Modeling the New Economic Geography
– R&D, Vertical Linkages, Policy Implications

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Für Ilias.
In Dankbarkeit meiner Frau und meiner Familie.

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1 Introduction

The New Economic Geography (from now on NEG), initially introduced by Krugman (1991), provides explanations for industrial agglomeration based upon increasing returns and imperfect competition. The NEG has its origin in the new trade theory providing the analytical framework of monopolistic competition pioneered by Dixit and Stiglitz (1977), and Samuelson iceberg trade costs.

As Ottaviano and Puga (1998) point out, traditional and new trade theories explain differing industrial patterns due to comparative advantages, exogenously given differences in market size, technology, and factor endowments. Nonetheless, both theories do not explain: i) where these differences arise from and why initially similar countries diverge in their industrial structure; ii) why some industries agglomerate and other industries regionally specialize; and iii) why industrialization sometimes goes along with a sudden and drastic re-organization of industrial patterns.

However, the NEG claims to provide new approaches to answer these open-ended questions. In his much noticed survey article, Neary (2001) underlines that 'the key contribution of the new economic geography is a framework in which standard building blocks of mainstream economics [...] are used to model the trade-off between dispersal and agglomeration, or centrifugal and centripetal forces.'

As summarized by Baldwin et al. (2003), three effects basically determine the spread of industries in models of the NEG: i) the market-access effect, which reflects the tendency of firms to locate their production in a larger market and export to the one that is smaller; ii) the cost-of-living effect, which describes how the extent of industrial activities affects the consumer price index (therefore, also known as the price-index effect); and iii) the market-crowding effect, which is the preference of firms for locations with low competition. While the market-crowding effect counteracts industrial clustering, the market-access and cost-of-living effects imply a self-reinforcing agglomeration mechanism, also referred to as cumulative causation. In this context, migration-based demand linkages, as well as vertical input-output linkages, play a crucial role in explaining industrial concentration.

As a basic principle, the polynomial function, which occurs in terms of the wiggle diagram (see, e.g., Figure 3.3 for an illustration) as well as of the profit function (see, e.g., Figure 4.4), controls the number of equilibria and their stability. In this context, the wiggle diagram represents the wage differential for the internationally mobile workforce; the profit function controls the interregional market entry and exit dynamics of vertically linked manufacturing firms. Although both functions differ in terms of shape and denotation, they also share several common attributes. First, they feature a symmetric root constant with respect to changes in trade costs. Second, due to a limitation of domains (in case of the wiggle diagram, it is the share of the mobile workforce in one location; for the profit function, these are two non-zero conditions), both curves have two corner solutions. Their positions determine the sustain point at which locational hysteresis starts. Third, both functions contain an alternating slope in the symmetric equilibrium inducing a change in stability, which indicates the break point. Finally, this implies also two additional unstable interior solutions occurring for a small range of trade costs.

All in all, this behavior leads to the characteristic bifurcation pattern as exemplarily displayed in Figures 3.1 and 4.3. It is apparent that for high trade costs the dispersive equilibrium is the only (stable) outcome, because it is profitable for firms to locate in both markets. At the sustain point, t^S, the corner solutions also become stable. The extent of exogenous shocks sufficient to push the economy out of the symmetric equilibrium decreases with decreasing trade costs, until the break point, t^B, is reached. When this occurs, an infinitely small out of equilibrium fluctuation causes immediate agglomeration, also known as the core-periphery formation.

Fujita and Mori (2005) distinguish between three classes of NEG models: 1) core-periphery models; 2) regional and urban system models; and 3) international models. In regard to Krugman (1991), a few additional publications deal with variations and extension of the seminal core-periphery model with the characteristic bifurcation pattern as discussed above. In this context, Ottaviano (1996) and Forslid (1999) made a valuable contribution by the *footloose entrepreneur* model incorporating closed-form solutions of most endogenous variables, which reduced the formal intractability of NEG models. Instead of considering bi-locational constellations, the second category focuses on the distribution of industrial agglomerations. The class of urban and regional system models departs from the assumption of exogenously given (point) locations in order to incorporate continuous space and to follow the question of where in space agglomeration takes place. Starting from the 'race-track economy' approach of Krugman (1993), central contributions have been made, e.g., by Fujita and Krugman (1995), Fujita and Mori (1997), or Fujita, Krugman and Mori (1999). The third class of NEG models considers inter-industrial linkages as a driving agglomeration force. This kind of model considers spatial concentration and specialization on an international aggregation level, where labor is assumed to be immobile in contrast to regional and urban models. Seminal works have been provided by Krugman and Venables (1995), Venables (1996), and Puga and Venables (1996).

Nonetheless, due to the same analytical monopolistic-competition groundwork, the NEG also interacts with the endogenous growth theory. Baldwin (1999) demonstrates in the standard growth environment of Romer (1990) that agglomeration can also be a result of accumulation processes. Similarly, Martin and Ottaviano (1999) and Waltz (1996) picked up this approach and showed that the presence of localized knowledge spillover effects additionally induce agglomeration.

Based upon these theoretical approaches, newer literature also concerns the political dimension of the NEG. Baldwin et al. (2003) give an overview about the impact of trade, tax, and regional policies; again, the new trade theory provided basic approaches. Starting from trade and infrastructure policies (e.g., Forslid and Wooton (2003), Baldwin and Robert-Nicoud (2000), and Martin (1998)), the role of tax competition and the provision of local public goods (infrastructure, for instance) has been considered by Baldwin and Krugman (2004) or Ludema and Wooton (2000).

Even though the NEG has come to age since the first steps in 1991, there are still open issues for recent research. The present work introduces four theoretical papers, which primarily focus on R&D, inter-industrial linkages, and their policy implications. All in all, three issues basically motivated conception and realization: At first, previous NEG models did not incorporate endogenous R&D activities of firms. As discussed above, existing models include R&D only in a growth context, which increases the formal complexity and departs from the simple core-periphery formulation. Second, vertical linkages are extensively considered in the class of international models. In face of its formal simplicity, the majority of publications refers to the standard model of Krugman and Venables (1995), utilizing intra-industry trade in which the manufacturing sector produces its own intermediates. However, the results are similar to the core-periphery model, but the implications of vertical linkages, especially in terms of specialization, cannot be reproduced. In contrast, the more challenging version of Venables (1996), which considers an inter-industry framework of an explicit upstream and downstream sector, is often cited (143 citations according to IDEAS/RePEc), but only few papers were directly built on it: Puga and Venables (1996), Amiti (2005), Alonso-Villar (2005). The third issue concerns the calibration of real economies. Although hundreds of numerical simulations have been done in order to display the modeling outcomes, an application to particular industries in terms of their spatial formation and evolution is still a neglected field of research.

Against this background, the present work aims to make a contribution to these topics. All four papers will be briefly summarized at this point.

The first paper, entitled *Too Much R&D? - Vertical Differentiation and Monopolistic Competition*, discusses whether product R&D in developed economies tends to be too high compared with the socially desired level. In this context, a model of vertical and horizontal product differentiation within the Dixit-Stiglitz framework of monopolistic competition is set up where firms compete in horizontal attributes of their products, and also in quality that can be controlled by R&D investments. The paper reveals that in monopolistic-competitive industries, R&D intensity is positively correlated with market concentration. Furthermore, welfare and policy analysis demonstrate an overinvestment in R&D with the result that vertical differentiation is too high and horizontal differentiation is too low. The only effective policy instrument in order to contain welfare losses turns out to be a price control of R&D services.

The main contribution of this closed economy model in the course of the present work is a modeling framework, which can easily be adapted to the NEG. This has been approached in the second paper, *R&D and the Agglomeration of Industries*, in which the seminal core-periphery model of Krugman (1991) is extended by endogenous research activities. Beyond the common *anonymous* consideration of R&D expenditures within fixed costs, this model introduces vertical product differentiation, which requires services provided by an additional R&D sector. In the context of international factor mobility, the destabilizing effects of a mobile scientific workforce are analyzed. In combination with a welfare analysis and a consideration of R&D promoting policy instruments and their spatial implications, this paper also makes a contribution to the *brain–drain* debate.

In contrast to this migration based approach, the third paper, *Agglomeration, Vertical Specialization, and the Strength of Industrial Linkages*, focuses on vertical linkages in their capacity as an additional agglomeration force. The paper picks up the seminal model of Venables (1996) and provides a quantifying concept for the sectoral coherence in vertical-linkage models of the NEG. Based upon an alternative approach to solve the model and to determine critical trade cost values, this paper focuses on the interdependencies between agglomeration, specialization and the strength of vertical linkages. A central concern is the idea of an 'industrial base,' which is attracting linked industries but is persistent to relocation. As a main finding, the intermediate cost share and substitution elasticity basically determine the strength of linkages. Thus, these parameters affect how strong the industrial base responds to changes in trade costs, relative wages, and market size.

The fourth paper, *The Spatial Dynamics of the European Biotech Industry*, presents a simulation study of the R&D intensive biotech industry using the standard Venables model. Thus, it connects all three preceding papers and puts them into the real economic context of the European integration. The paper reviews the potential development of the European biotech industry with respect to its spatial structure. On the first stage, the present industrial situation as object of investigation is described and evaluated with respect to a further model implementation. In this context, the article introduces the findings of an online survey concerning international trade, conducted with German biotech firms in 2006. On the second stage, the results are completed by the outcomes of a numerical simulation within the NEG, considering vertical linkages between the biotech and pharmaceutical industries as an agglomerative force. The analysis reveals only a slight relocation tendency to the European periphery, constrained by market size, infrastructure, and factor supply.

In the final conclusions, central results of all four papers are summarized with respect to economic policy. Against the background of general legitimization and the impact of political intervention, Chapter 6 draws the main conclusions for location and innovation policies. In this regard, the industrial base concept, as well as the mobility of R&D, plays a central role during this discussion.

2 Too Much R&D? Vertical Differentiation and Monopolistic Competition

2.1 Introduction

Based upon the results of the Fourth Community Innovation Survey (CIS4) conducted by the European Statistical Office, in 2004 about 40% of European firms, which account for more than 260,000 enterprises, undertook research activities for developing new products and technologies, and for improving existing products and processes, respectively. In this regard, they spent more than €222 billion.[1] In regard to the nature of R&D, more than 53% of the firms invest in product and about 47% in process innovation.[2]

Against the background of empirical facts, this paper poses the question: Is the extent of product R&D in developed markets on a socially optimal level? Furthermore, in consideration of intensive policy efforts to expand private and public research activities (in the European Union within the scope of the *Lisbon Strategy*, for instance), a central concern is to discuss whether a categorical research promotion is consistent with welfare maximizing policy objectives.

Based upon these leading questions, an adequate modeling approach needs to meet a few requirements. First, for analyzing the allocation from a macroeconomic point of view, a general equilibrium framework is required to incorporate not only income and employment effects, but also a tax base for political intervention. Second, for implementing product R&D, the model needs to include endogenous quality and R&D decisions of firms. Third, for the sake of analytical simplicity, the modeling set up should produce a closed and stable solution set avoiding corner solutions and case differentiations.

In this context, Dixit and Stiglitz (1977) provided a powerful tool for modeling macroeconomic aggregates – the beginning of the 'second monopolistic revolution,' as contemplated by Brakman and Heijdra (2004). Since this pioneering work, the concept of monopolistic competition has enjoyed great popularity and has penetrated different fields of research. Basic models of international trade utilize the monopolistically competitive framework (e.g., Krugman (1979, 1980), Dixit and Norman (1980)), as well as fundamental contributions within the endogenous growth literature (e.g., Romer (1987, 1990), Lucas (1988)).

An essential attribute in models of monopolistic competition is horizontal product differ-

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[1] Data source: EUROSTAT database, Eurostat (2008), newly acceded countries not included.

[2] The distinction between product and process innovation follows the definitions of the Oslo Manual (Eurostat and OECD (2005)).

entiation, as described by Hotelling (1929) and advanced by Chamberlin (1933).[3] Beside differentiation in terms of product characteristics (e.g., design, color or taste), newer literature considers quality as an additional vertical dimension of product space.[4] The corresponding branch of industrial organization was originated by Shaked and Sutton (1982, 1983, 1987) and Gabszewicz and Thisse (1979, 1980). Following the classification of Sutton (1991), Schmalensee (1992) distinguished Type 1 and Type 2 industries. While a Type 1 industry is characterized by horizontally differentiated (or homogenous) products, Type 2 firms compete not only in price and horizontal product attributes, but also in perceived quality. In this context, quality is influenced by R&D expenditures, so that a firm may increase its market share by increasing the quality of its product.

In this paper we implement endogenous quality and R&D in the seminal model of Dixit and Stiglitz (1977), and analyze both vertical and horizontal product differentiation. In order to meet the demands discussed above, we set up a model with three sectors: i) a traditional constant-return sector producing a homogenous product; ii) a monopolistic-competitive sector producing a continuum of cross-differentiated consumer products; and iii) a separate R&D sector.

Whereas horizontal differentiation is a result of consumer's love of diversity and fixed production costs, vertical differentiation results from R&D investments of manufacturing firms. The R&D sectors receives corresponding expenditures from the manufacturing industry, and in turn, providing quality improving R&D services.

Due to the general equilibrium setting, private households consume both types of goods, and they also provide the required labor input for this economy. The entire labor force splits up in two factor groups: production workers employed in the traditional and manufacturing sectors, and highly skilled labor, e.g., scientists, engineers, etc., exclusively engaged in the R&D sector.

The paper is structured as follows. Section 2.2 introduces the basic model. Section 2.3 analyzes the existence and stability of the equilibrium. In this context, the interdependencies that exist between quality and market concentration turn out to be the central adjustment mechanism in this model. Based upon the first-best optimum as a reference for political intervention, Section 2.5 considers three basic policy instruments: i) price control of R&D services; ii) taxation/subsidization on R&D expenditures; and iii) a regulation of the technological potential. Finally, Section 2.6 presents a concluding discussion of the main findings and their practical implications.

2.2 The Model

Private Demand

Private households consume two types of goods: i) a homogenous good A produced by a

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[3] See Skinner (1986) and Rothschild (1987).

[4] Furthermore, product differentiation is formalized by the *Goods Characteristics* approach, as pioneered by Lancaster (1966). See Tirole (1988), Chapter 2.

Walrasian constant-return sector (often described as an agricultural sector or an outside industry); and ii) differentiated industrial products provided by a manufacturing sector. Consumer preferences follow a nested utility function of the form:

$$U = M^{\mu} A^{1-\mu}, \tag{2.1}$$

where M denotes a concave subutility from the consumption of the continuum of n (potential) industrial goods:[5]

$$M = \left[\sum_{i=1}^{n} (u_i)^{1/\sigma} (x_i)^{(\sigma-1)/\sigma} \right]^{\frac{\sigma}{\sigma-1}} \quad , \ \sigma > 1 \ , u_i > 0. \tag{2.2}$$

While x_i is the quantity consumed of variety i, u_i denotes a product-specific utility parameter, henceforth labeled *product quality*, and σ is the constant substitution elasticity between varieties.[6] Applying *Two-Stage Budgeting*, we obtain the demand function for a representative industrial product sort:

$$x^D = \mu Y u p^{-\sigma} P^{\sigma-1}, \tag{2.3}$$

where μY represents the share in household income for industrial products, and p the market price. Further on, P is the price-quality index defined to be:

$$P = \left[\sum_{i=1}^{n} u_i (p_i)^{1-\sigma} \right]^{\frac{1}{1-\sigma}} . \tag{2.4}$$

From equation (2.3) it can be seen that the elasticity of demand in terms of quantity is σ, and in terms of quality, it is 1. The price-quality index contains information about product quality as a result of its being the minimum cost for a given subutility M. The demand increases linearly with respect to rising product quality, which results from the constant substitution elasticity. Henceforth, we assume symmetric varieties so that the price-quality index becomes: $P = p\,(nu)^{1-\sigma}$.

Industrial Supply

Turning to the supply side of this model, the production of a particular variety requires labor as the only input. The corresponding factor requirement is characterized by a fixed and variable cost:

$$l^M = F + ax, \tag{2.5}$$

where M is mnemonic for manufacturing. Because of economies of scale and consumer preference for diversity, it is profitable for each firm to produce only one differentiated

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[5] Henceforth, the traditional sector is treated as the numeraire.

[6] The functional form of the subutility is based upon the numerical example of Sutton (1991), p. 48 et seq..

variety, so that the firm number is equal to the number of available product sorts.
Furthermore, each variety is characterized by a certain level of product quality, which can be controlled by research investments of manufacturing firms according to Sutton (1991). This implies that consumer products do not only differ in terms of horizontal attributes, such as color, taste or design, but also in terms of quality as another dimension of the differentiation space, which is also referred to as vertical product differentiation. In contrast to the original Dixit-Stiglitz framework, which incorporates horizontal differentiation only, firms now have a further degree of freedom to build up a monopolistic scope.
Attaining and maintaining a certain level of quality requires research expenditures given by:

$$R(u) = \frac{r}{\gamma} u^{\gamma} \ , \ \gamma > 1. \tag{2.6}$$

The parameter, r, represents a constant cost rate and γ the research elasticity. The research expenditure function shows a convex, deterministic relation implying that it requires more and more research investments to increase product quality.[7] Finally, research is assumed to be indispensable, because, otherwise, product quality and thus demand become zero.[8]
In consideration of production and research, the profit function of a manufacturing firm is given by:

$$\pi = px - R - wF - wax, \tag{2.7}$$

where w denotes an exogenous wage rate. From profit maximization follows the price-setting rule:

$$p^{*} = \left(\frac{\sigma}{\sigma - 1} \right) aw, \tag{2.8}$$

where the term in brackets is the monopolistic price mark-up on top of marginal production cost. For analytical convenience, we normalize the variable production coefficient, a, by $(\sigma - 1)/\sigma$, so that the profit maximizing price becomes w.
The optimum research policy follows from the first derivative of the profit function with respect to quality:

$$\mu Y u p^{-\sigma} P^{\sigma - 1} (p - wa) = r u^{\gamma}. \tag{2.9}$$

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[7] Although research is assumed to be exogenous, this model also allows to consider a stochastic influence. However, this facet is negligible for the motivation and the qualitative results of this paper.

[8] Sutton (1991) assumes a minimum product quality of 1, even if no research is undertaken. For analytical convenience, we simplify this proposition.

The term on the right-hand side of (2.9) represents the average change in research costs in consequence of a change in quality, whereas the left-hand side shows the corresponding increase of the operating profit (profit less research costs). The optimum quality is:

$$u^* = \left(\frac{\mu Y w^{1-\sigma} P^{\sigma-1}}{\sigma r} \right)^{\frac{1}{\gamma-1}}. \tag{2.10}$$

From equation (2.10), it can be concluded:

Proposition 2.1. *The firm's choice of quality depends upon the research cost rate and the degree of competition.*

The higher the cost rate, r, the lower is the product quality due to the optimum rule in (2.9). Decreasing competitive pressure may result from an increase of market size, a lower substitution elasticity, or a higher profit maximizing price. In this case, firms compete in quality rather than in prices. In other words, firms expand their research activities as the degree of competition decreases.
Furthermore, we obtain central information on the interdependency between market concentration (measured in number of firms) and research expenditures:

Proposition 2.2. *Via the price-index effect, product quality and the corresponding research expenditures are negatively correlated with the manufacturing firm number.*

This becomes apparent by substituting the price index into equation (2.10):

$$u^* = \left(\frac{\mu Y}{\sigma r n} \right)^{\frac{1}{\gamma}} \quad \Rightarrow \quad R^* = \frac{\mu Y}{\sigma \gamma n}. \tag{2.11}$$

The firm behavior, in terms of firm number and quality, affects demand via the price-quality index. In case of an increasing firm number, the price index declines, and thus, the demand for a particular variety. In consequence, the capacity of firms to finance R&D investments decreases, which in turn leads to a reduction of product quality.

Long Run Equilibrium

In the long run, the equilibrium is characterized by free market entry and exit, and thus, a variable firm number. From the zero-profit condition, we obtain the equilibrium output of each firm:

$$x^* = \sigma \left(\frac{R^*}{w} + F \right) = \frac{\mu Y}{\gamma w n} + \sigma F. \tag{2.12}$$

Compared to the original Dixit-Stiglitz outcome, which is simply σF, the firm size in this model is larger, and the equilibrium output depends not only upon exogenous

parameters, but also upon the endogenous research expenditures.
From (2.12), we can also derive the equilibrium labor input:

$$\left(l^M\right)^* = F + ax^* = \sigma F + \left(\frac{\sigma - 1}{\sigma}\right)\frac{\mu Y}{\gamma w n}. \tag{2.13}$$

Finally, the equilibrium firm number comes from the market clearing condition: $\mu Y = p^* x^* n^*$:

$$n^* = \frac{\mu Y}{\sigma F}\left(\frac{\gamma - 1}{\gamma}\right). \tag{2.14}$$

General Equilibrium
Considering the model from a macroeconomic point of view, we adopt a simple general equilibrium framework. To internalize wages and income, we introduce a separate R&D sector receiving the corresponding expenditures of the manufacturing industry. We assume a linear constant-return technology, where one unit of R&D requires one unit of scientific input (e.g., research staff).[9]
The production labor force is employed in the traditional and the manufacturing sectors, whereas it is assumed to be intersectorally mobile. In the traditional sector, the labor is used within a linear technology in which one unit of labor generates one unit of output. The factor demand of the manufacturing sector follows equation (2.13).
In the long run, the GDP of the economy consists of the labor income in the manufacturing and the constant-return sectors plus the earnings of the R&D sector (manufacturing profits are zero). Because the homogenous good is the numeraire, the corresponding price is set to 1. Hence, the income of private households is given by:

$$Y = wL^M + L^A + nR, \tag{2.15}$$

where L^M denotes the manufacturing employment, and L^A the agricultural workforce. Normalizing the entire production labor force, $L = L^M + L^A$, with 1, the household income becomes: $Y = w + nR$.
We assume an inelastic labor supply, whereas the manufacturing wage comes from the zero-profit condition, which determines the level of prices and thus of wages at which manufacturing firms break even. This wage rate can be derived by solving equation (2.3) for the price, p, and using the price setting rule (2.8):

$$w^* = \left(\frac{\mu Y u P^{\sigma - 1}}{x^*}\right)^{\frac{1}{\sigma}}. \tag{2.16}$$

Thus, equation (2.16) implies the simultaneous clearing of the labor and consumer product markets. Due to intersectoral labor mobility, the equilibrium wage rates equalize

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[9] In fact, instead of considering an autonomous sector, it may be possible to regard R&D as an in-house process of the manufacturing industry that is staffed from a particular labor market.

in both sectors at $w = 1$, so that the household income is given by $Y = 1 + nR$. Turning to the R&D sector, the cost rate, r, results from the market equilibrium of research services: $rL^R = nR$. The supply of R&D is assumed to be fixed and price-inelastic, which conveys the idea of (a state-controlled) technological potential or an innovation frontier of this economy. Using equation (2.11) and setting the total supply of R&D services, L^R, equal to 1, the research cost rate fulfills:

$$r = \frac{\mu Y}{\sigma\gamma}. \tag{2.17}$$

Equation (2.17) implies that the cost rate of R&D services, r, i) decreases with a rising research cost elasticity, γ; and ii) increases with an increasing market size, μY, and a decreasing homogeneity of consumer products, σ. Whereas the first result is self-explanatory, the second comes from the firm's quality policy given by equation (2.10), which states that the research expenditures increase with a lower degree of competition.

2.3 Equilibrium and Stability

Finally, by use of equations (2.14) and (2.17), the household income can be expressed as:

$$Y^* = \frac{\sigma\gamma}{\sigma\gamma - \mu}. \tag{2.18}$$

Substituting this expression with the price index and the equilibrium output (2.12) into the wage equation (2.16), we obtain for the firm number:

$$n^* = \frac{\mu}{F}\left(\frac{\gamma - 1}{\sigma\gamma - \mu}\right). \tag{2.19}$$

Using this expression, the equilibrium firm size can be expressed as:

$$x^* = \sigma F\left(\frac{\gamma}{\gamma - 1}\right). \tag{2.20}$$

For the equilibrium rate of research services, we obtain:

$$r^* = \frac{\mu}{\sigma\gamma - \mu}, \tag{2.21}$$

so that product quality and research expenditures become:

$$u^* = \left[\frac{F}{\mu}\left(\frac{\gamma\left(\sigma\gamma - \mu\right)}{\gamma - 1}\right)\right]^{\frac{1}{\gamma}} \tag{2.22}$$

$$R^* = \frac{F}{\gamma - 1}. \tag{2.23}$$

From equations (2.19) and (2.23) follows:

Proposition 2.3. *In consequence of fixed firm size, the equilibrium research expenditures are constant with respect to fixed production costs and the research cost elasticity.*

From (2.20) it becomes apparent that the equilibrium firm size depends upon exogenous parameters, as it is a characteristic result of the the Dixit-Stiglitz settings.[10] Because of this scale invariance, the sales revenues and thus the financial base for R&D investments is also constant, which in turn leads to a constant product quality.
For considering the relation between the central endogenous variables, quality and firm number, equation (2.11) can with equations (2.18) and (2.21) be expressed as:

$$u = \left(\frac{\gamma}{n}\right)^{\frac{1}{\gamma}}. \tag{2.24}$$

As demonstrated in Proposition 2.2, the lower the firm number, the higher the research expenditures and product quality. Furthermore, equation (2.24) represents research market clearing, which can be seen by rearranging to: $n\frac{u^{\gamma}}{\gamma} = 1\left(= L^{R}\right)$.
The opposite relationship can be derived from the manufacturing market clearing condition: $\mu Y = n^{*}p^{*}x^{*}$. The firm number with respect to quality is given by:

$$n = \frac{\mu\gamma\left(\gamma-1\right)\left(\sigma\gamma-\mu\right)}{\gamma^{2}\sigma F\left(\sigma\gamma-\mu\right)-\mu^{2}\left(\gamma-1\right)u^{\gamma}}. \tag{2.25}$$

Proposition 2.4. *The manufacturing firm number positively depends upon the level of product quality.*

The simple market size argument indicates that the higher the quality, the higher the R&D expenditures, and thus, the corresponding proportion of household income. This leads to an increase in market size and new firm entries.[11]
The interaction between equations (2.24) and (2.25) is displayed in the lower part of Figure 2.1 for a representative numerical example (parameter settings: $\sigma = 2$, $\gamma = 2$, $F = 1$, and $\mu = 0.2$). Both curves represent the clearing of the research and manufacturing markets, whereas the intersection of both curves indicates the equilibrium firm number and product quality. Based upon these results, we can state the following proposition:

Proposition 2.5. *There exists a unique, positive and globally stable equilibrium.*

Whereas the existence of the equilibrium directly follows from equations (2.18)–(2.23), the stability can be proven by assuming an out of equilibrium adjustment process:

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[10] The firm size in the present model is times the term in brackets higher than the firm size of the original Dixit-Stiglitz model.

