{A,*})_+. \end{aligned}$$

These conditions ensure that $\phi_i^{A,*} = \phi^{A,*}$ is a local maximum for $\phi_j^{A,*} = \phi^{A,*}$. We have that

$$\begin{aligned} &\lim_{\phi_i \to (\phi^{A,*})_-} [\omega_1(\phi_i^{A,*}, \phi^{A,*})] - \lim_{\phi_i \to (\phi^{A,*})_+} [\omega_2(\phi_i^{A,*} \phi^{A,*})] \\ &= -\rho(\phi^{A,*})^2 \Delta'(\phi^{A,*}). \end{aligned}$$

Therefore, there is no symmetric equilibrium if $\Delta'(\phi^{A,*}) > 0$. Suppose instead that $\Delta'(\phi^{A,*}) = 0$. The first-order derivative of $\pi_i^A(\phi_i, \phi_j)$ is then continuous at $\phi_i^{A,*} = \phi^{A,*}$, which implies that $\pi_i^A(\phi_i, \phi^{A,*})$ is globally concave in ϕ_i. For $\Delta'(\phi^{A,*}) = 0$ the first-order condition (7) is thus both a necessary and a sufficient condition for a symmetric equilibrium in pure strategies to exist.

(ii) Consider now asymmetric equilibria where $\phi_i^{A,*} < \phi_j^{A,*}$. The first-order conditions (5) and (6) are necessary for an equilibrium to exist. We need to establish that if there exist $(\phi_i^{A,*}, \phi_j^{A,*})$ satisfying the first-order conditions, there exist no profitable deviations for the two firms. Consider firm i. Since the profit function of firm i is concave for $\phi_i \leq \phi_j^{A,*}$ and (5) is satisfied, there exists no profitable deviation to $\phi_i \leq \phi_j^{A,*}$. Instead consider a deviation to $\phi_i > \phi_j^{A,*}$. From symmetry follows that

$$\partial\pi_j^A(\phi_i, \phi_j)/\partial\phi_j \mid_{(\phi_i,\phi_j)=(\phi_i^{A,*},\phi_j^{A,*})} = \partial\pi_i^A(\phi_i, \phi_j)/\partial\phi_i \mid_{(\phi_i,\phi_j)=(\phi_j^{A,*},\phi_i^{A,*})} = 0.$$

Since $\pi_i^A(\phi_i, \phi_j)$ is concave for $\phi_i > \phi_j$, this implies that

$$\partial\pi_i^A(\phi_i, \phi_j)/\partial\phi_i \mid_{(\phi_i,\phi_j)=(\phi_j^{A,*}+\varepsilon,\phi_i^{A,*})} \leq 0$$

for all $\varepsilon > 0$. Finally, as $\partial^2\pi_i^A(\phi_i, \phi_j)/\partial\phi_i\partial\phi_j < 0$, we have that

$$\partial\pi_i^A(\phi_i, \phi_j)/\partial\phi_i^A < 0 \ \mid_{(\phi_i,\phi_j)=(\phi_j^{A,*}+\varepsilon,\phi_j^{A,*})} \ \forall\varepsilon > 0.$$

Continuity of $\pi_i^A(\phi_i, \phi_j)$ then implies that there exists no profitable deviation to $\phi_i > \phi_j^{A,*}$. A similar argument establishes that firm j neither has an incentive to deviate.

Existence and uniqueness of this equilibrium is established in the proof of Part (i) of Proposition 4.