[11] The polynomial (2.25) has a pole at $u = \left[\frac{\gamma^{2}\sigma F(\sigma\gamma-\mu)}{\mu^{2}(\gamma-1)}\right]^{1/\gamma}$, which is always below the equilibrium value (2.22).

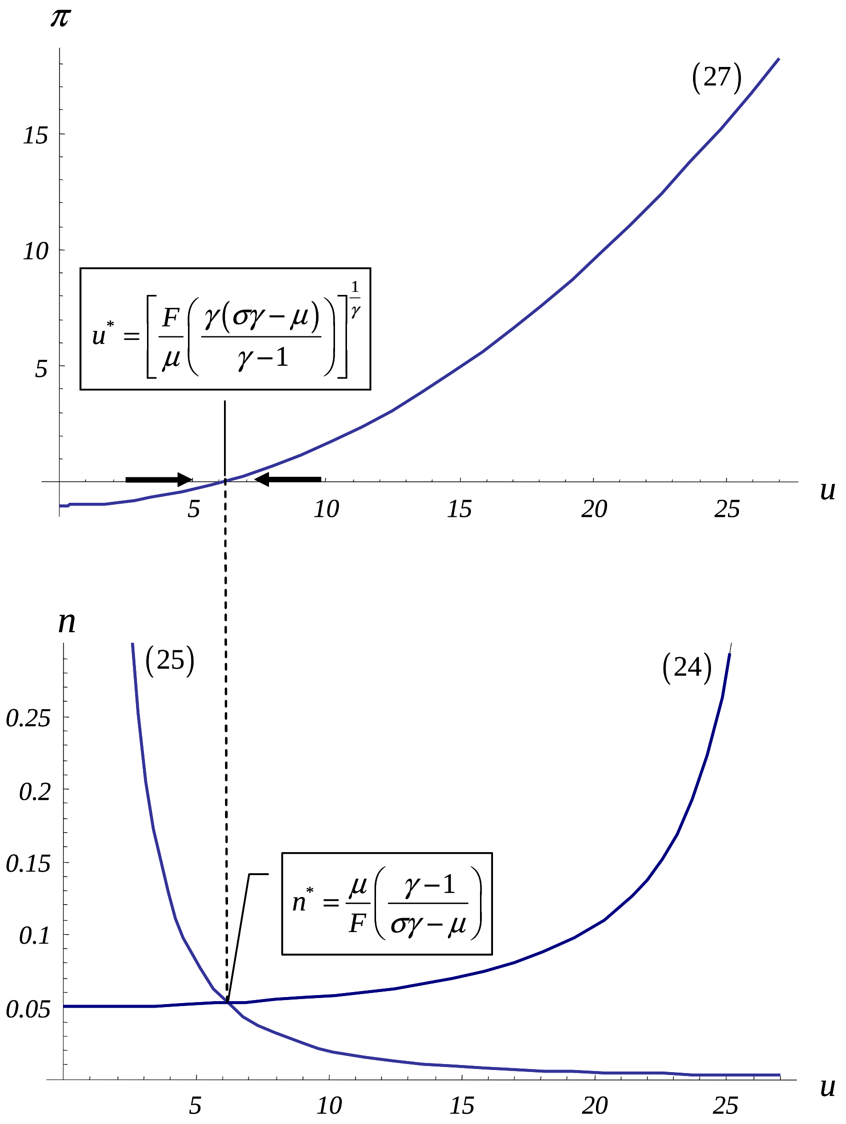

Figure 2.1: *Quality and firm number*

$\dot{n} = f(\pi), f(0) = 0, f' > 0.$[12]
Totally differentiating the profit function yields:

$$d\pi = \frac{p}{\sigma}dx + \left[\frac{\mu(\gamma-1)}{\sigma\gamma-\mu}u^{\gamma-1}\right]\frac{du}{u}. \tag{2.26}$$

As apparent, firm profits respond only to changes in demand and quality, while they are not affected by prices due to the price-setting rule. An increase in demand always gives rise to profits, and thus, to market entry of new firms. The same applies with a quality

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[12] See Neary (2001).

improvement. This dependency becomes apparent by expressing the profit function with respect to quality only:

$$\pi = \left(\frac{\gamma - 1}{\gamma}\right) r u^{\gamma} - wF. \tag{2.27}$$

For illustration, the upper diagram in Figure 2.1 shows the profit function (2.27). According to the total differential (2.26), an increase in product quality out of the equilibrium makes profits become positive due to an increase in demand. This leads to market entries of new firms. However, as given by equation (2.24) and Proposition 2.2, respectively, an increasing firm number is accompanied by decreasing R&D investments, and thus, a reduction of product quality down to the equilibrium level again.[13] Hence, the equilibrium has been proved to be globally stable, also indicated by the directional arrows in Figure 2.1.
Finally, the mutual interdependencies between firm number and quality comply with the results of Sutton (1998):

Proposition 2.6. *An increasing market concentration of industries accompanies a high R&D intensity. In the equilibrium, the R&D intensity increases with an increasing horizontal differentiation and decreasing costliness of research activities.*

This outcome can be shown by use of equations (2.11), (2.18)–(2.20):

$$\frac{R}{px} = \frac{\mu(\gamma - 1)}{\sigma F \gamma (\sigma\gamma - \mu) n} = \frac{1}{\sigma\gamma}. \tag{2.28}$$

In equation (2.28), R&D intensity is given by the ratio of R&D expenditures to turnover, and, as apparent, it is negatively correlated with the firm number. Furthermore, in the equilibrium, this ratio only depends upon substitution and research elasticity.

2.4 Intermediate Trade

In this section, we extend the model by a simple input-output structure, where the manufacturing industry uses differentiated intermediate products from an imperfect upstream sector, in accordance with Ethier (1982).[14] Instead of considering two separate sectors, we aggregate them to one manufacturing industry, where as a fixed proportion of output is used as input again. By this means, vertical linkages become horizontal, and inter-sectoral allocation intra-sectoral. The major implications are: i) the technical substitution elasticity for intermediates is identical to σ; ii) firms have the same quality

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[13] Alternatively, the profit function may be plotted with respect to firm number, which yields a monotonously decreasing hyperbola intersecting zero-profits at the equilibrium firm number. A firm number higher (lower) than this point implies negative (positive) profits, and thus, market exits (entries).

[14] This section is not part of the official publication in the Journal of Economic Studies, but included here with regard to the superordinate subject matter of the present work.

preferences as consumers; and iii) the price index for intermediates is the same as for final products. The corresponding production function is:

$$F + ax = Zl^{1-\alpha} I^{\alpha} \quad , \quad I = \left[\sum_{i=1}^{n} (u_i)^{1/\sigma} (x_i)^{(\sigma-1)/\sigma} \right]^{\frac{\sigma}{\sigma-1}} , \tag{2.29}$$

where I denotes an input composite of a continuum of differentiated products, which is the similar to the subutility M.[15] From two-stage budgeting, we obtain the cost function, which is the analogue of the expenditure function of consumers:

$$C = (F + ax) \, w^{1-\alpha} P^{\alpha} + R. \tag{2.30}$$

The intermediate demand function is:

$$x^u = \alpha \, (C - R) \, up^{-\sigma} P^{\sigma-1}, \tag{2.31}$$

where u denotes *upstream*. The total demand for a particular variety is composed of consumer and intermediate demand, x^d and x^u:

$$x = x^d + x^u = up^{-\sigma} P^{\sigma-1} \left[\mu Y + n\alpha \, (C - R) \right], \tag{2.32}$$

where the term in square brackets represents the total expenditures for industrial products, henceforth denoted by E. Equation (2.32) reflects the forward and backward linkages between firms. The more firms produce in the economy, the higher the intermediate demand, which in turn increases firm number. By contrast, as the number of firms increases, the price index decreases, implying a decrease of procurement costs for intermediates on one hand, and an increase of competition on the other hand. The interaction between these two forces is crucial for the model dynamics in this section. From profit maximization, we obtain the same price-setting rule as in the previous section:

$$p^* = w^{1-\alpha} P^{\alpha}, \tag{2.33}$$

where the term on the right hand side describes marginal cost as a composite of wage rate and intermediate prices. The optimum product quality is given by:

$$u^* = \left(\frac{x^D w^{1-\alpha} P^{\alpha}}{\sigma r} \right)^{\frac{1}{\gamma}} . \tag{2.34}$$

The associated research investments are:

$$R^* = \frac{x^D w^{1-\alpha} P^{\alpha}}{\gamma \sigma}. \tag{2.35}$$

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[15] Z represents a level parameter, which is normalized by $(1-\alpha)^{\alpha-1} \alpha^{-\alpha}$.

Using this expression, the equilibrium firm size results from the zero-profit-condition:

$$x^* = \sigma F \left(\frac{\gamma}{\gamma - 1} \right), \tag{2.36}$$

which is the same as in the model without vertical linkages. Turning to the labor market, the equilibrium wage rate follows from the wage equation:

$$\left(w^{1-\alpha} P^{\alpha} \right)^{\sigma} = \frac{u P^{\sigma - 1} E}{x}. \tag{2.37}$$

Due to inter-sectoral labor mobility, the wage rate is 1. In the research market, the equilibrium price for R&D services can be expressed with equations (2.35) and (2.36) as:

$$r = \left(\frac{1}{\gamma - 1} \right) n F P^{\alpha}. \tag{2.38}$$

With regard to the relation of quality and market concentration, it can be concluded:

Proposition 2.7. *Including intermediate trade, Proposition 2.2 remains valid. The product quality is in the same manner negatively correlated to firm number as in the model without intra-industrial trade.*

This result can easily be reproduced by substituting equations (2.36) and (2.38) into (2.34) leading to the same dependency as given by (2.24) in the previous section.
For the determination of the equilibrium firm number, the zero-profit condition, now $E = npx$, holds. Using equations (2.30)-(2.38), the firm number with respect to quality is:

$$n^* = \left[\frac{\mu (\gamma - 1)}{F \left(\sigma \gamma (1 - \alpha) + \alpha - \mu \right)} \right]^{\frac{(1-\sigma)(1-\alpha)}{(1-\sigma)(1-\alpha)+\alpha}} u^{\frac{\alpha}{(\sigma-1)(1-\alpha)-\alpha}}. \tag{2.39}$$

The firm number is positive due to a positive term in square brackets. Furthermore, considering the ambiguous sign of the exponent in equation (2.39), we can put forward the following proposition:

Proposition 2.8. *In contrast to Proposition 2.4, the firm number is negatively correlated with product quality, if:* $\left(\frac{1}{\sigma - 1} \right) \left(\frac{\alpha}{1 - \alpha} \right) > 1$.

The correlation between firm number and quality depends upon the strength of two competing forces arising from intra-sectoral linkages: (1) On one hand, an increasing quality raises R&D investments and simultaneously consumer and intermediate demand, which leads to market entries of new firms. (2) On the other hand, increasing quality reduces the price index, which leads to a reduction of demand and accompanying market exits of firms. Additionally, an increasing quality implies higher research expenditures, and thus, a smaller budget for intermediates. In this context, the production cost

$(C-R)$ can be expressed as: $FP^{\alpha}\left(\frac{\gamma\sigma-1}{\gamma-1}\right)$. It is apparent that a decreasing price index results in lower production costs, reducing the intermediate demand due to the constant cost share α.

Finally, the stronger intra-sectoral linkages, which is given for high values of the intermediate share, α, and low values of the substitution elasticity, σ, the stronger is the second effect.

Considering the equilibrium state, product quality and firm number are:

$$u^{*}=\gamma^{\frac{\alpha}{\gamma(1-\sigma)(1-\alpha)+\gamma\alpha-\alpha}}\left[\frac{\mu\left(\gamma-1\right)}{\gamma F\left(\sigma\gamma\left(1-\alpha\right)+\alpha-\mu\right)}\right]^{\frac{(1-\sigma)(1-\alpha)}{\alpha-\gamma(1-\sigma)(1-\alpha)-\gamma\alpha+\alpha}} \tag{2.40a}$$

$$n^{*}=\gamma^{\frac{\alpha-\gamma(1-\sigma)(1-\alpha)}{\alpha-\gamma(1-\sigma)(1-\alpha)-\gamma\alpha+\alpha}}\left[\frac{\mu\left(\gamma-1\right)}{\gamma F\left(\sigma\gamma\left(1-\alpha\right)+\alpha-\mu\right)}\right]^{\frac{\gamma(\sigma-1)(1-\alpha)}{\gamma(\sigma-1)(1-\alpha)-\alpha(\gamma-1)}}. \tag{2.40b}$$

From equations (2.40) follows:

Proposition 2.9. *Including intermediate trade, Proposition 2.5 remains valid: The equilibrium is unique, positive and globally stable.*

The stability may be proven by the same approach as exercised in the previous section. Totally differentiating the profit function yields:

$$d\pi=\left[\frac{1}{\sigma}\right]dx+\left[\underbrace{\left(\frac{\alpha}{(1-\sigma)\left(1-\alpha\right)}\right)}_{<0}\underbrace{\left(\frac{\mu-\left(\gamma\sigma-\alpha\left(\gamma\sigma-1\right)\right)}{\gamma\sigma+\gamma\alpha\left(1-\sigma\right)-\mu}\right)}_{<0}FP\right]\frac{du}{u}. \tag{2.41}$$

As in the model without linkages, profits and firm number respond positively on demand and quality, which ensures global stability.

2.5 Welfare and Policy Analysis

With respect to the allocation outcome in imperfect markets and the basic question of this paper, this section considers R&D policy instruments and their efficiency in terms of social welfare. First, we determine the first-best optimum as a reference to the cases in which public institutions are in position: i) to regulate the price for R&D services; ii) to impose a tax/subsidy on R&D expenditures; and iii) to control the technological potential.

First-Best Optimum

For considering the product quality as the central concern of this paper, we need to determine the socially optimal degree of vertical differentiation. The optimization problem of a social planner is to maximize household utility subject to technological and resource constraints:[16]

$$\max_{(M,A,n,u)} \quad U = M^{\mu} A^{1-\mu} \quad s.t. \;\; L^{M} = A + n\left(F + ax\right) \quad , \quad L^{R} = \frac{n}{\gamma} u^{\gamma}. \tag{2.42}$$

From the first-order conditions, we obtain a firm size, which is the same as in the equilibrium (2.20). In contrast, the socially optimal firm number and quality differ.[17]

$$n^{*} = \frac{\mu\left(\gamma - 1\right)}{F\left[\gamma\left(\sigma - 1\right) + \mu\left(\gamma - 1\right)\right]} > n^{e} \tag{2.43}$$

$$u^{*} = \left[\left(\frac{\gamma}{\gamma - 1}\right)\frac{F}{\mu}\left(\gamma\left(\sigma - 1\right) + \mu\left(\gamma - 1\right)\right)\right]^{\frac{1}{\gamma}} < u^{e} \tag{2.44}$$

From these equations follows:

Proposition 2.10. *While the first-best firm size complies with the equilibrium firm size, the socially optimal quality is lower, and thus, the socially optimal number of varieties is higher than the laissez-faire equilibrium.*

This results from the monopolistic scope of manufacturing firms. Because prices are set above marginal costs, firms overinvest their additional revenues in R&D to further increase demand. As a consequence of Proposition 2.2, if the equilibrium quality is too high, the firm number is too low.[18] The equilibrium welfare is:[19]

$$W^{e} = \gamma^{\frac{\mu}{\sigma - 1}}\left(\frac{\sigma\gamma}{\sigma\gamma - \mu}\right)\left[\frac{\mu}{F}\left(\frac{\gamma}{\gamma - 1}\right)\left(\frac{1}{\sigma\gamma - \mu}\right)\right]^{\frac{\mu(\gamma - 1)}{\gamma(\sigma - 1)}}. \tag{2.45}$$

From these results it can be concluded that setting minimum quality standards would miss the welfare maximum, whereas maximum standards are not practicable.

Optimal Control of Research Costs

With regards to the unconstrained optimum discussed above, there are lifelike more constraints for real economic policy. Deviating from the social planner approach, we now consider a constrained optimum, where policymakers are restricted in their instruments. We assume that the state can control the research cost rate, which may be motivated

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[16] Rearranging equation (2.2) provides an expression for x.

[17] In this section, the superscript, e, denotes the market equilibrium outcome, $*$ the first-best and $**$ the second-best values, respectively.

[18] This complies with the welfare results of the Dixit-Stiglitz model. See the introduction of Brakman and Heijdra (2004), p. 19 et seq., for instance. Furthermore, also the new growth theory came to similar results, whereas the optimum R&D level is not inevitably lower than the market outcome depending upon the extent of countervailing (technological) external effects.

[19] We neglect the term $\mu^{\mu}\left(1 - \mu\right)^{1-\mu}$.

by a publicly owned or regulated R&D sector. The argument for public intervention is the failure not of the competitive research market itself, but rather of the corresponding downstream sector.

In consideration of the inelastic supply of R&D services, the choice of a research cost rate is linked with excess supply or demand, so that case differentiation is required for the derivation of the welfare function.

First, we consider a cost rate above the equilibrium value, so that the demand for R&D becomes the limiting factor. While household income, firm number, and firm size remain constant, quality decreases due to the firm's policy. Although research investments do not change, employment in the R&D sector declines. The welfare function with respect to the research cost rate can be expressed as:

$$W\left(r > r^{*}\right) = \left[\frac{\sigma\gamma}{\sigma\gamma - \mu}\right]\left[\left(\frac{F\gamma}{\gamma - 1}\right)\frac{\mu\left(\gamma - 1\right)}{F\left(\sigma\gamma - \mu\right)}\right]^{\frac{\mu}{\sigma - 1}} r^{\frac{\mu}{\gamma(1-\sigma)}}. \tag{2.46}$$

The terms in square brackets are positive: the welfare decreases monotonically with increasing cost rate so that a scale-up of r leads always to welfare losses.

If the cost rate is set below the equilibrium value, the demand for R&D services is larger than the market capacity. Consequently, quality becomes:

$$u = \left[\frac{\gamma\sigma F}{\mu - r\left(\sigma - \mu\right)}\right]^{\frac{1}{\gamma}}. \tag{2.47}$$

The welfare function is now:

$$W\left(r < r^{*}\right) = \left(1 + r\right)\gamma^{\frac{\mu}{\gamma(\sigma-1)}}\left[\frac{\mu\left(1 + r\right) - r\sigma}{\sigma F}\right]^{\frac{\mu(\gamma-1)}{\gamma(\sigma-1)}}. \tag{2.48}$$

The limiting values of equation (2.48) are $\left(\frac{\mu}{\sigma F}\right)^{\frac{\mu(\gamma-1)}{\gamma(\sigma-1)}}$ for $r \rightarrow 0$ and $-\infty$ for $r \rightarrow \infty$.[20] From (2.48), the welfare maximizing research cost rate is:

$$r_{max} = \frac{\mu\left[\mu\left(\gamma - 1\right) + \sigma - \gamma\right]}{\sigma\left[\gamma\left(\sigma - 1\right) - \mu\right] + \mu\left[\gamma - \mu\left(\gamma - 1\right)\right]} < r^{e}. \tag{2.49}$$

If we do not allow for negative values of (2.49), the socially optimal research cost rate is defined as:

$$r^{**} = \begin{cases} r_{max} \;\; \forall \;\; \gamma < \frac{\sigma-\mu}{1-\mu} \\ 0 \;\; \forall \;\; \gamma > \frac{\sigma-\mu}{1-\mu}. \end{cases} \tag{2.50}$$

From this outcome it can be concluded:

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[20] If $\left(\frac{\gamma-1}{\gamma}\right) < \left(\frac{\sigma-1}{\mu}\right)$ holds, the domain of r is $]0, \frac{\mu}{\sigma-\mu}[$ due to a negative root. The upper limit is greater than the equilibrium cost rate without regulation so that it is not a part of the total (piecewise-defined) welfare function (2.46) and (2.48).

Proposition 2.11. *The second-best research cost rate,* r^{**}*, is always lower than the equilibrium value,* r^e*. The corresponding second-best quality and firm number are equal to the first-best values but implying a lower welfare level:* $W^* > W^{**} > W^e$*.*

If we complete the welfare function for the whole range of r, we must consider both equations (2.46) and (2.48). The graphs intersect at their lower and upper limits: the non-regulated equilibrium r^e. Thus, we obtain a continuous but non-differentiable welfare function. Figure 2.2 depicts the socially optimal and unregulated research cost rate and the corresponding welfare values for the same parameter values as in Figure 2.1. The welfare statement of Proposition 2.11 can be proved as follows. The firm size with respect to quality and research cost rate is:

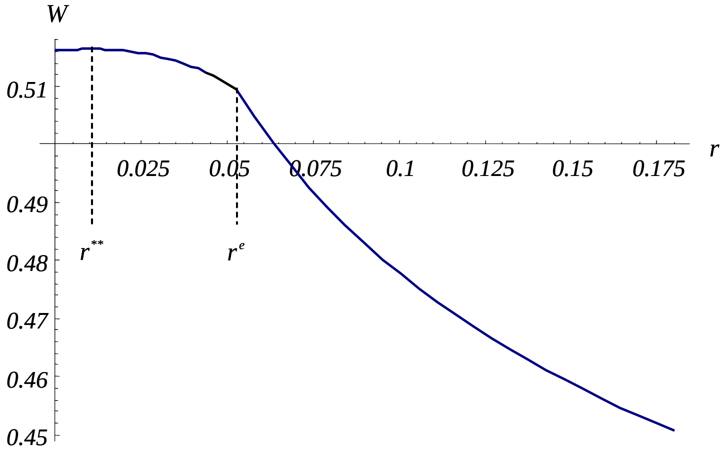

Figure 2.2: *Research cost rate and welfare*

$$x = \sigma \frac{r}{\gamma} u^{\gamma} + \sigma F. \tag{2.51}$$

Accordingly, the firm number can be expressed as:

$$n = \frac{\mu}{\frac{r^{**}}{\gamma} u^{\gamma} (\sigma - \mu) + \sigma F}. \tag{2.52}$$

From the research market clearing condition we obtain: $1 = \frac{n}{\gamma} u^{\gamma}$. Substituting equation (2.52) and solving for the research cost rate yields:

$$u^{**} = \left(\frac{\sigma \gamma F}{r^{**} (\sigma - \mu) - \mu} \right)^{1/\gamma}. \tag{2.53}$$

From equations (2.52) and (2.53) it can easily be derived that $u^* = u^{**}$ and $n^* = n^{**}$. The difference between first-best and second-best allocation is the manufacturing output given by equation (2.51). Because $r^{**} < r^e = r^*$, $x^{**} < x^* = x^e$. This leads to lower

economies of scale, and thus, to a lower welfare level of the second-best solution compared to the first-best.[21]
Including a tax to finance the research price reduction, leads to exactly the same results. The subsidized research price becomes: $r = r^e - \tau$, where τ is a non-negative transfer to R&D firms. In turn, private households pay a lump-sum tax on income: $Y = 1 - \tau + r^e$. Solving the model via the clearing condition of the R&D market yields a firm number and quality on the first-best levels given by equations (2.43) and (2.44). The corresponding welfare function with respect to the research subsidy is:

$$W(\tau) = \gamma^{\frac{\mu}{\gamma(\sigma-1)}} \left[\frac{\sigma\gamma(1-\tau)+\mu\tau}{\sigma\gamma-\mu}\right] \left[\frac{\sigma\mu(\gamma-1)+\tau(\sigma\gamma-\mu)(\sigma-\mu)}{\sigma F(\sigma\gamma-\mu)}\right]^{\frac{\mu(\gamma-1)}{\gamma(\sigma-1)}}. \quad (2.54)$$

Figure 2.3 shows the welfare function (2.54). For $\tau = 0$, the welfare takes the equilibrium value and becomes 0, if the maximum tax base is totally exhausted: $\tau = Y^e$. Maximization leads to the second best subsidy level:

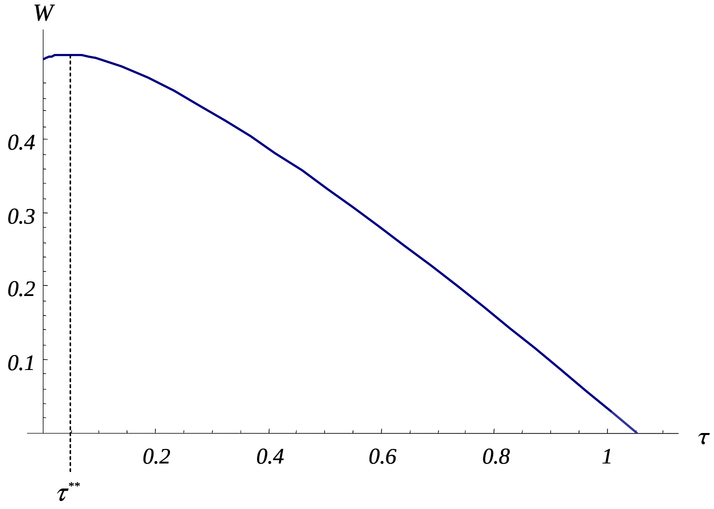

Figure 2.3: *Second-best R&D subsidy*

$$\tau^{**} = \left(\frac{\gamma-1}{\sigma\gamma-\mu}\right)\left(\frac{\mu\sigma\gamma}{\sigma-\mu}\right)\left(\frac{1-\mu}{\mu(\gamma-1)+\gamma(\sigma-1)}\right), \quad (2.55)$$

which corresponds with the research policy (2.50).
However, it is a noteworthy fact that reducing quality to the optimum level, is only realizable by a reduction/subsidization of the research market price. This seems to be

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[21] It follows from the second resource constraint in equation (2.42) implying perfect competition in the research market that the research cost rate is the same for equilibrium and first-best solution: $r^e = r^*$.

contrary to intuition and partial analytical results. In general, this dependency can be traced back to the disequilibrium in the research market. The decreasing research cost rate increases demand for R&D services. Because the supply is fixed and inelastic, the limited research output is rationed to the number of manufacturing firms. In consequence, the quality remains unchanged, whereas the research investments, and thus the fixed costs, decline, which makes firm profits become positive and new firms enter the market. Due to equations (2.24) and (2.51), the quality and firm size decrease to the (constrained) optimum level.

R&D Tax/Subsidy

Based on the results above, it may be a political option to raise a tax on R&D expenditures. Thus, the firm's profit function becomes:

$$\pi = px - awx - wF - R - \tau R, \tag{2.56}$$

where τ is a tax rate with respect to the R&D expenditures. At the first stage, the firms decrease their quality and R&D investments, whereas the price setting given by equation (2.8) holds. However, the supply of R&D is fixed and totally employed so that a reduction in demand leads to reduction of the research price and the corresponding income of R&D suppliers. Overall, the market size decreases, and thus, the number of firms, whereas the quality remains on the equilibrium level. This implies a reduction of social welfare.

If we assume for simplicity that the tax is used to pay a lump-sum grant for consumers, $Y = 1 + n\tau R + nR$, the market size is constant because of a 1:1 transfer between households. The overall effect is a decrease of the equilibrium research cost rate only, while the income, firm number and quality remain on the equilibrium values. In conclusion, this policy instrument turns out to be non-effective.[22]

Technological Potential

An alternative policy instrument exists in the control of the supply of R&D services and scientific personnel. In the first stage, we neglect the financing of public market intervention, but rather consider the impact on allocation and welfare.

In Section 2.2, we set the supply of R&D equal to 1. Here we relax this restriction and allow L^R to be non-zero positive. As a result, the equilibrium research cost rate becomes:

$$r^* = \frac{\mu}{L^R\left(\sigma\gamma - \mu\right)}, \tag{2.57}$$

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[22] The same implications hold, if we assume an R&D subsidy financed by a lump-sum tax on household income.

where income remains constant at (2.18). The equilibrium quality can now be expressed as:

$$u^* = \left[\frac{FL^R\gamma\left(\sigma\gamma - \mu\right)}{\mu\left(\gamma - 1\right)}\right]^{\frac{1}{\gamma}}. \tag{2.58}$$

As a result of the price inelasticity, an increase in the research supply allows firms to improve the quality without increasing their research investments. In consequence, market concentration and firm size remain unchanged. If the firm number is constant with increasing quality, the price index declines, ultimately increasing real income and welfare. In summation, these results imply:

Proposition 2.12. *An increase in R&D supply leads to a higher quality with unaffected market concentration. However, this policy increases social welfare, but it always fails to meet the welfare maximum.*

In the next step, we assume that the technological potential can be expanded by public expenditures financed by a lump-sum tax on household income. Up to now, the model was subject to a linear relationship of scientific work input and research output. Relaxing this restriction, market clearing requires:

$$L^R = \alpha\frac{n}{\gamma}u^\gamma, \tag{2.59}$$

where α denotes a productivity parameter in the production of R&D services. This technological capacity can be controlled by public expenditures given by:

$$\alpha\left(\tau\right) = \left(1 + \tau\right)^\beta \quad , \quad 0 < \beta < 1. \tag{2.60}$$

Accordingly, household income is:

$$Y = 1 + nR - \tau \quad , \quad 0 < \tau < 1. \tag{2.61}$$

From these settings follows that firm size and R&D expenditures are on the laissez-faire equilibrium level, whereas product quality and firm number become:

$$n = \frac{\mu}{F}\left(\frac{\gamma - 1}{\sigma\gamma - \mu}\right)\left(1 - \tau\right) < n^e \tag{2.62}$$

$$u = \left[\frac{F}{\mu}\left(\frac{\sigma\gamma - \mu}{\alpha\left(1 - \tau\right)}\right)\left(\frac{\gamma}{\gamma - 1}\right)\right]^{1/\gamma} > u^e. \tag{2.63}$$

From equations (2.62) and (2.63) it can be seen that for $\tau > 0$ the firm number is lower and the product quality is higher compared with the unregulated results. This leads us to the conclusions:

Proposition 2.13. *A publicly financed enhancement of product R&D capacities corresponds with a loss of social welfare in comparison with the laissez-faire, and thus, also with the first-best and second-best solution.*

The welfare function with respect to the tax rate is given by:

$$W = (1+\tau)^{\frac{\mu\beta}{\gamma(1-\sigma)}} W^e < W^e. \tag{2.64}$$

Figure 2.4 plots this function for the standard numerical example. From equation (2.64) follows a monotonic decreasing function, where $W(\tau = 0) = W^e$ and $W(\tau = 1) = 0$.

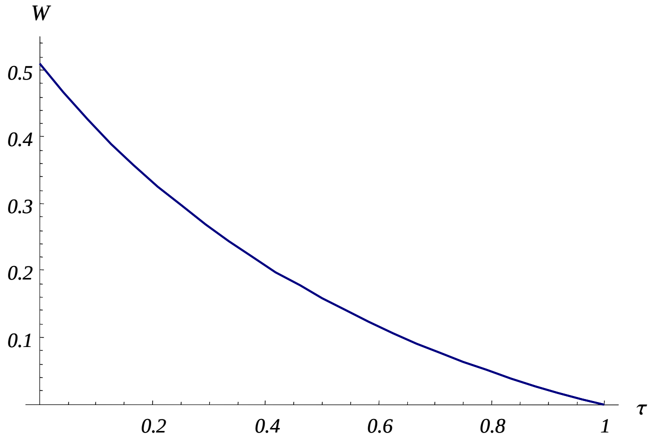

Figure 2.4: *Technological potential (required tax) and welfare*

2.6 Conclusions

The welfare and policy analysis pointed out that in economies with monopolistic–competitive industries, the degree of vertical differentiation, and thus the extent of product R&D, is higher than the socially optimum level. Furthermore, the horizontal product diversity is too low, which is primarily a result of too few manufacturing firms and a consequently higher price index.

As the paper reveals, the only effective policy instrument to contain welfare losses to the second-best optimum is to regulate the market price within the research sector. The basic idea is to generate a disequilibrium in the R&D market, and thus, to decrease the level of a firm's R&D expenditures by a rationing process. As demonstrated, this outcome critically depends upon the assumption of a fixed and price-inelastic R&D supply here conveying the idea of a technological potential. Relaxing this assumption would also make the research subsidization of manufacturing firms become efficient. However political intervention is realized, a public technology promotion in terms of product R&D has been shown to be the wrong way.

Hence, the efficiency of real economic policy requires a differentiated consideration. A categorical promotion of private or public R&D has to be questioned according to the nature on innovation and its impact on social welfare. Practically, policy efforts encounter some problems. Oftentimes a clear distinction between product and process R&D is difficult, even more so in the case of fundamental research and future applications.

Furthermore, the model considers an aggregate of manufactures and evaluates the optimum quality level by means of real income. Because of the macroeconomic perspective of this paper, an individual perception of quality is neglected. Thus, the argumentation of social welfare is not less a matter of the consumer's preferences but rather of income and employment effects. Finally, the results differ with respect to variations in market structure and partial analysis.[23]

In the face of the underlying assumptions, the model neglects two important issues. First, the paper does not include R&D cooperations among (manufacturing) firms due to the non-strategic Dixit-Stiglitz settings. Second, it may be interesting to consider spillover effects. In this context, the quality of a particular firm i is not only dependent upon the input of its own research input, $u_i\left(L_i^R\right)$, but also upon the R&D efforts of the whole sector: $u_i\left(L_i^R, \sum_{j=1}^{n} L_j^R\right)$. Including both sources of market failure, increasing returns and (positive) externalities, would produce allocation outcomes differing from the results presented in this paper. Nonetheless, they may expand political options and open up combinations of regulation instruments.

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[23] See, e.g., Symeonidis (2003).

3 R&D and the Agglomeration of Industries

3.1 Introduction

The Lisbon Strategy, constituted by the European Council in 2000 and revised in 2005, was targeted "to make the European Union (EU) the leading competitive economy in the world and to achieve full employment by 2010". A central part of this ambitious objective is to establish a sustainable growth based upon innovation and a knowledge-based economy. The Lisbon Strategy is closely connected with the European structural and cohesion policy. Under this directive, the EU provides overall €347 billion for the period 2007–2013 for national and regional development programmes, from which €84 billion will be made available for innovation investments. The main priorities are assigned to improve the economic performance of European regions and cities by promoting innovation, research capabilities and entrepreneurship with the objective of economic convergence.[1] National and regional programmes accompany the supranational efforts following the key-note that industrial dispersion, as well as spacious growth, can be realized by a competition of regions.

In their annual progress report, the European Commission draws a positive interim conclusion about the Lisbon Strategy.[2] The economic growth in the EU expected to rise at 2.9% in 2007, the employment rate of 66% was much closer to the target of 70%, and the productivity growth reached 1.5% in 2006. As also the report admits, the progress can only partly be ascribed to the Lisbon Strategy in the face of the global economic growth and increasing international trade. Furthermore, with regard to the political aim of cohesion, regional and national disparities are still present with respect to the recent economic advances. Likewise, the high and often cited target mark of 3% gross domestic expenditures on R&D is at a current value of 1.91% (Eurostat, estimated for 2006) still far from being achieved, which also concerns the aspired global leading position. The comparative empirical study of Crescenzi et al. (2007) finds evidence for a persisting technological gap of the EU in comparison with the United States. The authors conclude that two reasons might be responsible for this development: one is what they referred to as "national bias," which means the diversity of national innovation systems, and the second is the "European concern with cohesion, even in the genesis of

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[1] Council Decision of 6th October 2006 on Community strategic guidelines on cohesion (2006/702/EC).

[2] Strategic Report on the Renewed Lisbon Strategy for Growth and Jobs: Launching the New Cycle (2008-2010), COM(2007) 803, Brussels 11.12.2007.

innovation".[3]

In this regard, a dispersive regional policy inevitably implies a waiving of spatial efficiency due to lower external economies of scale. Furthermore, a subsidization and redistribution contrary to agglomeration forces is associated with possibly high budgetary efforts due to thresholds, nonlinearities and discontinuities.[4] Finally, considering a regional and national policy competition, it might be questionable if the way paved by the EU is efficient and will really meet supranational objectives.

Considering the linkage between regional and innovation policy as it is accelerated by the EU, the question arises if research promoting programmes are an appropriate instrument to foster economic agglomeration also in the European periphery. The leading thought of this approach is that a local research development is not only limited to high-tech sectors, but may also induce multiplicative employment and growth effects in linked sectors.

However, these endeavors go along with a couple of economic and political aspects. First, R&D activities are spatially concentrated, where the proximity to research institutions, as well as technology adapting downstream sectors, is relevant, which has been demonstrated by a multitude of empirical and theoretical publications.[5] In this context, knowledge and knowledge production as an essential attribute of high-tech clusters may be tacit, non-tradable and featuring a strong localization due to (technological) spillover effects. Second, the geographical concentration of research capacities and linked industries is critically influenced by the mobility of highly skilled labor. And third, the growth, evolution, and the macroeconomic relevance of emerging industries may be exposed to immense technological, political or social uncertainties.

Against the background of these problems, this paper addresses the following questions: *1) Which interdependencies determine the agglomeration of the research and manufacturing industry? 2) Which impact has the proceeding trade integration upon the spread and extent of R&D? 3) With respect to the conflict of agglomeration vs. dispersion, which spatial formation implies a welfare improvement? 4) How does a unilateral or regional R&D and innovation policy affect the locational competition? 5) Do bilateral competing regional or national policies really lead to spatial efficiency?*

The paper approaches these leading questions by means of an extended model of the New Economic Geography (NEG). The NEG is an analytical framework primarily established by Krugman (1991), Krugman and Venables (1995), and Fujita (1988), which considers geographical concentration based upon increasing returns, monopolistic competition and (iceberg) trade costs. As Fujita and Mori (2005) point out, the "NEG remains to be the only general equilibrium framework in which the location of agglomerations is determined explicitly through a microfounded mechanism".[6] In their survey article, the autors classify agglomeration forces into E-(conomic) and K-(nowledge) linkages. While

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[3] See Crescenzi et al. (2007), p. 31.

[4] See Baldwin et al. (2003) Chp. 9, for instance.

[5] See, e.g., Feldman (1999) for a survey.

[6] See Fujita and Mori (2005), p. 379.

the first category includes traditional mechanisms induced by production and transactions of goods and services, the second involves ideas and information creating local and global spillover effects.

Models of the first generation (see above) consider R&D activities only rudimentarily within fixed costs. The *footloose entrepreneur* model of Forslid and Ottaviano (2003) extended this approach by an implementation of a skilled workforce as a (fixed) human capital. Simultaneously, Martin and Ottaviano (1999) and Baldwin et al. (2001), later on Fujita and Thisse (2003) introduce technological spillover effects within an endogenous growth environment, where the capital is accounted to be a knowledge stock produced by an innovation sector with a private and a public output. The corresponding models orientate at renowned publications of Grossman and Helpman (1991a,1991b), as well as Segerstrom et al. (1990) and Flam and Helpman (1987). Recent works incorporating knowledge production and heterogeneity of agents are published by Berliant et al. (2006).

For providing answers to the initial subject, this paper picks up the seminal core-periphery model of Krugman (1991) and recombines it with endogenous R&D activities of firms. We focus on the destabilizing effects of highly-skilled migration, commonly referred to as the *brain drain*. Furthermore, we concentrate on quality improving R&D, which implies vertical product differentiation. For keeping the model tractable and simple as possible, we neglect public good characteristics of knowledge and knowledge creation, as well as endogenous spillover effects. The policy part is based upon the welfare implications derived from simple Pareto criteria. In addition, the economic policy is simplifying assumed as a tax-subsidy income transfer between factor groups, which finally sidesteps the modeling of a public sector. The major advantage of this approach is that it does not require to assume either a (ulitarian) welfare function or a government objective function because governmental action can directly be derived from the welfare propositions.

In order to examine the key questions above, this paper is structured as follows. In the next section we introduce the model assumptions and basic functionalities. In Section 3.3, we analyze the equilibrium states in terms of existence and stability. At this, we also consider the impact of exogenous asymmetries in country size deviating from the standard symmetric constellation. Section 3.4 focuses on the welfare analysis, which provides the formal legitimization for policy statements in Section 3.5. Finally, in Section 3.6, we return to the initial motivation of this paper, and derive conclusions for the European R&D and innovation policy.

3.2 The Model

Private Demand

Preferences of private households in both locations follow a nested utility function of the form:

$$U = M^{\mu} A^{1-\mu}, \tag{3.1}$$

where A denotes the amount of a homogenous good produced by a traditional constant-return sector, henceforth considered to be an outside industry, which represents all industries not in the focus of this model. M represents a subutility from the consumption of a continuum of differentiated consumer goods:[7]

$$M = \left[\sum_{i=1}^{n} (u_i)^{1/\sigma} (x_i)^{(\sigma-1)/\sigma} \right]^{\frac{\sigma}{\sigma-1}} \quad , \ \sigma > 1 \ , u_i > 0. \tag{3.2}$$

The subutility depends upon the amount x consumed of a particular product sort i out of the mass of (potential) varieties n. The parameter σ can easily be shown to be equal to the constant elasticity of substitution. The parameter u characterizes a further (vertical) dimension in the differentiation space, which can be interpreted as the quality of a particular variety.

The manufactures are internationally tradable involving ad valorem trade costs (Samuelson iceberg costs), $t > 1$, for goods shipped from location r to location s. From household optimization, we obtain the corresponding demand function:

$$x_r = \mu \sum_{s=1}^{S} Y_s u_r p_r^{-\sigma} t^{1-\sigma} P_s^{\sigma-1} \quad , \quad s = 1, ..., S \tag{3.3}$$

The utility parameter μ can be derived as the share in income, Y, spent for manufactures. The price index P summarizes information about quality and prices, of substitutes, whereat p_r is the price of a particular variety. From two-stage budgeting, the price-quality index for symmetric varieties is defined to be:

$$P_s^{1-\sigma} = \sum_{r=1}^{S} n_r u_r \left(p_r t\right)^{1-\sigma} \tag{3.4}$$

The Manufacturing Sector

Firms in the manufacturing sector use an increasing return technology for the production of a particular variety, which involves labor as the only input factor. The corresponding factor requirement of a single manufacturing firm in location s is characterized by a fixed and variable cost:

$$l_s^M = F + \alpha x_s. \tag{3.5}$$

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[7] See also Anderson et al. (1992) for details.

Due to economies of scale and consumer preference for product diversity, each firm produces only one differentiated variety, so that the firm number is equal to the number of available product sorts. The firms are in position to increase the willingness to pay of consumers by improving the quality of products, which, in turn, requires R&D investments. Following Sutton (1991), the level of quality is concave with respect to R&D expenditures, R:

$$u_s\left(R_s\right) = \left[\frac{\gamma R_s}{r_s}\right]^{1/\gamma}, \ \gamma > 1, \tag{3.6}$$

where r represents the price of one unit R&D, and γ the corresponding research cost elasticity. Because manufacturing firms finance their R&D by sales revenues, the profit function is given by:

$$\pi_s = p_s x_s - R_s\left(u_s\right) - w_s F - a w_s x_s, \tag{3.7}$$

where w denotes the wage rate for labor. Maximization leads to the standard monopolistic mark-up pricing. By normalizing a to $(\sigma-1)/\sigma$, the profit maximizing price is equal to marginal cost: $p = w$. Furthermore, the optimum quality and R&D expenditures are:

$$u_s^* = \left(\frac{p_s x_s}{\sigma r_s}\right)^{1/\gamma} \quad \Rightarrow \quad R_s^* = \frac{w_s x_s}{\sigma\gamma}. \tag{3.8}$$

From (3.8) it follows that firms tend to improve the quality of their products with: i) increasing sales revenues; ii) an increasing monopolistic scope, given by a lower substitution elasticity; and iii) decreasing research costs as a result of a decreasing research price, or a lower research cost elasticity.
Assuming zero profits, the long run equilibrium output of one manufacturing firm can be derived as:

$$x_s^* = \sigma F\left(\frac{\gamma}{\gamma-1}\right). \tag{3.9}$$

Equation (3.9) implies that the firm size is by the term in brackets higher than in the original Dixit-Stiglitz settings.

The R&D Sector

We introduce a separate research sector receiving the R&D expenditures of the manufacturing industry, and in turn providing R&D services. We assume a linear constant-return technology, where one unit of R&D requires one unit of scientific labor input. Furthermore, the R&D industry features a strong localization, meaning that a research facility in location s supplies its services for the manufacturing sector in the same location only. The equilibrium research price, r, results from the market clearing condition: $r_s L_s^R = n_s R_s$, where the turnover of the R&D sector on the left hand side is equal to the amount of research expenditures of the whole manufacturing industry on the right hand side. L indicates the amount of R&D output, while simultaneously representing the input of research personnel, n is the number of firms in the manufacturing sector. From this expression, the corresponding market clearing price for one unit of research is:

$$r_s = \frac{n_s R_s}{L_s^R}, \tag{3.10}$$

which simultaneously represents the wage rate for scientists. For the short run, we assume a fixed and price-inelastic supply of R&D and research personnel, respectively. In the long run, researchers are internationally mobile responding to real wage differentials. The migration of R&D personnel (and of R&D firms) follows the NEG models' commonly used *ad hoc* dynamics:[8]

$$\dot{s} = (\rho_s - \rho_r)\, s\, (1 - s)\,. \tag{3.11}$$

The parameter s denotes the share of global researchers in one particular location: (L_s^R / L^R), which is henceforward country 1 in the two-location version of this model. The real research price, ρ, is defined to be: $r_s P_s^{-\mu}$. For analytical simplicity, the global number of scientists, L^R, is set equal to 1 so that s denotes the number of researchers in location 1, and $(1 - s)$ in location 2.

Non-tradable R&D services?

The presumption of non-traded R&D needs a closer discussion due to a number of implications: At first, the size of the local research sector determines the quality, and thus, the demand for manufactures in the corresponding location. Second, we implement strong vertical linkages between manufacturing and research sectors. In consequence, a spatial specialization between R&D and production is excluded in this model.

However, the motivation for this assumption obviously is analytical simplicity. If we regard the R&D sector as being a scientific labor market rather than a de-integrated part of manufacturing firms, we obtain a pure *brain-drain* version of this model in which a local researcher is working in the laboratory of a local manufacturing firm only. From this point of view, R&D services become non-tradable because they are considered to be a (skilled) labor input.

Deviating from this perspective, there are also a number of arguments justifying the non-tradability assumption based upon the strong localization of innovative activities. This has been comprehensively proven by a couple of empirical studies, basically Audretsch and Feldman (1996), Jaffe et al. (1993), and Feldman (1994), strongly providing evidence that although the costs of transmitting information are independent from spatial distance, the costs of transferring (tacit) knowledge determine local spillover effects. In this model, we assume that (vertical) spillover effects only have a local impact. This primarily concerns industries characterized by a high technological complexity as well as

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[8] See Baldwin et al. (2003), Chapter 2 for a detailed discussion of the *ad hoc* dynamics.

a high degree of interaction between production and research.[9] Furthermore, this modeling set-up also includes university-based research in cooperation with local firms. The strong localization of this kind of R&D is either due to political intention or spillover effects as discussed above. In conclusion, technological knowledge in the present model diffuses by spatial mobility of knowledge producers. This certainly might not the case for the majority of firms but primarily applies for high-tech industries.

Production Wages and Household Income

Wages for workers in the manufacturing sector come from the wage equation, which represents the break-even rates a firm is willing to pay. The wage equation can be derived from solving (3.3) for the price, p. With the monopolistic price setting rule, we obtain:

$$(w_r)^\sigma = \frac{\mu \sum_{s=1}^{S} Y_s u_r t^{1-\sigma} P_s^{\sigma-1}}{x_r^*}. \tag{3.12}$$

The total supply of production labor is allocated between the traditional and the manufacturing sector, where workers are inter-sectorally mobile. For simplification, we set the total number of workers in both locations equal to one. In this way, the number of workers in the manufacturing industry is conform with the corresponding share λ_s, and the employment in the traditional sector corresponds with $1-\lambda_s$.[10]

Furthermore, we assume for the traditional outside industry a linear 1:1 technology, as we did for the R&D sector. This leads to an output, which quantity is the same as the sectoral labor input. If we treat the traditional industry as numeraire and set the price for its output equal to 1, the income of workers in this sector is $1-\lambda$. Via inter-sectoral mobility, the normalized wages in the traditional sector are equalized with the wages in the manufacturing sector. Finally, due to the (normalized) price setting of the competitive monopolists, the prices for manufactures are likewise equal to 1, which simplifies the algebra again.

In the long run, implying zero firm profits, the income of private households consists of the production wage bill, as well as the revenues from the R&D sector:

$$Y_s = w\lambda_s + w\,(1-\lambda_s) + n_s R_s = 1 + n_s R_s. \tag{3.13}$$

With these assumptions, the equilibrium R&D expenditures from equation (3.8) become with (3.9):

$$R^* = \frac{F}{\gamma - 1}. \tag{3.14}$$

Equation (3.14) implies that the equilibrium research investments are the same for each firm and each location. In consequence, the income of scientists in equation (3.13)

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[9] See e.g. Carrincazeaux et al. (2001).