Proof of Proposition 3

(i) In a symmetric equilibrium the first-order conditions (5) and (6) collapse into (7). It follows directly from a comparison of (4) and (7) that $\phi^{A,*} \geq \phi^{S,*}$ if and only if $\rho(\phi^{A,*}) \leq 1/2$. The profits from R&D investment are $\rho(\phi^{S,*})\Delta(\phi^{S,*})L/2 - g(\phi^{S,*})$ under separation and $\pi_i^A(\phi^{A,*}, \phi^{A,*})$ under agglomeration. Using $\phi^{A,*} \geq \phi^{S,*}$, it follows that the profits from R&D investment are highest under agglomeration for $\rho(\phi^{A,*}) \leq 1/2$ as

$$\rho(\phi^{S,*})\Delta(\phi^{S,*})L/2 - g(\phi^{S,*}) \leq \pi_i^A(\phi^{S,*}, \phi^{A,*}) \leq \pi_i^A(\phi^{A,*}, \phi^{A,*}).$$

A similar argument establishes that profits from innovation are highest under separation for $\rho(\phi^{A,*}) > 1/2$.

(ii) It follows directly from a comparison of the first-order conditions (4) and (5) that $\phi_i^{A,*} \geq \phi^{S,*}$ if and only if $\rho(\phi_j^{A,*}) \leq 1/2$. Since $\phi_i^{A,*} = \phi^{S,*}$ if $\rho(\phi_j^{A,*}) = 1/2$, we have that

$$\rho(\phi^{S,*})\Delta(\phi^{S,*})L/2 - g(\phi^{S,*}) = \pi_i^A(\phi_i^{A,*}, \phi_j^{A,*}).$$

The fact that firm j earns higher equilibrium profits than firm i and $\partial\pi_i^A(\phi_i, \phi_j)/\partial\rho(\phi_j) = -\rho(\phi_i)\Delta(\phi_i)L < 0$ imply that

$$\rho(\phi^{S,*})\Delta(\phi^{S,*})L/2 - g(\phi^{S,*}) \leq \pi_i^A(\phi_i^{A,*}, \phi_j^{A,*}) < \pi_j^A(\phi_i^{A,*}, \phi_j^{A,*})$$

if and only if $\rho(\phi_j^{A,*}) \leq 1/2$.

(iii) and (iv) Denote by $E(\pi_j^A)$ the expected profits of firm j under agglomeration. Notice that $E(\pi_j^A)$ is bounded from above and from below by the expected profits from R&D of the high and of the low investment firm, respectively. Reformulating the profits under separation shows that $v - \overline{u}$ merely shifts profits, and bears no impact on the determination of ϕ_j. Hence a unique level of $v - \overline{u}$ exists above which separation is preferred by firm j. Denote this threshold level ψ_j. Moreover, ψ_j is positive if firm j's expected profits from its R&D investment are greater under agglomeration than under separation. Similarly, ψ_j is negative, implying that the firm j prefers separation, if the expected profits from the R&D investment are lower under agglomeration. Applying the same argument to firm i and assuming that the firms can coordinate on a jointly preferred location outcome establish the results reported.

Proof of Proposition 4

(i) To ensure a strictly globally concave welfare function we assume throughout our analysis that

$$(i)\ W_{ii}, W_{jj} < 0,$$
$$(ii)\ W_{ii}W_{jj} - W_{ij}W_{ji} > 0,$$

where $W_{ij} = \partial^2 W/\partial\phi_i\partial\phi_j$. As can be easily checked, both conditions are satisfied if $g(\cdot)$ is sufficiently convex.

The equilibrium and the welfare maximizing R&D investments solve the same first-order conditions, (5) and (6). Since the welfare function is globally concave under the assumption that $g(\cdot)$ is sufficiently convex, there exists a unique $(\phi_i^{A,*}, \phi_j^{A,*})$ that solves the first-order conditions (modulo firm symmetry). Hence, we can also conclude that there exists one and only one pair that solves the equilibrium conditions of Proposition 2.

(ii) We have that

$$W^S(\phi^{S,*}, \phi^{S,*}) \leq W^A(\phi^{S,*}, \phi^{S,*}) \leq W^A(\phi_i^{A,*}, \phi_j^{A,*})$$

where the first inequality follows from the welfare analysis of the benchmark model presented in section 2. This proves the second part of the proposition.