[10] For the two-location version, the normalization implies that the global supply of production workers is twice the global supply of scientists. Though this setting is arbitrary, the qualitative results of the model are not affected. See Section 3.5 for details.

depends only upon the firm number in the local manufacturing industry.
In equilibrium, the total employment is equal to the total supply of manufacturing workers: $n_s l_s^M = \lambda_s$. From this market clearing condition and with the use of equations (3.5) and (3.9), the number of manufacturing firms can be derived:

$$n_s = \frac{\lambda_s (\gamma - 1)}{F (\sigma\gamma - 1)}. \tag{3.15}$$

Thus, the income of private households is:

$$Y_s = 1 + \frac{\lambda_s}{\sigma\gamma - 1}. \tag{3.16}$$

In the context of the two-location version, the research price (3.10) becomes with (3.14) and (3.15):

$$r_1 = \frac{\lambda_1}{s (\sigma\gamma - 1)} \tag{3.17a}$$

$$r_2 = \frac{\lambda_2}{(1 - s)(\sigma\gamma - 1)}. \tag{3.17b}$$

Substituting equations (3.17) and (3.9) into (3.8), the product quality can be expressed as:

$$u_1 = \left[\frac{F\gamma (\sigma\gamma - 1) s}{(\gamma - 1) \lambda_1}\right]^{1/\gamma} \tag{3.18a}$$

$$u_2 = \left[\frac{F\gamma (\sigma\gamma - 1)(1 - s)}{(\gamma - 1) \lambda_2}\right]^{1/\gamma}. \tag{3.18b}$$

In combination with firm number (3.15) and product quality (3.18), the price indices (3.4) can be rearranged to:

$$P_1^{1-\sigma} = \gamma^{1/\gamma} \left[\frac{\gamma - 1}{F (\sigma\gamma - 1)}\right]^{\frac{\gamma-1}{\gamma}} \left[(\lambda_1)^{\frac{\gamma-1}{\gamma}} s^{1/\gamma} + (\lambda_2)^{\frac{\gamma-1}{\gamma}} (1 - s)^{1/\gamma} t^{1-\sigma}\right] \tag{3.19a}$$

$$P_2^{1-\sigma} = \gamma^{1/\gamma} \left[\frac{\gamma - 1}{F (\sigma\gamma - 1)}\right]^{\frac{\gamma-1}{\gamma}} \left[(\lambda_1)^{\frac{\gamma-1}{\gamma}} s^{1/\gamma} t^{1-\sigma} + (\lambda_2)^{\frac{\gamma-1}{\gamma}} (1 - s)^{1/\gamma}\right]. \tag{3.19b}$$

Finally, the wage equations become:

$$\frac{\sigma\gamma F}{\mu (\gamma - 1)} = u_1 \left[Y_1 (P_1)^{\sigma-1} + Y_2 (P_2/t)^{\sigma-1}\right] \tag{3.20a}$$

$$\frac{\sigma\gamma F}{\mu (\gamma - 1)} = u_2 \left[Y_1 (P_1/t)^{\sigma-1} + Y_2 (P_2)^{\sigma-1}\right]. \tag{3.20b}$$

Basic Mechanisms

To understand the modeling results and to relate this paper to the standard NEG literature, it is useful to consider the main effects controlling the spatial allocation. For these purposes we determine the total differentials at the symmetric equilibrium so that, in the case of two symmetric locations, a change of a variable in location 1 goes along with an identical, but opposite, change in location 2. Considering a change in income, for instance, dY_1 is accompanied by $-dY_2$. Using the expressions given in the Appendix, we obtain from equations (3.16), (3.18), (3.19), and (3.20):

$$dY = \left(\frac{1}{\sigma\gamma - 1}\right) d\lambda \tag{3.21}$$

$$\frac{du}{u} = \left(\frac{2}{\gamma}\right) ds - \left[\frac{\sigma\gamma - \mu}{2\mu\gamma\left(\sigma\gamma - 1\right)}\right] d\lambda \tag{3.22}$$

$$\frac{dP}{P} = \frac{Z}{\gamma\left(1-\sigma\right)}\left[\left(\frac{\left(\sigma\gamma-\mu\right)\left(\gamma-1\right)}{\mu\left(\sigma\gamma-1\right)}\right) d\lambda + 2ds\right] \tag{3.23}$$

$$\frac{du}{u} = \left[\frac{Z\left(\mu - \sigma\gamma\right)}{\sigma\gamma}\right] dY + Z\left(\sigma - 1\right)\frac{dP}{P}. \tag{3.24}$$

From equations (3.21) – (3.24) follows:

Proposition 3.1. *Totally differentiating at the symmetric equilibrium reveals: i) an ambiguous home-market effect; ii) a negative price-index effect with respect to both factor groups; and iii) a positive research and manufacturing employment relationship.*

Equation (3.21) reveals the *home-market effect.* The positive correlation implies that an increase in income corresponds with an increase in manufacturing employment. In contrast to the core-periphery model, this relationship is not necessarily $dY/d\lambda > 1$. In fact, this result occurs only for small values of σ and γ. The dependency becomes more transparent by rearranging the term in brackets. Solving equation (3.15) for this expression and using (3.14), we obtain: $\left(n_s R_s\right)/\lambda_s$. Keeping in mind that manufacturing wages are normalized by 1, the term in brackets in equation (3.21) can be interpreted as the ratio of total R&D expenditures and the manufacturing wage bill. This means if the R&D expenditures are higher (lower) than the labor costs, we have a more (less) than proportional employment effect due to an increase in market size.

Equation (3.22) shows that quality rises with the mass of local scientists but falls with the mass of manufacturing firms. Whereas the first relation is obvious, the second results from a market-crowding effect in the research sector, which is induced by an increasing rivalry for a fixed supply of R&D services.

Equation (3.23) reveals a negative *price-index effect* for both the manufacturing and the researching population, where, according to Fujita, Krugman and Venables (1999), the trade cost index, Z, is defined to be:

$$Z \equiv \frac{1 - t^{1-\sigma}}{1 + t^{1-\sigma}}. \tag{3.25}$$

In this regard, a larger manufacturing sector implies a lower price index due to a reduction of trade costs and, thus, a higher local income and demand. An increasing R&D sector leads to an increase in quality, which finally reduces the price index, which also can be seen in equation (3.24).

Furthermore, by equalizing (3.22) and (3.24), we obtain:

$$d\lambda = \left[\frac{2\sigma\mu \left(\sigma\gamma - 1\right)\left(1 - Z^2\right)}{Z\left(\mu - \sigma\gamma\right)\left(\mu - \sigma Z\left(\gamma - 1\right)\right) + \sigma\left(\sigma\gamma - \mu\right)} \right] ds. \tag{3.26}$$

Nominator and denominator in equation (3.26) are greater than zero implying a positive research and manufacturing employment linkage.

3.3 Equilibrium Analysis

Dispersion vs. Agglomeration Equilibrium

Considering the formal nature of this model, (3.16), (3.18), (3.19) and (3.20) describe a system of eight nonlinear simultaneous equations, where (3.11) specifies the equilibrium condition. The differential equation has three stationary points: i) at $s = 1$, where the R&D sector is totally agglomerated in 1; ii) at $s = 0$, where the R&D sector agglomerates in 2; and iii) for a zero differential: $\rho_1 = \rho_2$.

In the symmetric equilibrium, all variables are constant except from the price index that is increasing with trade costs. In consequence, the real research price is increasing with trade costs as well.

Figure 3.1 shows s, the share of researchers in location 1, with respect to trade costs. This kind of comparative-static illustration is also referred to as bifurcation or tomahawk diagram concerning the progression and structure of multiple equilibria. Usually, the spatial formation of industries is considered in respect of a decline in trade costs. Starting from a high level of trade costs, a stable equilibrium (continuous bold line) appears at the symmetry, $s = 0.5$, while the agglomeration equilibria, $s = 0, 1$, are unstable (dashed line). This implies a dispersive distribution of R&D and manufacturing industries that is unaffected by trade costs.

At a critical level, indicated by the sustain point, t^S, the globally stable symmetric equilibrium becomes locally stable as a result of an alternating stability in the agglomeration equilibria. Later on, for trade costs lower than the break point, t^B, the symmetric equilibrium turns from stable to unstable, where the spatial distribution of both R&D and manufacturing industries takes form of the core-periphery outcome.

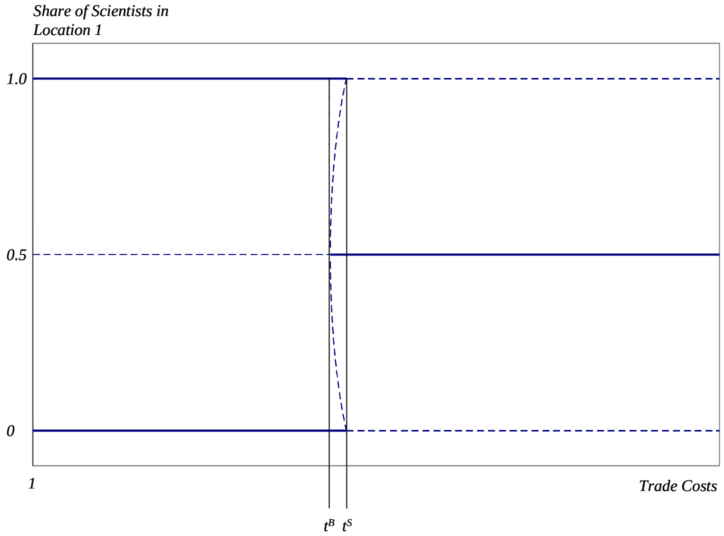

Figure 3.1: *Bifurcation Diagram for the Share of Scientists*

Proposition 3.2. *In the core-periphery constellation, the whole manufacturing and R&D industries agglomerate in the core, while in the periphery the traditional sector is the only industry remaining.*

This results from a complete withdrawal of researchers from the periphery, which reduces the quality of products locally manufactured. This, in turn, ceases the corresponding demand and the output of the manufacturing industry, which starts to relocate to the neighboring country with the larger sales market. In the agglomeration equilibrium, where the manufacturing industry and the research sector are entirely concentrated in one location, the earnings of private households in the core consist of the labor income plus the returns of the scientific workforce. In the peripheral location, the income comes only from labor totally employed in the constant-return sector.

In between of break and sustain points, also commonly classified as medium trade costs, we obtain three locally stable equilibria in symmetry and total agglomeration, as well as two additional unstable equilibria starting from total agglomeration at t^S and converging to the symmetric equilibrium at the break point, t^B.

In addition to Figure 3.1, this model features a second fundamental variable, the product quality in the manufacturing industry. In this context, Figure 3.2 shows the corresponding bifurcation diagram. Starting from the stylized Figure 3.2, it can be concluded:[11]

Proposition 3.3. *In the case of initially symmetric locations, the level of product quality in dispersion as well as in the agglomerated core is constant and thus, independent from trade costs. The quality in the periphery is zero as a result of a total relocation of R&D and the manufacturing industry.*

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[11] See also equations (3.54) and (3.59a) in the Appendix 3.7.

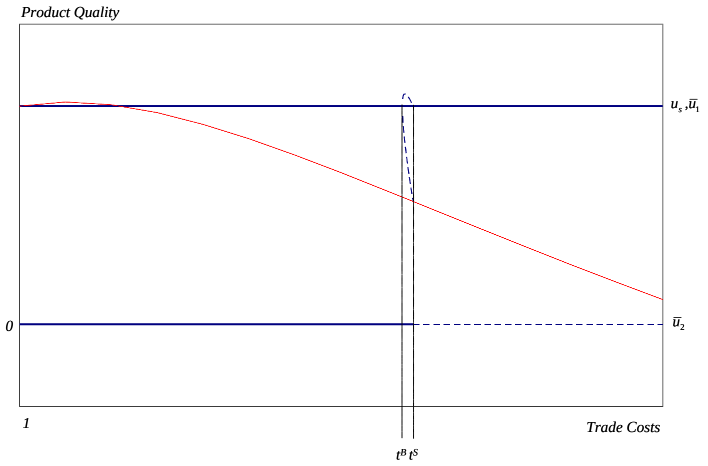

Figure 3.2: *Bifurcation Diagram for Product Qualities*

The constant level of quality constitutes a maximum that can be generated by the R&D facilities available in this economy. As given by equation (3.8), the quality depends only upon the market price for research services. In the agglomeration equilibrium, the number of manufacturing firms and scientists in the core is twice as in dispersion, which can easily be seen by equations (3.15), (3.53), and (3.58), respectively. Because the demand of a particular manufacturing firm for R&D services is fixed, equation (3.10) is constant in both agglomeration and dispersion equilibrium, since the ratio of supply and demand remains the same. In consequence, this level of quality is globally stable beyond break and sustain points. This implies that the quality of products available is always constant, before and after agglomeration.[12] In this context, the periphery, here location 2, does not produce manufactures due to a lack of the R&D sector that is totally relocated. Therefore, the corresponding quality, $\bar{u}_2$, becomes zero for trade costs lower than t^B. Although no R&D industry exists in region 2, there is still a hypothetical level of quality that would be generated if there would be any research activity. This hypothetical quality is represented by the (red) dashed line marking the lower limit of the unstable equilibrium arm.
However, between the critical trade costs values we observe two locally stable equilibrium qualities: i) location 1 is either in a dispersive equilibrium, or it becomes the core, which corresponds with the same quality level; ii) location 2 is either in a dispersive equilibrium, or it becomes the periphery implying the total loss of the manufacturing and R&D sectors and a zero quality.

Stability

Because of the static nature of this model, the stability of equilibria is ascertained via the *ad hoc* dynamics given by equation (3.11). For illustrating an out of equilibrium

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[12] These results may differ assuming spillover effects.

adjustment process, it is quite common to plot the real wage differential against the share of the mobile workforce. In this context, Figure 3.3 shows the real research wage gap, $\rho_1 - \rho_2$, with respect to the share of scientists, s, in location 1 for different levels of trade costs. Due to the non-closeness, the wage differential can only numerically be determined. The diagrams in Figure 3.3 are plotted for a specific parameter constellation that is henceforth used as a reference case in the course of this paper ($\sigma = 2$, $\gamma = 2$, $\mu = 0.4$, $F = 1$).
The stability of solutions can heuristically be proven: a positive (negative) wage differential implies an increasing (decreasing) share of researchers. As apparent, this model always features one symmetric and two corner solutions, where the filled dots represent a stable and the blank dots an unstable equilibrium.
Having a closer look on the evolution of the equilibria constellation, we can observe converging differentials of the unstable corner solutions, until the sustain point, t^S, where both equilibria exhibit a zero-differential. From this point on, the core-periphery constellation becomes stable. For trade costs lower than t^S, the corner solutions are diverging again. At the break point, t^B, the slope of the symmetric equilibrium changes its sign turning from negative to positive. This implies an alternation of the stability from stable to unstable – the core-periphery equilibrium becomes the only outcome.
Sustain and break points are determined using the same approach as suggested by Fujita, Krugman and Venables (1999)[13]. The sustain point can be found by identifying the trade costs level, where the wage differential of the agglomeration equilibrium becomes zero. The corresponding trade cost level solves:

$$t^S \rightarrow (\sigma\gamma + \mu)\, t^{1-\sigma-\mu/\gamma} + (\sigma\gamma - \mu)\, t^{\sigma-1-\mu/\gamma} - 2\gamma\sigma = 0. \tag{3.27}$$

By numerical inspection, equation (3.27) reveals the same qualitative characteristics of the comparative statics as the standard core-periphery model. An increasing substitution elasticity, σ, shifts the sustain point towards 1, because an increasing homogeneity of manufactures narrows the relevance of international trade. In addition, the larger the manufacturing sector, represented by an increasing share in household income, μ, the larger is the range of trade costs, which contain a sustain core-periphery equilibrium. Furthermore, the research cost elasticity, γ, as an additional parameter within this model, reveals the same comparative statics like the substitution elasticity, σ: the higher γ implying an increasing costliness of R&D, the lower is the sustain point.
The break point can be determined by totally differentiating at the symmetric equilibrium. Hence, the equation system can be reduced to $d\rho/ds = 0$. Solving for trade costs, we obtain the marginal case, where the slope at the symmetric equilibrium (see Figure 3.3, $t = t^B$) becomes zero:

$$t^B = \left[\frac{(\mu - \sigma\gamma)\,(\mu - \gamma\,(\sigma - 1))}{(\mu + \sigma\gamma)\,(\mu + \gamma\,(\sigma - 1))}\right]^{\frac{1}{1-\sigma}}. \tag{3.28}$$

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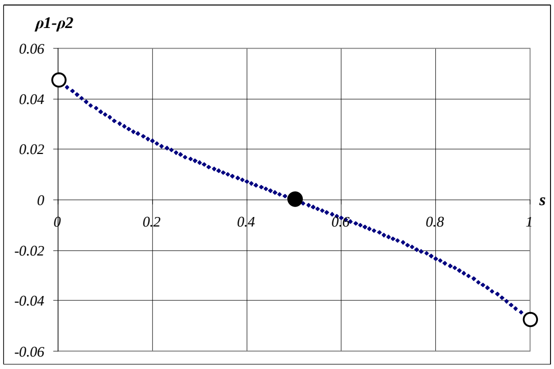
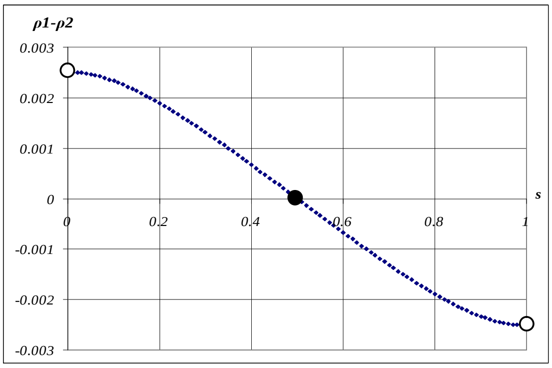
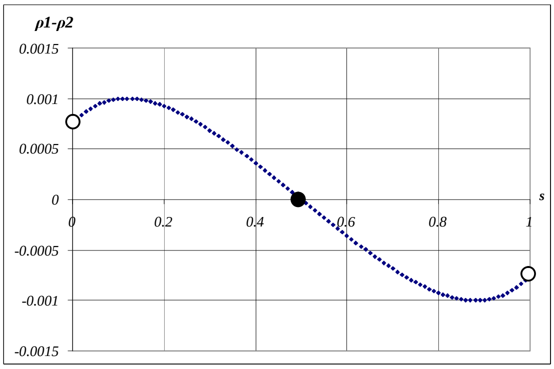
[13] See Appendix 3.7 for detailed derivations.



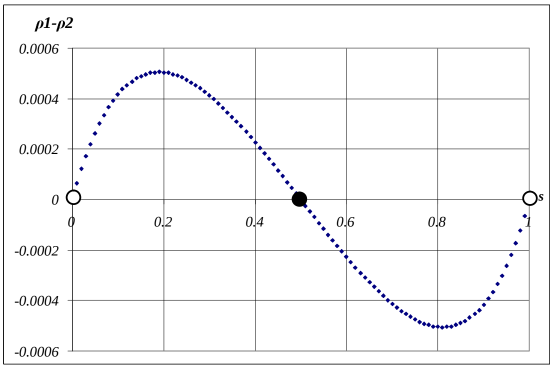
$t=2.5$



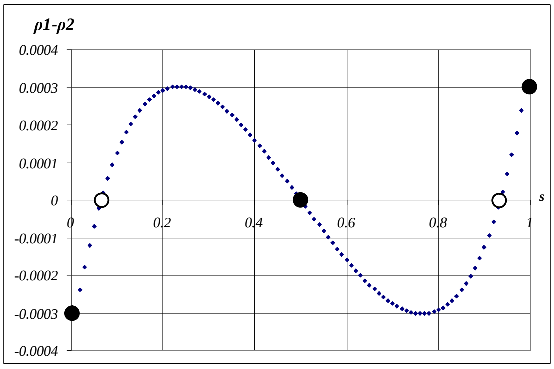
$t=1.9$



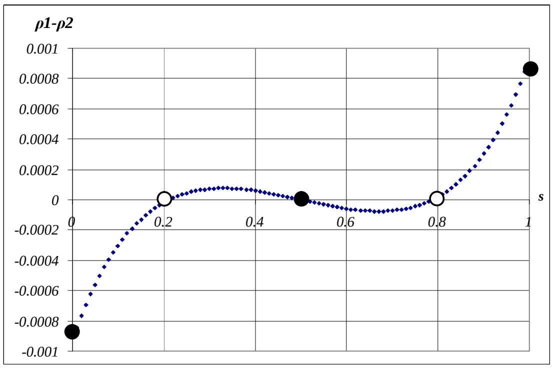
$t=1.87$



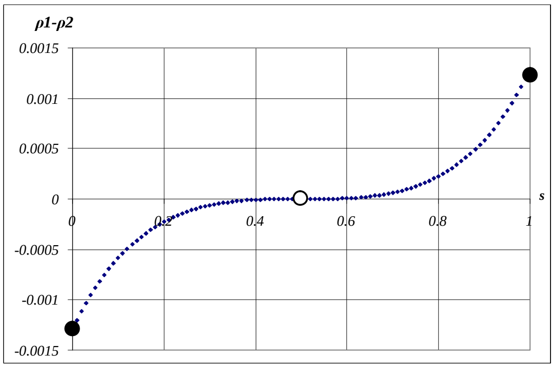
$t^S=1.85673$



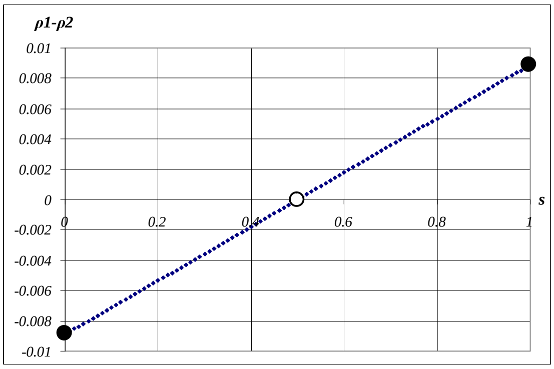
$t=1.85$



$t=1.84$



$t^B=1.8333$



$t=1.1$

Figure 3.3: *Wiggle diagrams for real research wage differentials*

For positive values of t^B, the second term in the nominator of (3.28) must be negative. From this term, the *no-back-hole condition* can be derived:[14]

$$\mu < \gamma\left(\sigma - 1\right). \tag{3.29}$$

The comparative statics of the break point qualitatively corresponds with the original core-periphery model: t^B increases with an increasing μ and decreases with a rising homogeneity of manufactures, σ. Additionally, an increase in the cost intensity of R&D, expressed by the parameter γ, reduces the break point level, too.

Asymmetric Locations
We previously assumed that both countries feature the same number of production workers employed in the manufacturing, as well as in the traditional, sector. Deviating from this simplification, we treat location 1 as reference and normalize the number of production workers L_1^M to 1. The size of the production labor force in location 2, L_2^M is defined to be a, where $a > 0$. Thus, the standard symmetric case is a knife-edge version of this general setting, where $a = 1$. Henceforth, the employment in the manufacturing sector of location 2 is $a\lambda_2$, and in the traditional sector: $a\left(1 - \lambda_2\right)$.
Figure 3.4 shows the bifurcation diagram for the case that location 2 is 1% larger than location 1 (parameter values: $\sigma = 2$, $\gamma = 2$, $\mu = 0.5$, $F = 1$, $a = 1.01$). Compared to symmetric locations, the structure of the tomahawk diagram has lost its simplicity. Instead of one, two sustain points occur, the path of the stable equilibrium right from the break point is bent towards an agglomeration within the larger country. As a result, the break point also appears shifted away from symmetry. The reason for these distortions

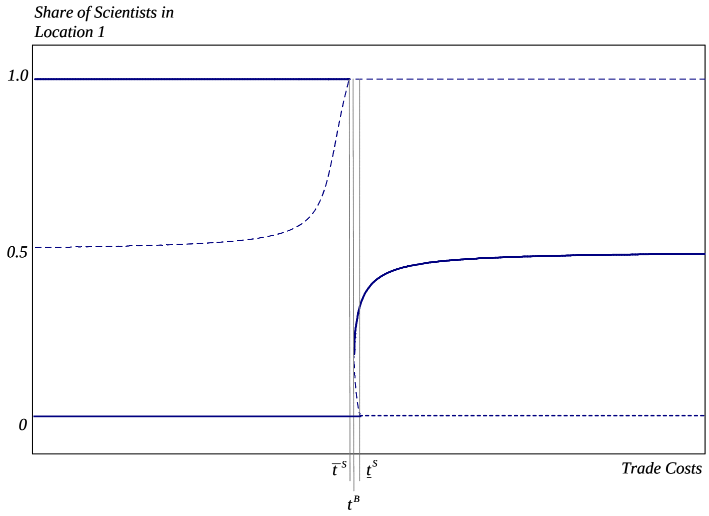


Figure 3.4: *Bifurcation Diagram for Asymmetric Locations*

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[14] See Appendix 3.7.

may be retraced by considering Figure 3.3 again. A smaller country size affects the real research wages via a higher price index. This implies that the wage gap function shifts downward originating the deviations from the symmetric equilibrium.
The trade cost levels indicating the first sustain point ($s = 1$) solves the equation:[15]

$$\bar{t}^S \to (a\sigma\gamma + a\mu)\, t^{1-\sigma-\mu/\gamma} + a\,(\sigma\gamma - \mu)\, t^{\sigma-1-\mu/\gamma} - (1+a)\gamma\sigma = 0. \tag{3.30}$$

Respectively, the second sustain point ($s = 0$) can be derived from:

$$\underline{t}^S \to (a\sigma\gamma + \mu)\, t^{1-\sigma-\mu/\gamma} + (\sigma\gamma - \mu)\, t^{\sigma-1-\mu/\gamma} - (1+a)\gamma\sigma = 0. \tag{3.31}$$

The second sustain point is singular and always existing for $t > 1$.[16] The break point can only be numerically investigated, but appears between the sustain points in the majority of cases. While the second sustain point is always given, the first sustain point as well as the break point disappear with an increasing exogenous asymmetry, a, which finally determines how far the stable path is moved away from symmetry.[17]
However, for the analysis of the critical trade cost values it may be useful to consider a couple of numerical examples. Table 3.3 shows the comparative statics of both sustain points with respect to changes in substitution and research elasticity, σ and γ, the size of the manufacturing sector, μ, and the asymmetry parameter, a. The computations are based upon a fixed parameter constellation given below the table, where each column shows the ceteris paribus changes in the corresponding variable. As apparent, the nu-

Table 3.1: *Sustain Points and Exogenous Asymmetry*

$\boldsymbol{\sigma = 3}$	$\boldsymbol{\gamma = 5}$	$\boldsymbol{\mu = 0.2}$	$\boldsymbol{a = 1.05}$
1.1774	1.1774	1.3400	1.7731
1.1886	1.1886	1.3660	1.9449
$\boldsymbol{\sigma = 5}$	$\boldsymbol{\gamma = 7}$	$\boldsymbol{\mu = 0.6}$	$\boldsymbol{a = 1.1}$
1.0436	1.0436	2.6060	1.6975
1.0487	1.0487	2.6562	2.03358
$\boldsymbol{\sigma = 7}$	$\boldsymbol{\gamma = 9}$	$\boldsymbol{\mu = 0.8}$	$\boldsymbol{a = 1.2}$
1.0192	1.0192	3.9132	1.5660
1.0225	1.0225	3.9923	2.2122

Reference case: $\sigma = 2$, $\gamma = 2$, $\mu = 0.4$, $a = 1.01$

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[15] The bar above (below) t denotes $s = 1$ ($s = 0$).

[16] Proof: If the *no-black-hole* condition holds, the function (3.31) shows i) a unique minimum for $t > 1$; ii) an intersection with the trade costs axis at $t = 1$; and iii) a negative slope at $t = 1$. Hence, there must be a second axis intersection for $t > 1$ solving equation (3.31).

[17] The function (3.30) intersects the trade cost axis at $t = 1$ and shows a unique minimum for $t > 1$ if $\frac{\sigma\gamma}{\mu}\left(\frac{a-1}{a}\right) < 2$. This minimum appears for positive as well as negative values so that a root for $t > 1$ is not inevitably existent.

merical results reveal the same dependencies as in the case of symmetric locations. The trade cost values of the sustain points decrease with decreasing horizontal and vertical differentiation indicated by an increasing σ and γ, and increase the larger is the income share for manufactures, μ. Furthermore, increasing the asymmetry parameter, a, the first sustain point moves towards 1 and the second moves in the opposite direction. This implies that the larger the disparity in country size, the sooner occurs the point of total agglomeration.

Although, from the technical point of view, the assignment which location becomes the core and which one becomes the periphery is still ambiguous; the common literature states that the smaller country tends to be the periphery.[18] The argumentation is based upon the magnitude of exogenous shocks that must be sufficiently high to make smaller locations become the industrialized core.

With increasing trade integration, country size asymmetry implies that the R&D capacity within the smaller country continuously diminishes until the break point is reached. At this critical trade cost level, the smaller location abruptly loses its residual R&D sector. Summing up, R&D mobility entails a destabilizing potential for smaller countries to the advantage of larger neighbors attracting scientists and the corresponding industry.

How does asymmetry affect the quality of manufactures? Figure 3.5 shows the corresponding bifurcation diagram for the product quality in location 1. As apparent, for high trade costs right from the first sustain point, the quality in location 1 continuously decreases due to a migration of scientists to location 2, so that it can be stated:

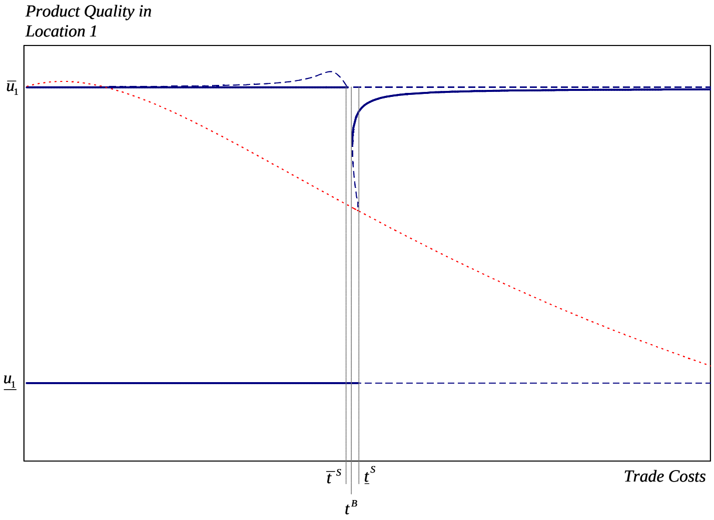

Figure 3.5: *Bifurcation Diagram for Product Quality in Asymmetric Locations*

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[18] See Baldwin et al. (2003), and Forslid and Ottaviano (2003), for instance.

Proposition 3.4. *With exogenous asymmetry in country size, the quality of manufactures produced in the larger country feature a higher quality.*[19] *Due to the home-market effect and the research-manufacturing employment linkage, an increasing quality of local manufactures increases demand, income and, consequently, the employment of additional R&D capacities. This cumulative causation leads to agglomeration within the larger country for decreasing trade costs.*

Left from the break point, the quality in the larger country is constant with respect to the trade cost level again because this location has attracted the whole research activities at fixed R&D expenditures.

Interim Results

Based upon the previous findings, the outcome of this model allows a couple of conclusions:

- Via cumulative causation, the production follows the R&D and vice versa.
- The settings allow catastrophic agglomeration as a common feature of the core-periphery model, but the "disastrous" extent for the peripheral region depends upon the importance of the manufacturing industry in the whole economic context. If the manufacturing industry is characterized by a low share in income, μ, a total relocation has a minor impact, in contrast to an industry exhibiting a dominant macroeconomic relevance.
- In the case of symmetric locations, international trade and R&D mobility do not affect the level of product quality as a result of a fixed firm size and identical endowments of scientists.
- A numerical analysis of break and sustain points reveals that international mobility of scientists affects the spatial formation of industries. But compared with the original core-periphery model of Krugman (1991), this impact is less destabilizing than the mobility of workers, which can be seen at lower values for the critical points, t^S and t^B.

The immanent instability of spatial dispersion and the risk of a total loss of manufacturing and research, especially for smaller countries, raise the question if a subsidization of local R&D may counteract deindustrialization. The following sections take up this consideration and analyze political intervention against the background of social welfare.

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[19] Indeed, this outcome has been confirmed by a couple of empirical studies, e.g., Hummels and Klenow (2005), Greenaway and Torstensson (2000).

3.4 Welfare and Spatial Efficiency

This section addresses the efficiency and optimality of agglomeration vs. dispersion. The considerations are based upon a global perspective incorporating the welfare of the population in both locations. With respect to external economies of scale as well as the distribution of social welfare, we examine the legitimization of location and research promoting policy instruments applied by supra-regional institutions. In the course of this paper, the findings provide the basis for the analysis of R&D and innovation policy instruments in the next section.

For these purposes, the approach of Charlot et al. (2006) and Baldwin et al. (2003) is applied. As discussed by the authors, the specification of a social welfare function is associated with an aggregation problem involving inequality aversion of two factor groups within two locations. However, instead of following this utilitarian approach, we rather focus on the analysis of Pareto-dominance combined with Kaldor-Hicks compensation criteria.

Pareto Dominance

Individual welfare is measured as the (maximized) consumer utility that can be derived as the real household income, $YP^{-\mu}$. The nominal income, $Y = Y^P + nR$ consists of i) fixed production wages, $Y^P = 1$, that is the same in both equilibrium states; and ii) the income of scientists. As mentioned above, the ratio of R&D demand and supply is equal in both equilibrium states so that the nominal research wage is also the same.[20]

In summation, the real income of production workers as well as scientists leads to a comparison of price indices.[21] In the agglomeration equilibrium, where the whole manufacturing industry gathers in the core (henceforth, location 1), the price index takes the lowest value compared with the peripheral location and the dispersion equilibrium. Because in the dispersive case the manufacturing is evenly spread across both locations, the corresponding price index is lower than in the periphery. Thus, it can be concluded:

Proposition 3.5. *Production workers in the core always prefer agglomeration, and production workers in the periphery always prefer dispersion due to higher real incomes. In this context and with the same argument, researchers always prefer agglomeration. In conclusion, neither agglomeration nor dispersion is a Pareto dominant equilibrium state because the labor force is split in agglomeration winners (production workers in the core and researchers) and agglomeration losers (production workers in the periphery).*

Compensation Tests

In accordance to Kaldor (1939) and Hicks (1940), potential compensations between agglomeration winners and losers are next to be verified. In the first step, we proof

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[20] See equations (3.56) and (3.61a).

[21] See equations (3.55), (3.60a), and (3.60b).

whether the winning factor group is able to compensate the disadvantaged production workers for remaining in the periphery in the sense of Kaldor. For utility equalization of the losing factor group, a compensation, C^K, has to be paid that fulfills the condition:

$$\left(1 + C^K\right) \bar{P}_2^{-\mu} = P_s^{-\mu}. \tag{3.32}$$

Substituting the price indices (3.55) and (3.60) yields:

$$C^K = \left(\frac{1 + t^{1-\sigma}}{2t^{1-\sigma}}\right)^{\frac{\mu}{\sigma-1}} - 1, \tag{3.33}$$

which corresponds with the outcome of Charlot et al. (2006). After compensation, the income of production workers in location 2 becomes $\bar{Y}_2^P = 1 + C$. The income of the winning factor groups, workers and scientists in 1, is given by: $\bar{Y}_1 = 1 + \bar{r}_1 - C^K$. In the dispersion equilibrium, the winners would earn: $1 + 2Y_s^R$. The net welfare in the sense of Kaldor is the difference of real income of the agglomeration winners in agglomeration and dispersion:

$$\Delta W^K \equiv \bar{W}_1 - W_s^{P,R} = \left(1 + r - C^K\right) \bar{P}_1^{-\mu} - (1 + r)\, P_s^{-\mu}, \tag{3.34}$$

where $r = \bar{r}_1 = r_s$. The sign of the net welfare (3.34) depends upon the level of trade costs:

$$\Delta W^K \gtrless 0 \quad \Rightarrow \quad 2\sigma\gamma \left(\frac{1 + t^{1-\sigma}}{2}\right)^{\frac{\mu}{1-\sigma}} - (\sigma\gamma - \mu)\, t^{\mu} - (\sigma\gamma + \mu) \gtrless 0. \tag{3.35}$$

From equation (3.35) follows:

Proposition 3.6. *For trade costs lower than a critical value t^K, agglomeration is preferred to dispersion due to a positive net welfare of agglomeration winners.*[22]

With respect to the Hicks compensation tests, the argumentation of Charlot et al. (2006) is based upon the allocation effects of a real redistributive transfer. Assuming that agglomeration losers compensate the winners by the amount of welfare surplus they would waive by staying in the symmetric equilibrium, such a transfer would prevent the clearing of factor and labor markets. The authors conclude that a (real) Hicks compensation is not feasible and thus agglomeration is always preferred to dispersion, taking into account the results of the Kaldor tests.

However, this paper deviates from this approach and follows the argumentation of a hypothetical compensation rather than assuming a real transfering system. In this context, a total compensation in the sense of Hicks requires a transfer C^H holding the condition:

$$\left(1 + 2Y_s^R + C^H\right) P_s^{-\mu} = \left(1 + \bar{Y}_1^R\right) \bar{P}_s^{-\mu}. \tag{3.36}$$

---

[22] K is mnemonic for *Kaldor*.

The corresponding net welfare of the losing factor group, the peripheral production workers in 2, is:

$$\Delta W^H \equiv W_s^P - \bar{W}_2^P = \left(1 - C^H\right) P_s^{-\mu} - \left(\bar{P}_1 t\right)^{-\mu}. \tag{3.37}$$

Dispersion compared to agglomeration represents a Pareto improvement in the sense of Hicks if the welfare of production workers in the (symmetric) location 2 is positive after compensating the agglomeration winners in 1. This situation is given by:

$$\Delta W^H \gtrless 0 \quad \Rightarrow \quad 2\sigma\gamma \left(\frac{1 + t^{1-\sigma}}{2}\right)^{\frac{\mu}{\sigma-1}} - (\sigma\gamma - \mu)\, t^{-\mu} - (\sigma\gamma + \mu) \gtrless 0. \tag{3.38}$$

From equation (3.38) follows:

Proposition 3.7. *For trade costs higher than a critical level t^H, dispersion is preferred to agglomeration in the sense of Hicks.*

This result differs from the outcome of the referenced study, where the authors state that only agglomeration is a Pareto improvement until the critical trade cost level t^K is reached. Due to diverging concepts of compensation, this paper finds that a range of trade costs exists where dispersion might be a preferred equilibrium outcome. In this context, Figure 3.6 shows the net welfare functions with respect to trade costs for the standard numerical example. For the numerical case considered, there are two range of trade costs where either agglomeration is preferred in the sense of Kaldor ($1 < t < t^K$), or dispersion is preferred in the sense of Hicks ($t^H < t$). Between the critical levels, any statements about potential Pareto improvements are not possible. In this regard, the break and sustain points remarkably appear in between. This implies that with decreasing trade costs, dispersion loses its welfare dominance sooner than the economy reaches

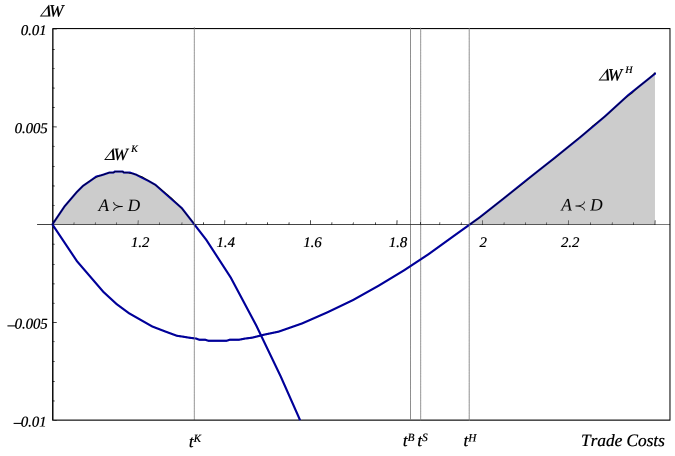

Figure 3.6: *Net welfare after compensation*

the core-periphery outcome. Furthermore, agglomeration later appears to be a clear Pareto improvement than the core-periphery formation actually becomes established.

Varying Research Potential
With regard to the arbitrary setting of the global number of scientists ($L^R = 1$), the question may arise if the results of the welfare analysis crucially depend upon the size of this factor group, which benefits from agglomeration. Based upon this consideration, an increasing number of internationally mobile researchers may imply an increasing potential for compensating agglomeration losers. In turn, in the sense of Hicks, this may imply a higher claim for compensation to be borne by production workers in the (potential) periphery, so that agglomeration becomes increasingly a Pareto improvement the larger the size of the researcher population.

However, this outcome appears not to be imminent considering the competitive research market. The higher the supply of researchers and of R&D, respectively, the lower is the corresponding market price. This leads to an increase in the product quality and simultaneously to a reduction of the price-quality index. Because this affects each individual manufacturing firm, the demand for manufactures finally remains unchanged.[23] At a constant demand, firm size remains constant as well, and for this reason the R&D expenditures, too. This finally results in unaffected research investments of the total industry, which implies lower per-capita income of scientists. All in all, the nominal household income remains the same, while the price index declines. In consequence, the welfare is higher in the case of an increasing researcher population. Having a look on the corresponding price indices for both equilibria, agglomeration and dispersion, they reveal the impact of an increasing number of scientists on the critical trade cost value, t^K and t^H:

$$P_s^{1-\sigma} = \left(\frac{\gamma L^R}{2}\right)^{1/\gamma} \left[\frac{\mu(\gamma-1)}{F(\sigma\gamma-\mu)}\right]^{\frac{\gamma-1}{\gamma}} \left(1+t^{1-\sigma}\right) \tag{3.39}$$

$$\bar{P}_1^{1-\sigma} = \left(\gamma L^R\right)^{1/\gamma} \left[\frac{2\mu(\gamma-1)}{F(\sigma\gamma-\mu)}\right]^{\frac{\gamma-1}{\gamma}} \quad , \ \bar{P}_2 = \bar{P}_1 t. \tag{3.40}$$

These price indices differ from the basic price indices, (3.55) and (3.60), only in terms of the first expression in brackets. This implies that the trade cost values, where the net welfare functions, (3.34) and (3.37), become zero, must be identical to the values solving (3.35) and (3.38). In consequence, it can be stated:

Proposition 3.8. *The critical trade cost values, t^K and t^H, are independent from the total number of scientists. Hence, a political intervention in terms of an increase in*

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[23] This can easily be seen by considering simplifying a closed economy. The demand is $x = \mu Y p^{-\sigma} P^{\sigma-1}$. For symmetric varieties, the price index becomes: $P^{1-\sigma} = n^{-1} u^{-1} p^{\sigma-1}$. Substitution yields a demand that is independent from quality, u, eventually.

R&D capacities leads to a higher social welfare, but it does not affect the evaluation of equilibria in terms of Kaldor and Hicks.

Numerical Calibration

General results beyond this numerical example, especially with regard to the existence of both critical trade cost values, t^K and t^H, are not possible due to non-closeness of equations (3.35) and (3.38). Following Charlot et al. (2006), a numerical analysis of parameter values in real economic domains draws a rough picture about the welfare situation within this model. In this context, Table 3.4 shows the calibration results, which are structured in the same way as demonstrated for Table 3.3.[24] Although this sample lacks generality, some observations can still be made: i) both values are always separated, while $t^K < t^H$; ii) the critical trade cost value of the Hicks compensation test disappears for large values of the income share, μ; iii) varying the substitution elasticity, σ, reveals that t^H falls below the sustain point, for values larger than 5, even below the break point, while t^K is always smaller than break and sustain points; iv) the critical values show the same comparative static behavior like the break and sustain points (increasing with decreasing σ and γ, and increasing with μ). Summarizing, the numerical investigation demonstrates the complexity of welfare statements with respect

Table 3.2: *Welfare and critical thresholds*

	$\boldsymbol{\sigma = 3}$	$\boldsymbol{\gamma = 5}$	$\boldsymbol{\mu = 0.2}$
t^K	1.1178	1.1212	1.1816
t^B	1.1819	1.2717	1.3509
t^S	1.1830	1.2727	1.3529
t^H	1.1822	1.3065	1.2848
	$\boldsymbol{\sigma = 5}$	$\boldsymbol{\gamma = 7}$	$\boldsymbol{\mu = 0.6}$
t^K	1.0371	1.0851	1.4598
t^B	1.0461	1.1872	2.5126
t^S	1.0461	1.1875	2.6309
t^H	1.0455	1.2101	5.1695
	$\boldsymbol{\sigma = 7}$	$\boldsymbol{\gamma = 9}$	$\boldsymbol{\mu = 0.8}$
t^K	1.0180	1.0656	1.5697
t^B	1.0209	1.1427	3.5000
t^S	1.0225	1.1429	3.9525
t^H	1.0206	1.1598	-

Reference case: $\sigma = 2$, $\gamma = 2$, $\mu = 0.4$

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[24] The parameters are oriented to the range of values given by Charlot et al. (2006), following Head and Mayer (2004).

to industrial agglomeration. If an equilibrium represents a Pareto improvement, it critically depends upon the parameter constellation, which is nonetheless evidently sensitive with respect to exogenous changes.
Complementing these results from a supra-national perspective, the next section considers first the impact of a unilateral R&D policy, and second the case of conflicting bilateral policies.

3.5 R&D and Innovation Policy

In the course of the policy analysis during this section, the paper focuses on the impact of a public R&D policy within one country, which henceforward will be location 2. Considering the outcomes of the previous sections, the social welfare of the population in the core is higher than in the periphery. Starting from dispersion but threatening agglomeration (the economy is close to the break point), an individual national policy would most likely take actions to avoid the situation in which the domestic location (2) becomes the periphery. A political goal may be that the dispersion is maintained, or, better yet, the location 2 becomes the industrialized core.
In this model, a policy meant to promote local R&D involves the subsidization of private R&D activities. With regard to real economic policy, a large repertory of instruments is utilized ranging from public funding of research projects, start-up promotion for high-tech firms, and tax abatements for private R&D expenditures, for instance.
Based upon the previous considerations, this section concerns three major questions: 1) Does a unilateral subsidization of R&D lead to a reallocation of industrial activities to the advantage of the intervening location? 2) In the case that country 2 is smaller: Which amount of subsidization has to be transferred to balance out the corresponding local disadvantage? 3) In contrast to a centrally planned or cooperative solution between both countries, as described in Section 3.4, what is the outcome of conflicting bilateral R&D policies? 4) Does this locational competition lead to a socially preferred outcome?

R&D Subsidies in the Symmetric Case
Based upon the findings in the previous section, the government in country 2 aims its own location to become the industrialized core knowing that all its inhabitants would benefit due to higher real incomes. Starting from a situation, in which both locations are in the dispersion equilibrium, the government in 2 decides to introduce a system of income transfer between both factor groups. The simple idea is that a lump-sum subsidy for the mobile scientific workforce may imply a sufficient incentive to migrate towards location 2. The subsidy is financed by a (non-distorting) lump-sum tax, $0 < \tau < 1$, paid by the immobile production workers in 2. Because the transfer is only realized between the inhabitants of one location, the nominal income of households remains the same as in the model without distributive intervention. Thus, the equations (3.16), (3.18), (3.19), and (3.20) describing the system do not change, contrary to the equilibrium condition

given by (3.11), where the real research price in location 2 becomes: $\rho_2 = (r_2 + \tau)\, P_2^{-\mu}$. Because the real research earnings of scientists in 2 are higher after subsidization, the real wage differential curve must be shifted downwards. This results in a distortion of the tomahawk symmetry generating a bifurcation that is the same as for exogenous asymmetry. Indeed, the subsidization produces an allocation as if location 2 would be larger in terms of country size. The appropriate sustain points for agglomeration in location 1 ($s = 1$) solve:[25]

$$\bar{t}_S^S \to t^{\mu} - \left[\left(\frac{\sigma\gamma + \mu}{2\sigma\gamma}\right) t^{1-\sigma} + \left(\frac{\sigma\gamma - \mu}{2\sigma\gamma}\right) t^{\sigma-1}\right]^{\gamma} - \left(\frac{\sigma\gamma - \mu}{2\mu}\right) \tau = 0, \tag{3.41}$$

and for agglomeration location 2 ($s = 0$):

$$\underline{t}_S^S \to t^{\mu} - \left[\left(\frac{\sigma\gamma + \mu}{2\sigma\gamma}\right) t^{1-\sigma} + \left(\frac{\sigma\gamma - \mu}{2\sigma\gamma}\right) t^{\sigma-1}\right]^{\gamma} + \left(\frac{\sigma\gamma - \mu}{2\mu}\right) \tau t^{\mu} = 0. \tag{3.42}$$

Against the background of these possibilities the question arises: What is the optimum R&D policy to affect industrial agglomeration for location 2?

First of all, it must be constituted if the government follows a strategy of instantaneous agglomeration at given trade costs. However, this policy may go along with a high burden for tax payers depending upon the degree of trade integration. In contrast, policymakers could also aim to achieve total agglomeration in the long run, while trade costs decrease. This approach is based upon the tendency of location 2 to agglomerate as a result of a quasi-exogenous asymmetry induced by a subsidy. Which strategy is chosen, depends upon the time preference of the economic agents, as well as the tax burden the production workers are willing to accept.

A. Instantaneous Agglomeration

For the case that policymakers in location 2 aim to achieve instantaneous agglomeration within their home country, they set a subsidy that completely shifts the wage gap function below zero. By means of Figure 3.3, it becomes apparent that the (real) subsidy, necessary to push location 2 into the core, depends upon the level of trade costs. Again, it is useful to differentiate between three cases: 1) For high trade costs (e.g., $t = 2.5$), the corresponding real subsidy is equal to the wage differential at $s = 0$. 2) If the trade integration continues, the maximum of the wage gap curve separates from the corner solution at a certain level of trade costs (approximately $t = 1.9$ in terms of Figure 3.3). 3) In the third stage, the wage differential of the corner solution $s = 1$ outruns the wage gap maximum ($t = 1.85$ in Figure 3.3).

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[25] The subscripts denote *subsidy* – the situation after introducing income transfers; the superscripts still stand for *sustain point*.

In the first case, the corner solution $s = 0$ gives the highest wage gap value, the corresponding subsidy τ' can be derived from equation (3.42) by solving for τ:[26]

$$\tau'\left(t \in T'\right) = \left(\frac{2\mu}{\sigma\gamma - \mu}\right)\left\{\left[\left(\frac{\sigma\gamma + \mu}{2\sigma\gamma}\right)t^{1-\sigma} + \left(\frac{\sigma\gamma - \mu}{2\sigma\gamma}\right)t^{\sigma-1}\right]^{\gamma} t^{-\mu} - 1\right\}, \quad (3.43)$$

where T' is the domain of trade costs in which the corner solution $s = 0$ is relevant.

In the second stage, the critical subsidy given by the interior maximum of the wage gap curve can only numerically be determined. At a given level of trade costs, T'', this subsidy fulfills:

$$\tau''\left(t \in T''\right) \rightarrow t = t_S^B, \quad (3.44)$$

where T'' is the domain of trade costs in which the interior maximum of the wage differential curve, $\partial\Omega/\partial s = 0$, is relevant.

Finally in the third case, for achieving instantaneous agglomeration, a policy concerning the corner solution $s = 1$ has to be applied in the third stage. The corresponding critical subsidy can be derived from equation (3.41):

$$\tau'''\left(t \in T'''\right) = \left(\frac{2\mu}{\sigma\gamma - \mu}\right)\left\{t^{\mu} - \left[\left(\frac{\sigma\gamma + \mu}{2\sigma\gamma}\right)t^{1-\sigma} + \left(\frac{\sigma\gamma - \mu}{2\sigma\gamma}\right)t^{\sigma-1}\right]^{\gamma}\right\}, \quad (3.45)$$

where T''' is analogically the domain of trade costs in which the relevant target value is represented by the wage differential at the corner solution $s = 1$.

For illustration, Figure 3.7 shows the critical subsidy that ensures instantaneous agglomeration with respect to trade costs. As apparent, the curve decreases for high trade costs (τ') following the corner solution $s = 0$. From the point, where the policy alternates from equation (3.43) to (3.44), the curve (τ'') is kinked and decreases with a lower slope. Finally, where the wage differential at the corner solution $s = 1$ exceeds the interior maximum, the subsidy (τ''') increases again due to stronger agglomeration forces. After a unique maximum, the curve declines towards zero for $t \rightarrow 1$. Furthermore, while the sustain point level of trade costs is always element of T'', the trade costs indicating the break point are always in the domain of T'''.

B. Long Run Agglomeration

In the case that policymakers decide to achieve agglomeration in the long run presuming decreasing trade costs, it is useful to distinguish two initial situations: 1) trade costs are higher; and 2) trade costs are lower than the sustain point level. The optimum R&D policy is illustrated by a numerical example given by the parameters: $\sigma = 2$, $\gamma = 2$, and $\mu = 0.4$. The break point occurs at: $t^B = 1.8333$, the sustain point at: $t^S = 1.8567$.

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[26] Furthermore, it can easily be shown that production workers in the subsidized core feature a higher welfare due to agglomeration, in spite of a lump-sum tax, until a critical level of trade costs, $t > 1$, has passed. For trade costs higher than this level, the welfare loss in the course of taxation is higher than the welfare gain due to a lower price index.

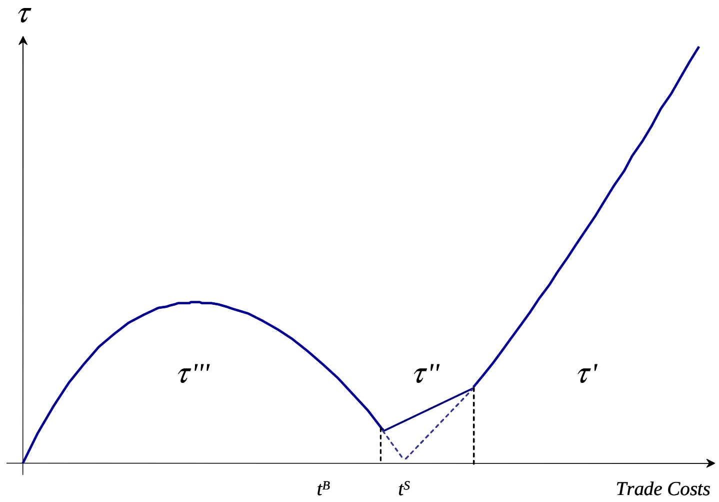

Figure 3.7: *Critical subsidy (unilateral R&D policy)*

Introducing a subsidy, $\tau = 0.001$, yields two sustain points for $s = 1$ at $\bar{t}^S_{S,1} = 1.0076$ and $\bar{t}^S_{S,2} = 1.8448$, one sustain point for $s = 0$ at $\underline{t}^S_S = 1.8717$. A break point does not exist. For cases i) and ii), the following policy statements can be formulated.