6 Appendix 2: Data Descriptions

We started from the full panel of MIP firms which we observe from 1992 to 2004. This panel consists of 30,275 observations across firms and time. We dropped observations with missing information on turnover, missing *per capita* innovation expenditures or with more than 500,000 employees. We also excluded research institutes (NACE 731 and 732), outliers and miscodes. Outliers are defined as obervations where the *per capita* innovation expenditures exceed 10 times the industry average, firms whose innovation expenditures exceeded their turnover, and firms for which the year of birth was before 1000AD. In total, we dropped 10,340 observations.

We considered several definitions of separation and agglomeration which we summarize in Table 4. Naturally, the five definitions overlap. Table 5 contains the correlation between the definitions in the entire pooled MIP data set before dropping any observations. While the definitions of separation all correlate highly with each other, the first definition of agglomeration correlates badly with all other definitions because it is too restrictive. The weak correlation between definitions 2 and 4/5 shows that including additional restrictions in the

definition	separation	agglomeration
no. 1	only 1 firm	exactly 2 firms
no. 2	only 1 firm	2 or more firms
no. 3	1 or 2 firms	3 or more firms
no. 4	only 1 firm or less than 0.01 per cent of the employees of the industry	2 or more firms and at least 1 per cent of the employees of the industry and a HHI exceeding 0.18
no. 5	only 1 firm	2 or more firms and at least 1 per cent of the employees of the industry and a HHI exceeding 0.18

Table 4: Alternative definitions of separation and agglomeration, respectively.

latter is important as it helps to distinguish regions with a reasonable degree of labor market competition, which we try to identify, from regions in which there are simply many small firms as it could be the case for definition 2. At any rate, our results turn out to be robust with respect of the definition that was chosen.

Summary statistics across firms and years of the data set used for the analysis are contained in Tables 6 through 8.

Figure 4 shows the standard deviation of *per capita* innovation expenditure in agglomerations plotted against standard deviation in separations before controlling for firm characteristics. Agglomeration and separation are defined according to definition 5 in Table 4.

agglomeration	no. 1	no. 2	no. 3	no. 4	no. 5
no. 1	1				
no. 2	0.1345	1			
no. 3	-0.2308	0.9331	1		
no. 4	-0.0548	0.3519	0.3654	1	
no. 5	-0.0548	0.3519	0.3654	1	1

separation	no. 1	no. 2	no. 3	no. 4	no. 5
no. 1	1				
no. 2	1	1			
no. 3	0.6851	0.6851	1		
no. 4	0.8411	0.8411	0.6855	1	
no. 5	1	1	0.6851	0.8411	1

Table 5: Correlation between definitions of separation and agglomeration based on the full MIP data set.

Variable	Obs.	Mean	Std. Dev.	Min	Max
year	19,935	1,998.436	3.742349	1,992	2,004
number of employees	19,935	1,150.42	9878.368	1	44,6800
innovation expenditures	19,935	33.83918	349.9453	0	13,164.69
per capita R&D expenditures	19,935	0.0100784	0.0207005	0	0.3852586
percentage of employees with higher education degree	10,115	31.84532	28.65605	0	100

Table 6: Summary statistics of the data set used.