For trade costs higher than the sustain point, a subsidization leads to a migration of scientists towards location 2, which makes s decrease. Potentially, the new break and sustain points, t^S_S and t^B_S, are immediately reached depending upon the level of subsidization. As long as the trade costs are above the (uncontrolled) sustain point level, t^S, a cancelation of the transfer system would lead back to dispersion again. Accordingly, the subsidization must be maintained until i) location 2 becomes the core ($t < t^B_S$), and ii) the trade costs become sufficiently low so that the (symmetric) sustain point, $t < t^S$ has passed. This finally ensures that location 2 becomes the (locally) stable core after stopping subsidization. Considering the parameterized example, trade costs are $t = 2$, for instance, the research sector is almost totally agglomerated in location 2. After reaching the sustain point, t^S, a subsidization is not necessary anymore because the core-periphery equilibrium is (locally) stable.

For trade costs lower than the sustain point level, and agglomeration in the competing location, the subsidy should be set in order to move the (asymmetric) sustain point $s = 1$ leftwards. In terms of the wiggle diagram, this policy implies a downward shift of the wage gap function, until the corner solution $s = 1$ becomes negative. This finally destabilizes the core in location 1, the economy alternates to the decreasing arm in the tomahawk diagram generating an increasing advantage for location 2. In the case of the numerical example, we assume trade costs at $t = 1.84$ again. Increasing the subsidy to $\tau = 0.002$ makes the opposite sustain points diverge from each other. The critical sustain points become: $\bar{t}^S_{S,2} = 1.8326$ and $\underline{t}^S_S = 1.8864$. In consequence, location 2 attracts the whole R&D and manufacturing industry. However, the subsidization may be limited for very low trade costs. Assuming a very large manufacturing sector with $\mu = 0.8$ and a very low costliness of R&D with $\gamma = 1.3$, the corresponding targeted sustain point is $\bar{t}^S_{S,2} = 10.2567$ that can be just realized by subsidy of $\tau = 1$. For trade costs below this level, a way out of the periphery is impossible for location 2. In this context, the maximum tax burden, $\tau = 1$, which is the whole income of production workers, is totally exhausted. With regard to a more realistic picture, the maximum reasonable tax rate would be much lower, so that the domain of parameter values restricting this *agglomeration trap* becomes much larger.

R&D Subsidies and Exogenous Asymmetry

In the next step, we pursue the question: If location 2 is smaller in terms of country size, how can its government implement a subsidization policy to alleviate the disadvantageous effects of agglomeration?

As shown in Section 3.3, an exogenous difference in country size shifts the wage gap function. For the situation now considered, where location 2 is smaller, this curve moves upwards implying a stable arm in the tomahawk diagram that is bent towards $s = 1$. In contrast, an R&D subsidy works like an artificial country enlargement, because the wage gap function is shifted downwards. Hence, a subsidy level exists where the disadvantage of country size is totally compensated by the subsidization effect. Based upon this consideration, the government in location 2 should implement a subsidy (and tax) that is larger than this critical level. In consequence, the smaller country would gain a migration tendency directed to total agglomeration for trade costs lower than the break point level.

For determining the critical level of subsidization, it is necessary to equate the symmetric with the asymmetric differential and solve for the subsidy, τ. Following this approach, two problems occur: First, due to non-closeness, the wage gap can only numerically computed, except from the symmetric and corner solutions. Second, while a subsidy implies a parallel shift of the wage differential curve, an exogenous difference in country size also changes the shape of this curve. Hence, the critical level of subsidization pushing the smaller country to agglomeration can only numerically be determined. The critical subsidy solves:

$$\tau^* = \left(\frac{2P_2^{\mu}}{\sigma\gamma - 1} \right) \left(\lambda_1 P_1^{-\mu} - a\lambda_2 P_2^{-\mu} \right) \tag{3.46}$$

Figure 3.8 plots the subsidy, τ^*, with respect to trade costs for the standard numerical example ($a = 0.99$). The curve features three essential attributes: 1) The subsidy totally compensating a disadvantage in terms of country size is unique and positive for trade costs, $t > 1$. 2) For $a = 1$ and $t = 1$ the subsidy is zero. 3) The subsidy varies with the degree of trade openness, where the subsidization increases with increasing trade costs.[27]

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[27] For large values of σ and γ, the subsidy features a unique maximum and a moderate decline right from this point.

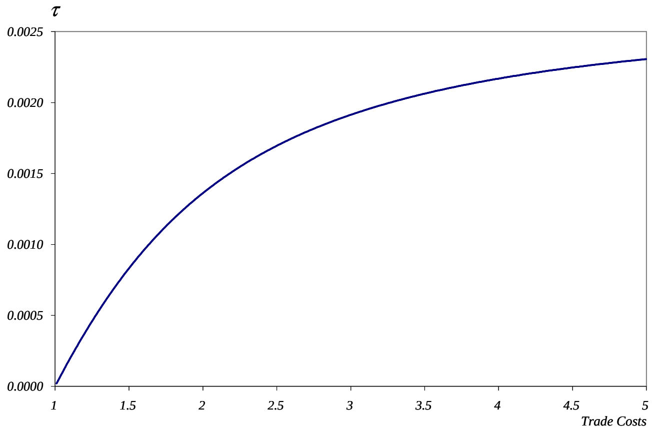

Figure 3.8: *Critical subsidy for asymmetric locations*

This results from higher price indices implying larger real wage differentials, which have to be overcome by the subsidy.

In addition to the considerations about the optimum R&D policy in the symmetric case, as given in the previous subsection, the government in 2 is in the position to route its country to agglomeration in spite of an initial disadvantage in terms of country size. According to the instantaneous agglomeration strategy as described above, the critical subsidy given by equation (3.46) has to be added on top the values of (3.42), (3.44), and (3.45), respectively. For the case that political decision-makers aim to achieve long run agglomeration, the corresponding subsidy has to exceed τ^*.

Conflicting Bilateral Policies

In the case of opposite policies in two symmetric countries, the considerations above may lead to an escalation of the R&D subsidy competition. Because agglomeration implies a welfare improvement for researchers as well as production workers in the core, both governments aim to direct their own locations into agglomeration. Contemplating the situation like a sequential game, one country would exceed the subsidy of the other country to finally gain an agglomeration advantage.

To formally treat this situation, we refer to the results above and assume by reason of formal simplicity that both countries follow an instantaneous agglomeration strategy. The basic principle of an R&D and innovation policy is still the same: a subsidy introduced by country 2 leads to a downward shift of the wage gap function. With regard to the policy implications above, one country would, given a policy of the rivalling country, consequently choose a subsidy according to equations (3.43), (3.44), and (3.45), respectively. To that above, we distinguish between three cases according to the degree of trade integration: 1) high trade costs ($t \in T'$); 2) medium trade costs ($t \in T''$); and 3) low trade costs ($t \in T'''$).

In the first case, at a given level of high trade costs, $t \in t'$, both locations follow a subsidization policy according to equation (3.43). Since both countries implement a transfer system, the subsidy in one location is set with respect to trade costs, and a given level of subsidy in the competing location. The corresponding symmetric reaction functions in the terms of a Cournot competition are:

$$\tau_1(\tau_2, t) = \tau' + \tau_2 t^{-\mu} \tag{3.47a}$$

$$\tau_2(\tau_1, t) = \tau' + \tau_1 t^{-\mu} \tag{3.47b}$$

Equations (3.47) are illustrated in Figure 3.9 by means of a specific numerical example ($t = 3$). Generally, both functions are linearly increasing. Concluding from equation (3.42), the critical subsidy, τ', is always positive. Furthermore, the reaction function τ_2 intersects the antagonistic curve τ_1 always from above because $t > 1$. These results imply a unique, globally stable and positive Nash equilibrium at:

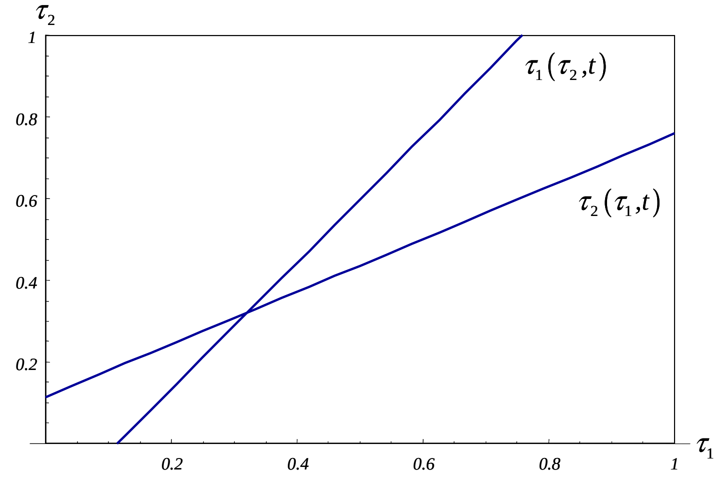

Figure 3.9: *Equilibrium subsidy in the symmetric policy game*

$$\tau^* = \tau' \left[\frac{1 + t^{\mu}}{t^{\mu} - t^{-\mu}} \right] \quad \forall \ t \in T'. \tag{3.48}$$

In spite of a lack of generality, we can again derive a couple of results from numerical investigations. Table 3.5 shows the equilibrium subsidy with respect to trade costs for several parameter constellations in the same way, as illustrated in Tables 3.3 and 3.4, where fields without values are out of the domain $t \in T'$. As reproduced, the equilibrium subsidy increases with i) increasing trade costs; ii) decreasing horizontal and increasing vertical differentiation (high σ and γ); and iii) decreasing income share, μ. In general, the calibration reveals that the equilibrium subsidy is relatively high; a couple of parameters show values even beyond the maximum tax base, $Y^P = 1$.

In summary, the subsidy race does not promote agglomeration; in fact, it preserves

Table 3.3: *Nash equilibrium subsidies*

t	$\sigma = 3$	$\gamma = 5$	$\mu = 0.2$
1.1	-	-	-
1.5	3898	0.0970	0.0553
2.0	> 1	0.3608	0.2276
3.0	> 1	> 1	0.5630
t	$\sigma = 5$	$\gamma = 7$	$\mu = 0.4$
1.1	0.1723	-	-
1.5	> 1	0.1486	-
2.0	> 1	0.5349	0.0425
3.0	> 1	> 1	0.3219
t	$\sigma = 7$	$\gamma = 9$	$\mu = 0.6$
1.1	0.4321	-	-
1.5	> 1	0.1875	-
2.0	> 1	0.7516	-
3.0	> 1	> 1	0.0824

Reference case: $\sigma = 2$, $\gamma = 2$, $\mu = 0.4$

spatial dispersion. The picture changes if exogenous asymmetry is included, because the larger country has access to a larger tax base and is able to finally exceed the subsidy of the smaller country.

In the second stage, for medium trade costs, $t \in T''$, the regional governments orientate at the general policy given by equation (3.44). Similar to the reaction functions (3.47), the subsidy in one location should exceed the maximum wage gap plus the increase of real research wages due to the subsidization of the competing country:

$$\tau_1 (\tau_2, t) = \tau'' + \tau_2 P_2^{-\mu} \tag{3.49a}$$

$$\tau_2 (\tau_1, t) = \tau'' + \tau_1 P_1^{-\mu}. \tag{3.49b}$$

The resultant Nash equilibrium occurs at:

$$\tau^{**} = \tau'' \left[\frac{1 + P_s^{\mu}}{P_s^{\mu} - P_s^{-\mu}} \right] \quad \forall \;\; t \in T''. \tag{3.50}$$

The equilibrium subsidy in this stage is also positive, globally stable, and increasing in trade costs.

In the third case, for low trade costs, $t \in T'''$, the reaction functions become according to (3.45):

$$\tau_1 (\tau_2, t) = \tau''' + \tau_2 t^{\mu} \tag{3.51a}$$

$$\tau_2(\tau_1, t) = \tau''' + \tau_1 t^{\mu}. \tag{3.51b}$$

Because the corner solution $s = 1$ ($s = 0$) is relevant for location 2 (1), the slopes of both functions are inverse compared to equations (3.47). In consequence, a positive equilibrium is not existent, and the subsidy race escalates.

Summarizing the results of a policy competition:

Proposition 3.9. *For the case of a bilateral R&D subsidy competition, a Nash equilibrium subsidy exists for high trade costs, but is not realizable due to a high tax burden for critically high trade costs. As trade costs decrease, the equilibrium subsidy decreases as well; the symmetric distribution across both locations remains unchanged also after passing the sustain point. After a critical value, where* $t \in T'''$*, the Nash equilibrium disappears. In comparison with the laissez-faire outcome, the political competition preserves industrial dispersion also for trade costs below the sustain point. However, as soon as the trade costs fall below the domain* T''*, the subsidy race escalates until the maximum viability of the tax base is reached. Even at this point, the symmetric outcome remains because both countries subsidize local R&D in the same (maximum) extent.*

Herewith, the symmetry perpetuates so that both the break and sustain points lose their central relevance. In the end, both countries are situated in a regional-political prisoners' dilemma. Due to mutual compensation of subsidy effects, both locations bear an income transfer between production workers and scientists that does not have an impact either on product quality and private R&D expenditures or on the spatial distribution of industries.

In the case of exogenous asymmetries, the smaller country has to apply a higher subsidy for compensating the initial disadvantage. Therewith, its already lower maximum tax burden is sooner exhausted so that the smaller country finally loses the locational competition.

Combining these results with the outcome of Section 3.4, an answer can be found for the question, if a locational competition leads to a welfare improvement in contrast to a centrally planned or cooperative solution:

Proposition 3.10. *For high trade costs* $t > t^H$*, dispersion implies a Hicksian welfare improvement despite unavailing policy efforts, if the net welfare of production workers,* ΔW^H*, is higher than the lump sum tax to be paid for R&D subsidies.*

If the trade costs decrease, until agglomeration is socially preferred, the outcome of the political game allows the following conclusion:

Proposition 3.11. *For low trade costs* $t < t^K$*, the preservation of symmetry as a result of an (escalating) political R&D competition precludes not only a welfare improving agglomeration in the sense of Kaldor, but also burdens the tax paying production workers at their maximum capacity.*

Concerning governmental R&D strategies, the standard trade policy literature follows the seminal work of Spencer and Brander (1983). In terms of product R&D, prominent contributions are provided by Zhou et al. (2002), Park (2001), and Jinji (2003), who consider vertically differentiating oligopolies. The structure of these models basically differs from the underlying paper in trade flows: two firms in two countries, either developed and less developed or symmetric, supply the market of a third country. The authors show that in the unilateral case, a government has an incentive to subsidize the firm in the home country. In the bilateral constellation, the optimum policy depends upon which oligopolistic competition, Bertrand or Cournot, is assumed for the market, the technological endowment, as well as political objectives. The latter implies the main difference to policymakers in the present model. Instead of affecting product quality to maximize local welfare, which is simply firm profits minus subsidy, the grant in this paper is used as a migration incentive aiming to achieve agglomeration within the home country. In spite of the complexity of model assumptions, especially with respect to the general equilibrium framework, the implications of the political game derived here are much simpler. Primarily, this is due to the monopolistic competitive setting of the manufacturing sector, where firms lack the opportunity for strategic behavior.

3.6 Conclusions

Summing up and coming back to the European case, the model results demonstrate a strong destabilizing impact of R&D and highly skilled migration on the spatial formation of industries. For an increasing trade integration, the mechanisms inevitably lead to a total relocation of R&D and the corresponding downstream sector. As shown in Section 3.3, larger countries reveal a stronger agglomeration tendency due to a larger market potential and, thus, stronger home market and price index effects.

Turning to the recent policy efforts, from a unilateral perspective an R&D and innovation policy via subsidization is viable to achieve agglomeration in the home country. In particular, a realization is not inevitably possible due to a limited tax base, and depending upon the level of trade costs, not a welfare improvement. Further on, as the numerical calibrations reveal, outcomes and thus policy implications are very sensitive to the choice of parameters so that general *yes/no* recommendations are not reasonable. Before the constitution of the Lisbon strategy, each European state has followed its own R&D policy and still does. Since direct export subsidizations are explicitly prohibited in the course of the common market, subsidizing R&D is partly used as indirect promotion of the domestic industry. However, as the non-cooperative policy game results of this paper show, a conflicting subsidy race may lead to a stable Nash equilibrium for high and medium trade costs, where the equilibrium subsidy decreases with increasing integration. At a critical level the equilibrium disappears implying an escalating race. Between similar countries, the policy interventions do not have an impact at all. The tax-subsidy income transfer is inefficient with respect to the political objectives.

Nonetheless, a unilateral exit would lead to a total relocation so that both countries are forced to maintain the subsidy competition. For large differences in country size, the smaller country has to pay a higher subsidy to compensate its initial disadvantage. For decreasing trade costs, this country would finally lose the R&D race – a result that occurs also for the laissez-faire case.

In summary, these outcomes clearly legitimate a harmonized R&D policy, which raises the conflict between European dispersion and agglomeration. In spite of European and national political interests, spatial dispersion is not necessarily a Pareto superior state, as shown in Section 3.4. In the course of a further European integration going along with decreasing trade costs, agglomeration increasingly tends to be a welfare improvement due to an increasing compensation potential in the sense of Kaldor. In addition, an agglomeration of research and manufacturing sectors implies a higher spatial efficiency as a result of external economies of scale. The model demonstrates that in the agglomeration equilibrium, the periphery entirely focuses on the constant-return sector, while the production labor force in the core is mainly employed in the monopolistic competitive sector. On one hand, this spatial specialization implies a distinguished industrial pattern that is also verified for Europe by the much noticed empirical studies of Midelfart-Knarvik et al. (2000) and Combes and Overman (2004). On the other hand, this outcome concludes that primarily low skilled and mature industries tend to relocate towards peripheral countries. In fact, this restricts the technological potential of these regions but ensures a division of labor according to comparative advantages and, thus, an increasing employment in these industries.

Midelfart-Knarvik et al. (2000) and Combes and Overman (2004) provide a couple of stylized results relevant for this paper: 1) The location of R&D intensive industries is increasingly responsive to the local endowments of researchers. 2) High-tech and increasing returns industries tend to be more spatially concentrated. 3) The dissimilarities between peripheral and core countries become more and more obvious involving an increasing degree of geographical specialization. Furthermore, Midelfart-Knarvik and Overman (2002) show that countries with an increasing endowment of high-skilled labor succeed in attracting R&D intensive industries. What can be concluded from the model results presented in this paper?

The spatial concentration on the national aggregation level can also be continued on the regional level. Midelfart-Knarvik and Overman (2002) show that on the international level the industrial pattern in Europe did not change in a major degree. In contrast, on the regional level, the trend of increasing concentration has accelerated. This development can be traced back to the decreasing relevance of trade costs the lower the level of spatial aggregation. Combined with a higher regional labor mobility, this leads to a weakening of dispersive forces and an enhancement of agglomeration forces between regions. In consequence, growing high-tech clusters are located in already established metropolitan areas. In the case of biotechnology, these are mainly in the direct proximity of London, Munich, and Paris.[28]

A proceeding integration process, especially in terms of the common market, and a further liberalization of national labor markets remove still persisting mobility barriers for workers also with respect to the Eastern European acceding countries, which exhibit a considerably westward brain drain tendency.[29] All in all, an increasing importance of R&D intensive industries and highly-skilled migration will foster industrial disparities across the EU on a national, as well as on a regional, level.

Midelfart-Knarvik and Overman (2002) find that two scenarios might be possible for the European future depending upon the degree of factor mobility and agglomeration gains. The authors state that at low labor and high capital mobility, as well as small agglomeration gains, a possible outcome is specialization. Furthermore, the study finds evidence for strong agglomeration forces within rather than across industries implying "industry black holes," which connotes agglomeration for particular industries. Between those possibilities, the model supports the latter. Although low-skilled migration is relatively low in Europe, the mobility of high-skilled workers, especially of scientists, is higher and increasing.[30] Although the home market effect due to high skilled migration is presumably low, the migration effect is strengthened by the accompanying gain of R&D advantages.

In consequence, *industry black hole* agglomeration will occur primarily for R&D intensive industries and this most likely in the European core. Since the welfare implications argue for agglomeration rather than dispersion at increasing trade integration, not only a geographical specialization in terms of vertically linked sectors has to be promoted, but also in terms of R&D intensity. To put the policy implication more strikingly, the model combined with the empirical results suggest a European structural policy that promotes high-tech industries within the core, and low- and medium-tech within the periphery.

3.7 Technical Appendix

Symmetric Equilibrium

Because the equation system is symmetric in terms of location, there exists a symmetric equilibrium, which can be determined by simply dropping the subscripts and substitution. Thus, the symmetric equilibrium is:[31]

$$Y_s = \frac{\sigma\gamma}{\sigma\gamma - \mu} \tag{3.52}$$

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[28] See, e.g., Allansdottir et al. (2000).

[29] See, e.g., Straubhaar (2000).

[30] This aspect is also part of the EU program European Research Area (ERA). See "Second Implementation Report on A Mobility Strategy for the European Research Area", Commission Staff Working Paper, SEC(2004) 412.

[31] In this context, the subscript s is mnemonic for *symmetry*.

$$\lambda_s = \frac{\mu\left(\sigma\gamma - 1\right)}{\sigma\gamma - \mu} \tag{3.53}$$

$$u_s = \left[\frac{F\gamma\left(\sigma\gamma - \mu\right)}{2\mu\left(\gamma - 1\right)}\right]^{1/\gamma} \tag{3.54}$$

$$P_s^{1-\sigma} = \left(\frac{\gamma}{2}\right)^{1/\gamma}\left[\frac{\mu\left(\gamma - 1\right)}{F\left(\sigma\gamma - \mu\right)}\right]^{\frac{\gamma-1}{\gamma}}\left(1 + t^{1-\sigma}\right) \tag{3.55}$$

$$r_s = \frac{2\mu}{\sigma\gamma - \mu}. \tag{3.56}$$

Corner Solutions

Assuming that the whole R&D sector is totally agglomerated in location 1, so that $s = 1$ and $\lambda_2 = 0$ (analogously, for the inverse relation: $s = 0$ and $\lambda_1 = 0$), we obtain the agglomeration equilibrium characterized by the following derivations:

$$\bar{Y}_1 = \frac{\sigma\gamma + \mu}{\sigma\gamma - \mu} \tag{3.57a}$$

$$\bar{Y}_2 = 1 \tag{3.57b}$$

$$\bar{\lambda}_1 = \frac{2\mu\left(\sigma\gamma - 1\right)}{\sigma\gamma - \mu} \tag{3.58}$$

$$\bar{u}_1 = \left[\frac{F\gamma\left(\sigma\gamma - \mu\right)}{2\mu\left(\gamma - 1\right)}\right]^{1/\gamma} \tag{3.59a}$$

$$\bar{u}_2 = \frac{\sigma\gamma\left(\frac{\sigma\gamma-\mu}{2}\right)^{\frac{1-\gamma}{\gamma}}\left(\frac{\gamma F}{\mu(\gamma-1)}\right)^{1/\gamma}}{\left(\frac{\sigma\gamma+\mu}{\sigma\gamma-\mu}\right)t^{1-\sigma} + t^{\sigma-1}} \tag{3.59b}$$

$$\bar{P}_1^{1-\sigma} = \gamma^{1/\gamma}\left[\frac{2\mu\left(\gamma - 1\right)}{F\left(\sigma\gamma - \mu\right)}\right]^{\frac{\gamma-1}{\gamma}} \tag{3.60a}$$

$$\bar{P}_2 = \bar{P}_1 t \tag{3.60b}$$

$$\bar{r}_1 = \frac{2\mu}{\sigma\gamma - \mu} = r_s \tag{3.61a}$$

$$\bar{r}_2 = \bar{r}_1\left[\frac{\left(\sigma\gamma + \mu\right)t^{1-\sigma} + \left(\sigma\gamma - \mu\right)t^{\sigma-1}}{2\sigma\gamma}\right]^{\gamma} \tag{3.61b}$$

Sustain and Break Points

Considering the agglomeration equilibrium, the sustain point occurs at the zero-wage differential: $\bar{\rho}_1 - \bar{\rho}_2 = 0$. Using equation (3.60b), this expression can be rearranged to: $\bar{r}_1 = \bar{r}_2 t^{-\mu}$. Substituting (3.61b) yields equation (3.27) for the sustain point, finally.

For the break point, we determine the trade costs level, where the slope of the symmetric wage differential with respect to s becomes zero. Totally differentiating the real research price yields:

$$d\rho = 2P^{-\mu} = \left[\frac{d\lambda}{(\sigma\gamma - 1)} - \left(\frac{2\mu}{\sigma\gamma - \mu}\right) ds - \left(\frac{\mu^2}{\sigma\gamma - \mu}\right)\frac{dP}{P}\right]. \tag{3.62}$$

From substitution of equations (3.23) and (3.26) in (3.62) and solving for Z, we obtain:

$$Z = \frac{1 - t^{1-\sigma}}{1 + t^{1-\sigma}} = \frac{\mu\gamma\,(2\sigma - 1)\,(\sigma\gamma - \mu)}{\gamma^3\sigma^2\,(\sigma - 1) - \mu\left[\mu\,(\mu - \sigma\gamma) - \gamma^2\sigma\,(1 - \sigma)\right]}. \tag{3.63}$$

Solving for trade costs, equation (3.63) becomes (3.28).

***No-Black-Hole* Condition**

The validity of the no-black-hole condition can be seen at the requirement for a positive nominator of equation (3.28). The condition implies that both break and sustain points occur for $t > 1$. This restriction can also be derived by following the approach of Fujita, Krugman and Venables (1999). Starting from the total differential of the real research wage, we obtain at the symmetric equilibrium:

$$\frac{d\rho}{\rho} = \frac{dr}{r} - \mu\frac{dP}{P}. \tag{3.64}$$

From equation (3.17) in combination with (3.53) and (3.56), the relative change in the research wage is:

$$\frac{dr}{r} = \left[\frac{\sigma\gamma - \mu}{\mu\,(\sigma\gamma - 1)}\right] d\lambda - 2ds. \tag{3.65}$$

By substitution of equations (3.23) and (3.65) in (3.64) and considering the case of infinitely high trade costs, implying that $Z = 1$, leads to:

$$\frac{d\rho}{\rho} = \left[\frac{\sigma\gamma - \mu}{\mu\,(\sigma\gamma - 1)}\right]\left[\frac{(1 - \sigma)\,\gamma - \mu\,(\gamma - 1)}{\gamma\,(1 - \sigma)}\right] d\lambda + 2\left[\frac{\mu - \gamma\,(\sigma - 1)}{\gamma\,(\sigma - 1)}\right] ds. \tag{3.66}$$

The sign of the partial derivative with respect to s in equation (3.66) provides information about the slope of the wage gap function plotted in Figure 3.3. Considering the upper limit of the trade costs domain, that is $Z = 1$, a negative slope of the wage differential in the symmetric equilibrium ensures that the break point must occur for smaller, non-infinite values of trade costs. Therefore, the nominator of the derivative must be negative, which finally requires: $\mu < \gamma\,(\sigma - 1)$.

4 Agglomeration, Vertical Specialization and the Strength of Industrial Linkages

4.1 Introduction

The *New Economic Geography* (NEG), initially introduced by Krugman (1991), provides explanations for industrial agglomeration based upon increasing returns and imperfect competition. Whereas international labor mobility initiates the central agglomeration mechanism in the core-periphery model, the observation that industrial clustering also is present in regions with relatively low migration has challenged the application of inter-industrial trade as an additional agglomeration force.

In their analysis of European industries, Midelfart-Knarvik et al. (2000) point out that vertical linkages have become increasingly significant since 1980. Hummels et al. (2001) estimate that about 30% of world exports account for inter-industrial trade.[1] This share has grown by 40% since 1970, which emphasizes the increasing role of what the authors call *vertical specialization*. These results are consistent with those of Yeats (1998), who considers the exports of the OECD countries within the classification group SITC-7 (key machinery and transportation equipment). In 1995, the share of components and parts was about 30%, which approximates $132 billion (US). Characterizing the relevance of vertical linkages in expanding international trade, Hummels et al. (1998) come to the conclusion that the nature of international trade 'has changed to the point where countries increasingly specialize in producing particular stages of goods, rather than making a complete good from start to finish'.

Based upon the seminal works of Ethier (1982), Rivera-Batiz (1988) and Markusen (1989), Krugman and Venables (1995) implement vertical linkages into the *core-periphery model*, where the upstream industry provides differentiated intermediate products to the downstream industry that produces differentiated consumer goods. For simplification, both sectors are integrated into one so that the manufacturing firms produce their own intermediates. In contrast, Venables (1996) separates the sectoral structure and analyzes the particular spatial distribution of both upstream and downstream industries. A couple of additional publications picked up the vertical-linkage (VL) mechanism. Baldwin et al. (2003) classify these models into: i) CPVL models in the course of Krugman and Venables (1995); ii) FEVL models, which are based upon the footloose-entrepreneur framework (Ottaviano (2002)); and iii) FCVL (footloose capital) models due to Robert-Nicoud (2002).

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[1] Estimation for 1995.

In the context of existing NEG literature considering vertical linkages, the dimension of industrial agglomeration depends upon four categories of factors: i) trade costs; ii) local production costs; iii) local market size; and iv) the strength of vertical linkages. The higher the trade costs, the stronger firms tend to locate at the larger market for reducing the costs of spatial transfers. In contrast, at low trade costs, local cost advantages become more important than local market size. Including inter-industrial trade, the allocation between upstream and downstream sectors is characterized by mutual interdependencies, which are also referred to as forward and backward linkages. The forward linkage describes the dependency of the upstream industry upon the downstream industry: the larger the downstream sector, the larger is the relevant market for the intermediate sector. The backward linkage results from the price-index effect: the more firms produce in the upstream sector, the higher is the competitive pressure implying decreasing intermediate prices, which finally decrease the procurement costs of the downstream industry. It is applied for both mechanisms: the larger one sector is, the larger is the other.

Although the strength of vertical linkages is attributed to be an important factor for industrial clustering, it only is discussed casually. For quantification, a frequently used reference is the share of downstream costs for intermediate products. This approach raises certain questions: Is the strength of linkages an endogenous or exogenous factor? What are the main factors controlling industrial interdependencies, and is the strength of linkages fixed or variable? Can the sectoral coherence be described as one measure, or does it require a separate analysis dealing with forward and backward linkages?

In comparison with the diversity of models considering vertical linkages, the Venables (1996) model shows a number of distinctive features. First, it is the only partial-analytical model, which describes agglomeration and the characteristic bifurcation pattern of NEG models. In this context, it allows to focus on industrial linkages without income and labor market effects. Second, due to the disaggregated sectoral set up, the Venables model gives insight into firm behavior in both upstream and downstream sectors, and thus, it opens the potential to reproduce vertical specialization. Third, it directly refers to the strength of inter-industrial linkages and its impact upon the spatial distribution of both sectors.

However, the model also features some difficulties. The modeling framework is comparatively complex including four boundary conditions and twofold price-index and home-market effects. Furthermore, the model results are only given in relative values rather than absolute firm numbers in both sectors. The paper also leaves some open questions regarding the sustain point, a more detailed description of the boundary and stability conditions, exogenous asymmetries between locations, and political implications.

Against this background, the objective of this paper is to suggest a concept for quantifying the strength of vertical linkages in NEG models. Further on, it explicitly considers the Venables model in terms of the absolute size of industries, and thus, it provides an alternative approach to determine the break and sustain point, as well as the specialization point where vertical specialization breaks off for decreasing trade costs. Moreover,

Venables (1996) approaches the idea of an 'industrial base,' which describes a sufficient market size and presence of suppliers to attract and maintain additional firms in one particular location. This paper complements these considerations i) by the classification of industries by means of the strength of linkages; and ii) by quantifying the *inertia* of the downstream industry with respect to a relocation of the upstream industry. Finally, it considers exogenous asymmetries in terms of wage rate and market size and their impact upon agglomeration and specialization. In this context, it also includes a subsidization policy for compensating disadvantages in country size.
The paper is structured as follows. In the next section, we introduce the basic model of a closed economy to analyze vertical linkages and to develop a measuring concept of the linkage strength. In Section 4.3, we refer to the standard Venables model and consider equilibria, stability, critical trade costs values, and the impact of linkage strength. Section 4.4 focuses on the effects of exogenous asymmetries. The last section returns to the idea of an industrial base and draws the main conclusions based upon the modeling results.

4.2 Closed Economy

In this section, we consider a simple supply chain consisting of an upstream industry forwarding intermediate products to a downstream industry, which manufactures final products for private consumers. Both sectors are characterized by increasing returns and monopolistic competition.

Consumer Demand
Starting from consumer preferences, the private households face a linear–homogenous utility function in the form of:

$$U = M^{\mu} A^{1-\mu} \ , \ 0 < \mu < 1, \tag{4.1}$$

where M represents a sub-utility from the consumption of manufactures, A is the quantity of a homogenous (outside) good, and μ the share in private expenditures for manufactures. The sub-utility, M, is given by:

$$M = \left[\sum_{i=1}^{n^d} \left(x_i^d \right)^{(\sigma-1)/\sigma} \right]^{\sigma/(\sigma-1)} \qquad , \ \sigma > 1, \tag{4.2}$$

where x_i^d is the quantity of a particular variety, i, out of all varieties available, n^d, that are produced by the downstream industry (d is mnemonic for *downstream*). The preference parameter, σ, can be shown to be the constant elasticity of substitution; for concavity it is defined to be greater than 1. The demand for manufactures can be derived by *two-stage budgeting*:

$$x^d = \mu Y \left(p^d \right)^{-\sigma} \left(P^d \right)^{\sigma-1}, \tag{4.3}$$

where p^d denotes the downstream price, and μY the share in income of the private households spent on consumer goods. P^d is the consumer price index, defined as:

$$P^d \equiv \left[\sum_{i=1}^{n^d} \left(p_i^d\right)^{1-\sigma}\right]^{\frac{1}{1-\sigma}}. \tag{4.4}$$

Equation (4.4) reveals the price-index effect: an increase in product variety reduces the price index because a given level of subutility can be achieved with a lower quantity of a particular product sort.

Downstream Industry

Based upon Ethier (1982), the technology for final good production is given by a implicit Cobb-Douglas type production function:

$$F^d + a^d x^d = Z\left(l^d\right)^{1-\alpha} I^\alpha. \tag{4.5}$$

The right hand side of equation (4.5) represents the input composite of labor and intermediates in order to produce one unit of downstream output, x^d, which involves a fixed cost, F^d, and a variable cost, a^d, on the left hand side. Z controls the output level, while α is the partial substitution elasticity of the intermediate aggregate, I, which is:

$$I = \left[\sum_{i=1}^{n^u} \left(x_i^u\right)^{(\varsigma-1)/\varsigma}\right]^{\varsigma/(\varsigma-1)}, \tag{4.6}$$

where the superscript u denotes *upstream*. Production function and intermediate aggregate are structurally the same as utility and sub-utility functions in which ς corresponds with σ. The common pattern involving downstream and consumer preferences implies a price index for intermediates that is similar to the one for consumer goods:

$$P^u \equiv \left[\sum_{i=1}^{n^u} \left(p_i^u\right)^{1-\varsigma}\right]^{1/(1-\varsigma)}. \tag{4.7}$$

By applying two-stage-budgeting again, we obtain the cost function of one downstream firm:

$$C^d = \left(F^d + a^d x^d\right) w^{1-\alpha} \left(P^u\right)^\alpha. \tag{4.8}$$

The downstream costs positively depend on the wage level, w, on the fixed and variable costs, F^d and a^d, as well as on the intermediate price index. The latter responds to changes in the number of upstream firms in the same way as the price index for consumer goods, implying that an increasing number of intermediate varieties cuts down the cost of the downstream industry, via a negative (intermediate) price index effect. Furthermore, equation (4.8) reveals the cost rate of the downstream factor composite consisting of labor and intermediates: $w^{1-\alpha}\left(P^u\right)^\alpha$. From the cost function the demand for intermediates can be derived:

$$x^u = \alpha C^d \left(p^u\right)^{-\varsigma} \left(P^u\right)^{\varsigma-1}. \tag{4.9}$$

Summing up, the downstream profit function is given by:

$$\pi^d = p^d x^d - w^{1-\alpha}\left(P^u\right)^\alpha \left[F^d + a^d x^d\right]. \tag{4.10}$$

Substituting consumer demand (4.3) and differentiation yield the profit maximizing downstream price:

$$\left(p^d\right)^* = w^{1-\alpha}\left(P^u\right)^\alpha a^d \left(\frac{\sigma}{\sigma-1}\right). \tag{4.11}$$

Equation (4.11) represents monopolistic mark-up pricing on-top marginal costs. For analytical convenience, we normalize a^d by $(\sigma-1)/\sigma$.
Using this simplification, the equilibrium output of a downstream firm following from zero-profits is:

$$\left(x^d\right)^* = \sigma F^d. \tag{4.12}$$

Upstream Industry
The upstream industry produces intermediates by use of a linear technology given by:

$$l^u = F^u + a^u x^u, \tag{4.13}$$

where l^u is the amount of labor required to produce one unit of upstream output. The corresponding upstream profit function can be written as:

$$\pi^u = p^u x^u - w\left(F^u + a^u x^u\right). \tag{4.14}$$

The profit maximizing upstream price is by use of intermediate demand (4.9):

$$\left(p^u\right)^* = w a^u \left(\frac{\varsigma}{\varsigma-1}\right). \tag{4.15}$$

Again, we use a standard normalization: $a^u = (\varsigma-1)/\varsigma$, so that the equilibrium output of one upstream firm is:

$$\left(x^u\right)^* = \varsigma F^u. \tag{4.16}$$

Equilibrium Firm Number
Market clearing in both the upstream and downstream sectors requires total supply being equal to total demand. In terms of the upstream industry holds:

$$n^u p^u x^u = n^d \alpha C^d. \tag{4.17}$$

From (4.17) the number of upstream firms can be determined by substituting equations (4.8), (4.9), (4.15), and (4.16):

$$n^u = \left[\alpha \frac{\sigma}{\varsigma} \frac{F^d}{F^u} n^d\right]^{\frac{1-\varsigma}{1-\varsigma-\alpha}} \equiv N^u. \tag{4.18}$$

Similarly, the downstream market clearing condition is:

$$n^d p^d x^d = \mu Y. \tag{4.19}$$

Accordingly, the downstream firm number is by use of (4.3), (4.11), and (4.12):

$$n^d = \frac{\mu Y}{w\sigma F^d} \left(n^u\right)^{\frac{\alpha}{\varsigma-1}} \equiv N^d. \tag{4.20}$$

Equations (4.18) and (4.20) describe the forward and backward linkages, meaning that the number of upstream firms depends positively upon the number of downstream firms and vice versa. The forward linkage acts upon a simple market size argument: the larger the number of firms in the downstream sector, the larger is the corresponding market size for intermediate suppliers leading to an entry of new upstream firms. The backward linkage is based upon the (intermediate) price index effect: the more firms produce in the upstream industry, the lower is the corresponding price index. This implies lower procurement costs for the subsequent industry, thus increasing profits and market entries of new downstream firms. Setting (4.18) equal to (4.20) yields a unique and stable equilibrium at:[2]

$$\left(n^u\right)^* = \frac{\alpha\mu Y}{w\varsigma F^u} \quad , \quad \left(n^d\right)^* = \frac{\varsigma F^u}{\alpha\sigma F^d} \left(\frac{\alpha\mu Y}{\varsigma w F^u}\right)^{\frac{1-\varsigma-\alpha}{1-\varsigma}} . \tag{4.21}$$

Figure 4.1 illustrates the equilibrium by means of equations (4.18) and (4.20).

The curve progression of N^d critically depends upon the exponent of n^u. As long as $\alpha < (\varsigma - 1)$ holds, the function is concave with respect to the upstream firm number. Otherwise, the price index effect escalates and the graph becomes convex. However, this case differentiation does not affect the existence and stability of the equilibrium at all, but has implications for the following subsection.

The Strength of Vertical Linkages

Considering the zero-profit isoclines, N^u and N^d, as forward and backward linkages, they provide information about the mutual coherence between the upstream and downstream sectors. The basic idea is that the slope of the isoclines represents the strength of the relative linkages. Assuming an infinitely fast adjustment process, the derivatives evaluated at the equilibrium are:

$$\frac{\partial n^u}{\partial n^d}|\left(n^d\right)^* = \sigma F^d \left(\frac{1-\varsigma}{1-\varsigma-\alpha}\right) \left(\frac{\varsigma F^u}{\alpha}\right)^{\frac{\alpha+1-\varsigma}{\varsigma-1}} \left(\frac{\mu Y}{w}\right)^{\frac{\alpha}{1-\varsigma}} \tag{4.22a}$$

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[2] See Appendix 4.6 for a simple stability analysis.

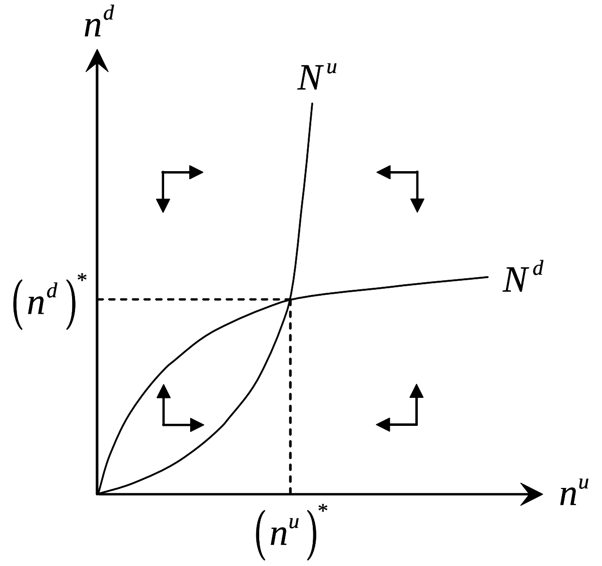

Figure 4.1: *Equilibrium upstream and downstream firm number*

$$\frac{\partial N^d}{\partial n^u}|(n^u)^* = \frac{\left(\frac{\alpha\mu Y}{w}\right)^{\frac{\alpha}{\varsigma-1}}\left(\varsigma F^u\right)^{\frac{\alpha-\varsigma+1}{1-\varsigma}}}{\left(\varsigma-1\right)\sigma F^d}. \tag{4.22b}$$

The derivatives quantify the change in the number of firms in one sector, in response to changes in the quantity of firms in the other sector. If we choose the point elasticities based upon equations (4.22), we obtain:

$$\varepsilon^u = \frac{1-\varsigma}{1-\varsigma-\alpha} \quad , \quad 0 < \varepsilon^u < 1 \tag{4.23a}$$

$$\varepsilon^d = \frac{\alpha}{\varsigma-1} \quad , \quad 0 < \varepsilon^d < 1 \;\; \forall \;\; \alpha < \varsigma - 1 \tag{4.23b}$$

These elasticities can be considered to be a measure for the strength of inter-sectoral linkages. The only parameters affecting sectoral coherence are the intermediate differentiation, ς, and the cost share for intermediates, α. The elasticities are positive, constant and independent from exogenous parameters as market size or technology, which can be attributed to the specific CES-typed functions. Furthermore, both values are within the same domain, where the border case, $\alpha > (\varsigma - 1)$, as discussed above, is excluded.
The strength of vertical linkages can be measured as the percentage change in the quantity of firms in one industry, due to a one percent change in the number of firms in the other industry. The major advantages of this approach are: i) the availability of the parameters from official statistics and econometric estimations; ii) the potential to compare industrial linkages beyond particular supply chains; iii) a dimensionless measure; and iv) nonetheless, an ultimately intuitive economic interpretation.

Figure 4.2 represents the graphs of equations (4.23a) and (4.23b). It is apparent that the forward linkage, which is the dependence of upstream firms upon the downstream industry, increases the lower the intermediate differentiation as well as the intermediate share in downstream costs. The backward linkage and, in this context, the dependence of downstream firms upon their suppliers, intensifies with increasing intermediate differentiation and expanding cost share. The isoclines for a given elasticity are linear, with the slope, $(1-\bar{\varepsilon^u})/\bar{\varepsilon^u}$, for the forward linkage and $\bar{\varepsilon^d}$ for the backward linkage. This implies that an increase in ς must go along with an increase in α to maintain a certain level of linkage strength.

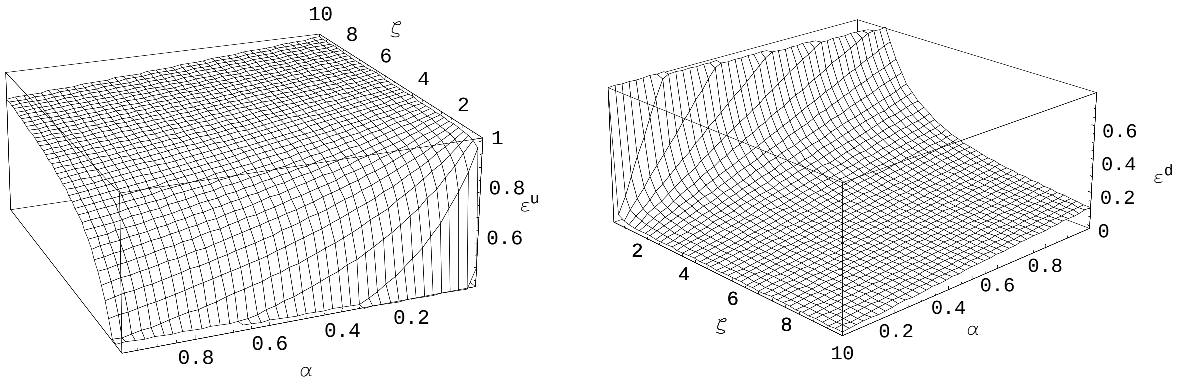

Figure 4.2: *Strength of forward and backward linkage*

All in all, this measuring concept has a couple of implications:

- The sectoral coherence is a bi-directional relationship of forward and backward linkages, so that the strength of linkages is composed of two measurements.
- The strengths of both linkages are converse, which implies that the higher the strength of the forward linkage, the weaker is the backward linkage and vice versa. This constellation also excludes combination of mutual weak or strong linkages.
- The sum of both elasticities as a rough aggregate for the overall sectoral coherence is always larger than 1, increasing with α, and decreasing with ς.

All in all, the common approach used in the NEG literature to quantify the strength of linkages by the intermediate cost share is not sufficient to display the whole mechanism between vertically linked sectors, as this closed economy framework reveals.

4.3 Open Economy

For considering the impact of different linkage strengths, this section refers to the partial model introduced by Venables (1996). This model analyzes the supply chain described in the previous section within an open economy with two locations. While the workforce is immobile, the output of the upstream and downstream industries are internationally tradable, which causes Samuelson iceberg trade costs, $t > 1$. Preferences and technologies are the same across both locations, whereas market size and wages are allowed to differ. In accordance with equations (4.4) and (4.7), the price indices are:

$$\left(P_1^u\right)^{1-\varsigma} = \left(p_1^u\right)^{1-\varsigma} n_1^u + \left(p_2^u t\right)^{1-\varsigma} n_2^u \tag{4.24a}$$

$$\left(P_2^u\right)^{1-\varsigma} = \left(p_1^u t\right)^{1-\varsigma} n_1^u + \left(p_2^u\right)^{1-\varsigma} n_2^u \tag{4.24b}$$

$$\left(P_1^d\right)^{1-\sigma} = \left(p_1^d\right)^{1-\sigma} n_1^d + \left(p_2^d t\right)^{1-\sigma} n_2^d \tag{4.25a}$$

$$\left(P_2^d\right)^{1-\sigma} = \left(p_1^d t\right)^{1-\sigma} n_1^d + \left(p_2^d\right)^{1-\sigma} n_2^d, \tag{4.25b}$$

where upstream and downstream prices depend upon local costs: $p_s^u = w_s$ and $p_s^d = w_s^{1-\alpha}\left(P_s^u\right)^{\alpha}$. Based upon equation (4.8), the downstream cost functions become:

$$C_1^d = \left(F^d + a^d x_1^d\right) w_1^{1-\alpha} \left(P_1^u\right)^{\alpha} \tag{4.26a}$$

$$C_2^d = \left(F^d + a^d x_2^d\right) w_2^{1-\alpha} \left(P_2^u\right)^{\alpha}. \tag{4.26b}$$

The upstream industry supplies downstream demand, whereas the proportion of intermediates, which are forwarded to the foreign location, has to be t times higher because this amount melts away en route.

$$x_1^u = \alpha C_1^d \left(p_1^u\right)^{-\varsigma} \left(P_1^u\right)^{\varsigma-1} n_1^d + \alpha C_2^d \left(p_1^u t\right)^{-\varsigma} \left(P_2^u\right)^{\varsigma-1} n_2^d t \tag{4.27a}$$

$$x_2^u = \alpha C_1^d \left(p_2^u t\right)^{-\varsigma} \left(P_1^u\right)^{\varsigma-1} n_1^d t + \alpha C_2^d \left(p_2^u\right)^{-\varsigma} \left(P_2^u\right)^{\varsigma-1} n_2^d. \tag{4.27b}$$

Downstream output follows equation (4.3):

$$x_1^d = \mu Y_1 \left(p_1^d\right)^{-\sigma} \left(P_1^d\right)^{\sigma-1} + \mu Y_2 \left(p_1^d t\right)^{-\sigma} \left(P_2^d\right)^{\sigma-1} t \tag{4.28a}$$

$$x_2^d = \mu Y_1 \left(p_2^d t\right)^{-\sigma} \left(P_1^d\right)^{\sigma-1} t + \mu Y_2 \left(p_2^d\right)^{-\sigma} \left(P_2^d\right)^{\sigma-1}. \tag{4.28b}$$

Because of zero-profits, both upstream and downstream output is fixed at ςF^u and σF^d, respectively, which implies the same fixed firm size in both locations. Furthermore, we add two market clearing conditions for both sectors according to (4.17) and (4.19):

$$n_1^u p_1^u x_1^u + n_2^u p_2^u x_2^u = n_1^d \alpha C_1^d + n_2^d \alpha C_2^d \tag{4.29}$$

$$n_1^d p_1^d x_1^d + n_2^d p_2^d x_2^d = \mu Y_1 + \mu Y_2, \tag{4.30}$$

where the left-hand sides represent supply and the right-hand sides demand. Overall, the equations (4.24) – (4.30) describe a system including a non-closed solution set for n_1^u, n_2^u, n_1^d, and n_2^d.

The location decision of manufacturing firms is due to the tension of local market size and production costs. Because of the sectoral linkages, the downstream firms do not only locate at the larger sales market, but also account for the presence of suppliers due to the (intermediate) price-index effect. In turn, the upstream industry locates not only in response to local labor costs, but also to the size of the local downstream industry. However, with decreasing trade costs, differences in labor costs become more and more relevant, which weakens the linkage to the relevant sales market. In extreme, it is possible that trade costs become so low that the whole industry locates in one location and exports to the other, which is also known as the core-periphery outcome. Also in the case of initially symmetric countries, the model generates a core-periphery constellation for sufficiently low trade costs.