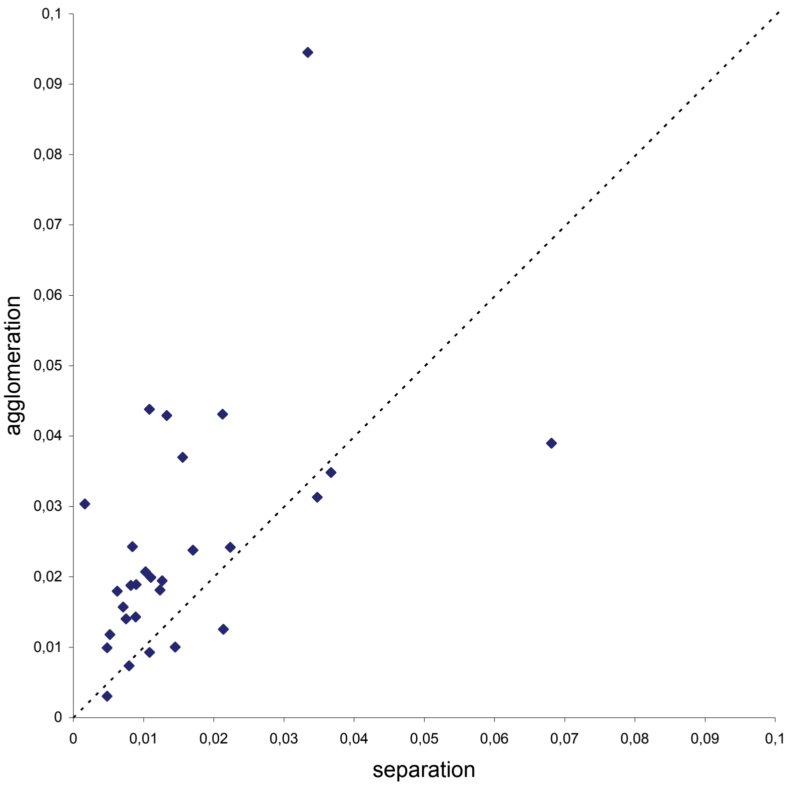

Figure 4: Standard deviation of *per capita* innovation expenditure in agglomerations plotted against standard deviation in separations.

year	separation no. 5	agglomeration no. 5
1992	46	200
1993	45	220
1994	50	351
1995	50	287
1996	33	211
1997	38	208
1998	45	295
1999	46	275
2000	56	322
2001	42	237
2002	64	340
2003	65	346
2004	58	299
Total	638	3,591

Table 7: Number of firms by year and location type.

NACE3	sep.	aggl.
Manufacture of refined petroleum products	0	5
Manufacture of basic chemicals	44	153
Manufacture of pesticides and other agro-chemical products	11	8
Manufacture of pharmaceuticals, medicinal chemicals and botanical products	37	114
Manufacture of soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations	16	93
Manufacture of other chemical products	15	129
Manufacture of machinery for the production and use of mechanical power, except aircraft, vehicle and cycle engines	23	234
Manufacture of other general purpose machinery	21	247
Manufacture of agricultural and forestry machinery	14	20
Manufacture of machine-tools	14	85
Manufacture of other special purpose machinery	0	94
Manufacture of weapons and ammunition	6	3
Manufacture of office machinery and computers	1	37
Manufacture of electric motors, generators and transformers	10	70
Manufacture of electricity distribution and control apparatus	39	68
Manufacture of accumulators, primary cells and primary batteries	2	15
Manufacture of lighting equipment and electric lamps	33	122
Manufacture of electrical equipment n.e.c.	6	54
Manufacture of electronic valves and tubes and other electronic components	28	121
Manufacture of television and radio transmitters and apparatus for line telephony and line telegraphy	34	91
Manufacture of television and radio receivers, sound or video recording or reproducing apparatus and associated goods	30	47
Manufacture of medical and surgical equipment and orthopaedic appliances	0	119
Manufacture of instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process control equipment	31	187
Manufacture of industrial process control equipment	37	71
Manufacture of optical instruments and photographic equipment	31	159
Manufacture of motor vehicles	32	78
Manufacture of parts and accessories for motor vehicles and their engines	31	138
Manufacture of railway and tramway locomotives and rolling stock	20	48
Manufacture of aircraft and spacecraft	31	69
Software consultancy and supply	2	186
Data processing	15	67
Data base activities	3	10
Architectural and engineering activities and related technical consultancy	0	504
Technical testing and analysis	21	145
Total	638	3,591

Table 8: Number of firms by NACE3 class and location type.

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