Interior and Corner Solutions

Considering two locations, which are symmetric in terms of market size, consumer preferences, technology and labor costs, Figure 4.3 maps the equilibrium set of the downstream firm number with respect to trade costs.[3] With regard to the characteristic pattern, these illustrations are also referred to as bifurcation or tomahawk diagrams, where solid lines represent stable and dashed lines unstable solutions. For high trade costs, $t > t^S$, the only stable equilibrium is symmetric dispersion, where both firm numbers are equal across both locations.[4] For medium trade costs, $t^B < t < t^S$, two corner solutions additionally occur implying a (locally) stable symmetric equilibrium as well as a core-periphery constellation, which becomes the only stable solution for low trade costs, $t < t^B$. The peripheral upstream firm number is zero for all trade costs. In contrast, there exists a domain of trade costs, $t^C < t < t^S$, where still a non-zero downstream firm number produces in the periphery, although the upstream sector is totally relocated to the core. Henceforth, this is called the *specialization set.*

However, the set of corner solutions is defined by two non-zero conditions: First, the red dotted line illustrates the zero-profit firm number of downstream firms in the periphery. Second, the green dotted line represents the restriction given by zero upstream firms (expressed in terms of downstream firms).

The first restriction implies that as soon as this curve exceeds the lower corner solution, the firm number in the periphery decreases until the downstream profits are zero. Because firms leave the market, if profits become negative, the zero-profit restriction holds for positive firm numbers as being the peripheral corner solution.

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[3] Parameters: $\alpha = 0.5$, $\sigma = 3$, $\varsigma = 3$, $Y_1 = Y_2 = 1$, $w_1 = w_2 = 1$.

[4] See Appendix for a detailed derivation of symmetric and corner solutions.

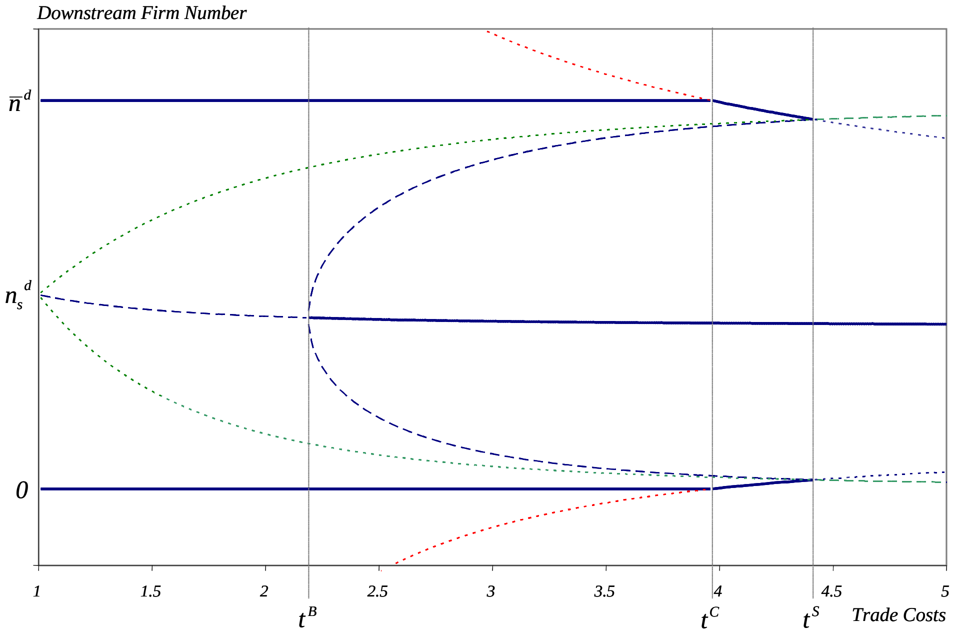

Figure 4.3: *Bifurcation diagram downstream*

The zero-profit restriction can be determined by equating (4.28). By use of the downstream price indices (4.25) follows:

$$\frac{t^{-\sigma\alpha}-t^{1-\sigma}}{\eta\left(1-t^{1-\sigma-\sigma\alpha}\right)}=\frac{t^{\alpha(1-\sigma)}\bar{n}^d+t^{1-\sigma}\underline{n}^d}{t^{\alpha(1-\sigma)+1-\sigma}\bar{n}^d+\underline{n}^d}, \tag{4.31}$$

where η is defined to be: Y_2/Y_1. A bar on top a variable represents the core and below the peripheral equilibrium state. In the next step, from the downstream market clearing condition (4.30) follows:

$$\underline{n}^d=\frac{\mu Y_1+\mu Y_2}{\sigma F^d}\left[\frac{\alpha\mu\left(Y_1+Y_2\right)}{\varsigma F^u}\right]^{\frac{\alpha}{\varsigma-1}}-\bar{n}^d t^{\alpha}. \tag{4.32}$$

Substituting this expression into equation (4.31) yields the zero-downstream profit restrictions:

$$\underline{n}^d\left(\pi^d=0\right)=-\bar{n}^d\left[\frac{t^{1-\sigma-\alpha}}{t^{-\alpha\sigma}-t^{1-\sigma}}\right]\left[\frac{\eta\left(1-t^{1-\sigma\alpha-\sigma}\right)-t^{\sigma-1-\sigma\alpha}+1}{\eta\left(1-t^{1-\sigma\alpha-\sigma}\right)-t^{1-\sigma-\sigma\alpha}+1}\right]\equiv\Omega \tag{4.33}$$

For the upper bound holds:

$$\bar{n}^d\left(\pi^d=0\right)=\bar{n}^d-\Omega t^{\alpha}. \tag{4.34}$$

The critical trade cost value, t^C, at which downstream specialization breaks off, can be determined by simply setting (4.33) equal to zero. The corresponding value solves:

$$t^C\rightarrow\eta\left(1-t^{1-\sigma\alpha-\sigma}\right)-t^{\sigma-1-\sigma\alpha}+1=0. \tag{4.35}$$

The second restriction (green dotted line) can be determined by equating (4.27), which implies zero upstream profits. Solving for the peripheral downstream firm number yields:

$$\underline{n}^d = \bar{n}^d t^{\varsigma-1+\alpha}. \tag{4.36}$$

Substituting this expression into (4.32) again, leads to the lower bound:

$$\underline{n}^d \left(\underline{n}^u = 0\right) = \frac{\bar{n}^d}{t^{\alpha}\left(1+t^{\varsigma-1}\right)}. \tag{4.37}$$

In consequence, the upper bound is:

$$\bar{n}^d \left(n^u = \bar{n}^u\right) = \bar{n}^d \left[\frac{t^{\varsigma-1}}{1+t^{\varsigma-1}}\right]. \tag{4.38}$$

Furthermore, at the sustain point, t^S, at which the corner solutions become stable, two conditions must be fulfilled: i) The zero-downstream profit restriction holds (profits in the core turn from negative to positive); and ii) the upstream firm number in the periphery becomes zero so that the second restriction holds. Thus, the sustain point occurs, where the red curves intersect the green curves, and accordingly equation (4.33) is equal to (4.37). The corresponding trade cost value solves:

$$t^S \rightarrow \frac{t^{-\sigma\alpha} - t^{1-\sigma}}{\eta\left(1 - t^{1-\sigma-\sigma\alpha}\right)} - \frac{t^{-\sigma\alpha} + t^{\varsigma-\sigma}}{t^{1-\sigma\alpha-\sigma} + t^{\varsigma-1}} = 0. \tag{4.39}$$

Stability Analysis

The stability of equilibria is ascertained by firm profits again, as assumed in the previous section and equation (4.47) in the Appendix, respectively. Positive profits imply an increasing firm number either by international relocation or a market entry of new firms. In this context, Figure 4.4 shows the downstream profits with respect to the downstream firm number in the corresponding location. In order to analyze the impact of integration, the function is plotted for a couple of trade costs ranging from high values ($t = 5$) until low values ($t = 2$), which includes the critical values, t^B, t^C, and t^S.[5]

Though the function is non-closed, some general attributes can be derived. First, the function is a non-symmetric polynomial, whereat one root is always constant: the symmetric equilibrium, n^d_s. Second, the function is implicitly restricted by four bounds: i) non-negativity of the downstream firm number, $n^d \rightarrow \left[0, \bar{n}^d\right]$; ii) non-negativity of the upstream firm number, $n^u \rightarrow \left[0, \bar{n}^u\right]$, which is again represented by the green curve; and iii) zero-downstream profits (red curve), $n^d \rightarrow \left[n^d\left(\underline{\pi}^d = 0\right), n^d\left(\bar{\pi}^d\right)\right]$.

With regard to stability, an equilibrium is assumed to be stable (unstable), if the marginal profit is negative (positive). In terms of the symmetric equilibrium, the stability alternates from stable to unstable if the slope of the profit function becomes zero,

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[5] The figures are plotted for the same parameter values as in Figure 4.3.

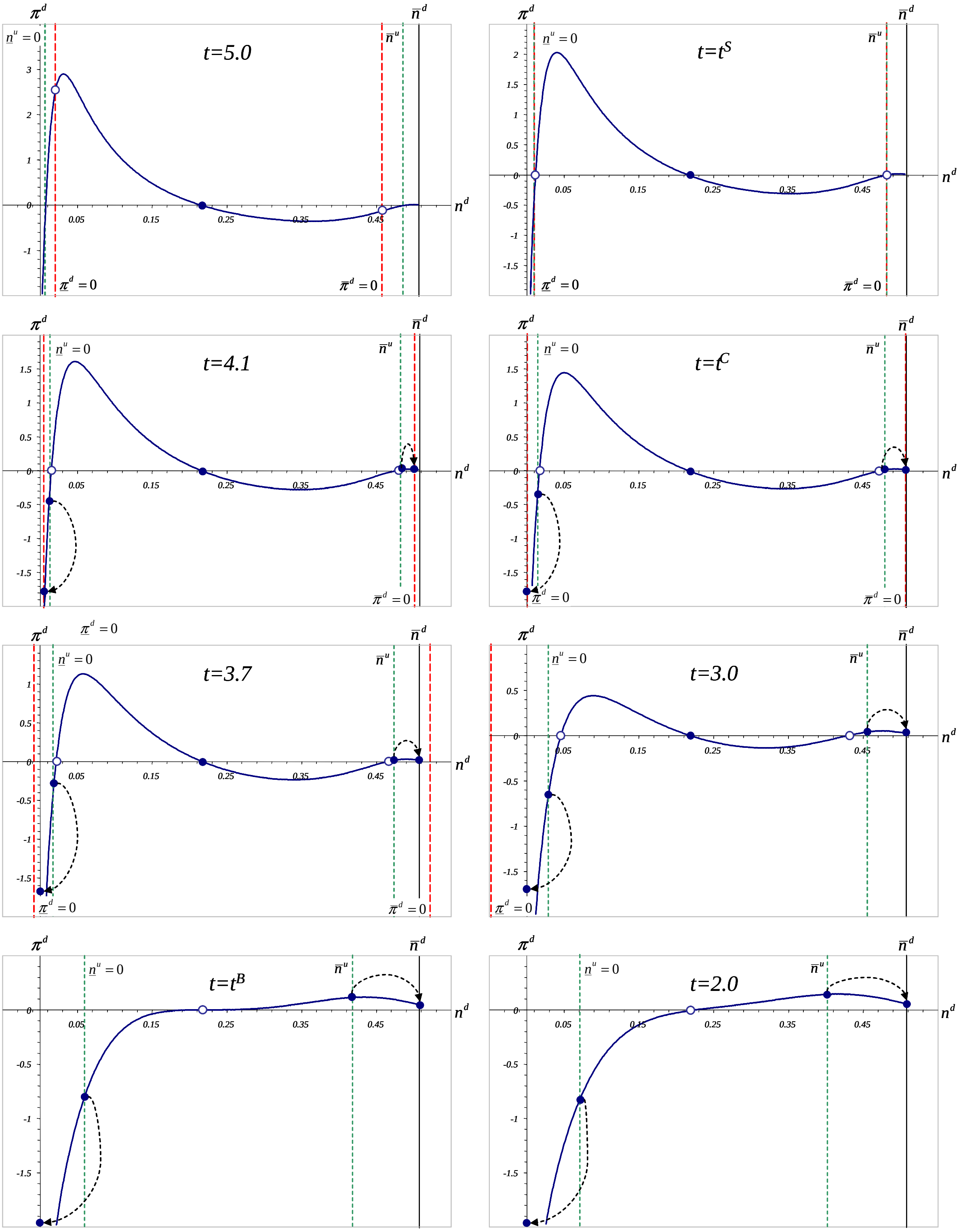

Figure 4.4: Downstream profit function

which is denoted as the break point. By totally differentiating the equation system at this point, the break point level of trade costs can be determined:[6]

$$t^B \rightarrow \frac{\alpha\sigma}{\alpha\sigma + \varsigma - 1} - \left[\frac{1 - t^{1-\sigma}}{1 + t^{1-\sigma}}\right]^2 = 0. \tag{4.40}$$

Moreover, Figure 4.4 shows the behavior of the corner solutions with respect to the variability of non-negativity conditions. For decreasing trade costs, the zero-upstream firm number restriction moves inwards, while the zero-downstream profit restriction moves outwards. At the sustain point level, t^S, both bounds superpose. For trade costs between break and sustain points, $t^B < t < t^S$, multiple equilibria occur, whereas the symmetric and corner solutions are stable, indicated by a filled dot, and the equilibria in between are unstable, indicated by a non-filled dot. Furthermore, for trade costs lower than the sustain point level, the zero-upstream firm number restriction holds, and the corresponding corner solution implies a positive downstream firm number with non-zero profits. In the case of the lower bound, for instance, the corner solution would imply negative profits in the downstream sector. This leads to market exits of firms until: i) the zero-downstream profit restriction (red dotted curve) is reached for $t^C < t < t^S$; or ii) the downstream firm number in the periphery becomes zero for $t < t^C$. For illustration, the directional arrows in Figure 4.4 represent the respective alternation of corner solutions.

Comparing break, sustain, and specialization points, all three critical trade cost values are implicitly defined. Numerical investigation reveals that the sustain point occurs first for increasing trade integration, whereas the ranking of break and specialization points varies: $t^B, t^C < t^S$.[7]

Table 4.1 in the Appendix 4.6 shows the comparative statics of all three critical trade cost values with respect to changes in the parameters controlling the linkage strength: the intermediate cost share, α, and the intermediate substitution elasticity, ς (standard parameter constellation: $\sigma = 3$, $F = 1$). As the numerical example reveals, the break point generally increases in α and decreases with ς. In this context, equation (4.40) shows a linear relationship between cost share and substitution elasticity for a constant break point. This implies that an increase in the cost share can be compensated by a decrease in the substitution elasticity so that the break point remains unchanged.

Furthermore, the specialization point, t^C, increases with α, but is independent from ς, as equation (4.35) clarifies. The sustain point, t^S, is positively correlated with α and negatively with ς.

In summary, all three critical trade cost values increase as the strength of the backward linkage (BL) increases. This implies the stronger the dependency of the downstream industry upon the upstream industry, the sooner agglomeration occurs. In turn, this

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[6] See Appendix 4.6 for a detailed derivation.

[7] Due to non-closeness of corresponding equations, a general proof according to Baldwin et al. (2003), p.49, is not possible.

same holds for a weaker forward linkage (FL) because both forces are opponent.

The Inertia of the Downstream Industry

For quantifying the "*inertia*" of the downstream industry, the area between zero -downstream profit restriction and the lower bound provides information about how many downstream firms remain in the periphery since the agglomeration process has started. The *inertia*, Θ, is defined to be the integral of equation (4.33) between the sustain and specialization points:

$$\Theta = \int_{t^C}^{t^S} \underline{n}^d \left(\pi^d = 0\right) dt \tag{4.41}$$

Table 4.1 shows the corresponding values for the numerical example. In addition, Figure 4.5 plots the Θ-values with respect to both parameters, α and ς.[8] Based upon these results, we can state the following propositions: 1) For very high values for ς, the inertia, Θ, tends to zero because sustain and specialization points converge. This implies that as the downstream sector becomes footloose, the intermediates are more homogenous. 2) The inertia tends to infinity for very low α- and ς-values. This results from a parameter

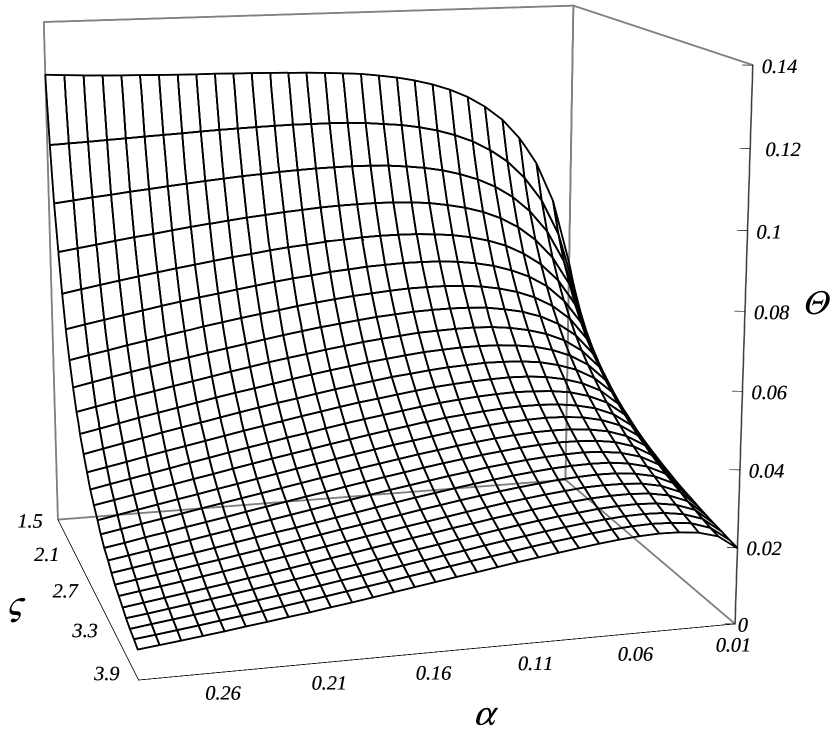

Figure 4.5: *Inertia of the downstream industry*

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[8] See also the calibration results of Table 4.1 in the Appendix 4.6.

constellation very close to a black-hole economy, $t^S \to \infty$. Because the backward linkage escalates ($\varepsilon^d > 1$), this case is excluded in Figure 4.5. 3) The graph is non-monotonous with respect to α (and for ς, not displayed). For low α- and ς-values, the inertia increases with an increase in both parameters, whereas for higher values the correlation is negative. The strength of linkages discussed in the preceding section provides an explanation for these non-monotonicities. According to equation (4.23b), an increase in α and a decrease in ς implies an increasing backward linkage (BL), which leads to an increase in all three critical trade cost values. Thereby, the distance between sustain and specialization points tends to expand, and thus to increase the inertia of the downstream industry due to a stronger dependency upon the upstream sector. However, the numerical calibration reveals that an increasing backward linkage also tends to decrease the zero-profit restriction at the sustain point, as indicated at the Ω-values in Table 4.1. All in all, a rise in the backward linkage strength increases the interval $[t^S, t^C]$ but decreases the height of the integral Θ. Finally, the interaction between these effects produces the shape as well as the non-monotonicities of the graph in Figure 4.5.

4.4 Comparative Advantage vs. Market Size

Deviating from the assumption of symmetric locations, this part considers the impact of differences in local wages and country sizes. Having a look at Figure 4.4 again, a decrease in the local wage rate leads to a shifting of the corresponding profit function downwards, while an increase in local income shifts the function upwards. Figure 4.6 illustrates the downstream firm number in both locations for the case that the wage rate in location 1 is lower than in location 2 ($w_1 = 0.95$, $w_2 = 1$). As both diagrams reveal, the bifurcation pattern becomes more complex compared with the symmetric case. The boundary conditions shift, especially the curve for the zero-upstream firm number is distorted towards the upper and lower bounds. Furthermore, the number of sustain points may vary. In this context, the subscripts denote the location where the industry agglomerates, and the superscripts denote the sustain point, S, and the corresponding numbering. In the lower diagram of Figure 4.6, for instance, two sustain points of agglomeration in location 2 and one sustain point for agglomeration in location 1 occur. The ascription as to which location becomes the core and which one becomes the periphery is still ambiguous. However, the initially symmetric stable path is bent towards the location with the comparative advantage so that it increasingly benefits from trade integration. For trade costs lower than the break point level, location 1 tends to be the industrialized core region. The sustain points can be computed by the same approach discussed above:[9]

$$t_1^{S1} \to \frac{\omega^{\sigma\alpha-\sigma} t^{-\sigma\alpha} - t^{\sigma-1}}{\eta\left(1-\omega^{\sigma\alpha-\sigma} t^{\sigma-1-\sigma\alpha}\right)} - \frac{1+\omega^{\sigma\alpha-\sigma} t^{2-\sigma-\varsigma-\sigma\alpha}\left(\frac{1-\omega^{-\varsigma} t^{1-\varsigma}}{\omega^{-\varsigma}-t^{1-\varsigma}}\right)}{t^{1-\sigma}+\omega^{\sigma\alpha-\sigma} t^{1-\varsigma-\sigma\alpha}\left(\frac{1-\omega^{-\varsigma} t^{1-\varsigma}}{\omega^{-\varsigma}-t^{1-\varsigma}}\right)} = 0 \tag{4.42}$$

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[9] The parameter ω denotes relative wages, w_2/w_1.

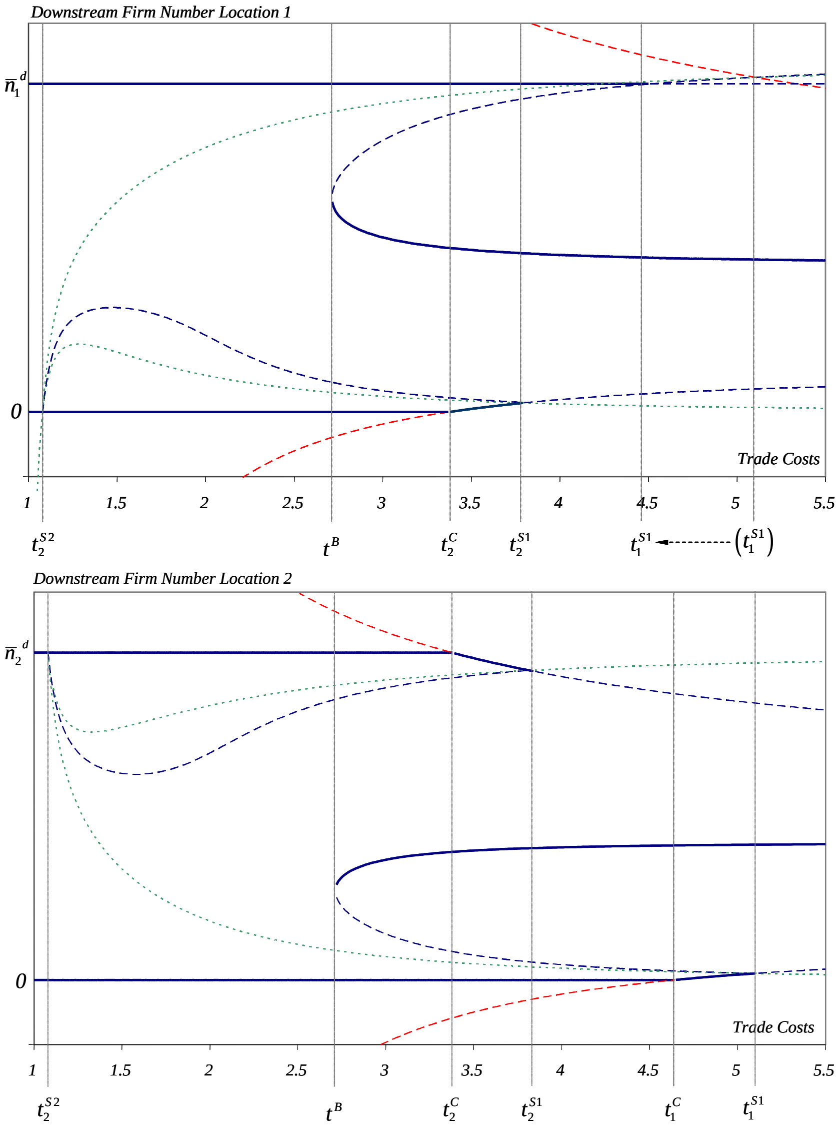

Figure 4.6: *Asymmetries: downstream bifurcation diagrams*

$$t_2^{S1} \rightarrow \frac{t^{-\sigma\alpha} - \omega^{\sigma\alpha-\sigma} t^{1-\sigma}}{\eta\left(\omega^{\sigma\alpha-\sigma} - t^{1-\sigma-\sigma\alpha}\right)} - \frac{t^{-\sigma\alpha} + \omega^{\sigma\alpha-\sigma} t^{\varsigma-\sigma}\left(\frac{1-\omega^{-\varsigma}t^{1-\varsigma}}{\omega^{-\varsigma}-t^{1-\varsigma}}\right)}{t^{1-\sigma-\sigma\alpha} + \omega^{\sigma\alpha-\sigma}t^{\varsigma-1}\left(\frac{1-\omega^{-\varsigma}t^{1-\varsigma}}{\omega^{-\varsigma}-t^{1-\varsigma}}\right)} = 0. \tag{4.43}$$

Equations (4.42) and (4.43) represent the intersection of zero-profit and zero-upstream firm restrictions. Thus, they provide the sustain points as long as: $n_1^d\left(t_1^S\right) \leq \bar{n}_1^d$ and $n_2^d\left(t_2^S\right) \leq \bar{n}_2^d$, respectively. This implies that the intersection must be in between the upper and lower bounds. In the upper diagram of Figure 4.6, the sustain point, t_1^{S1}, (location 1 is the core) occurs for a downstream firm number higher than the upper bound so that the intersection of the unstable interior solution becomes the sustain point as indicated by the left arrow. The sustain points t_1^{S2} and t_2^{S2} are identical and occur at the trade cost level, at which the zero-upstream firm restriction intersects the lower and the upper bound, respectively:

$$t_1^{S2} = t_2^{S2} = \omega^{\frac{\varsigma}{\varsigma-1}}. \tag{4.44}$$

Moreover, the specialization points, t_1^C and t_2^C, differ, and can be determined by solving:

$$t_1^C \rightarrow \eta\left(1 - \omega^{\sigma\alpha-\sigma} t^{\sigma-1-\sigma\alpha}\right) - \omega^{\sigma\alpha-\sigma} t^{1-\sigma-\sigma\alpha} + 1 = 0 \tag{4.45}$$

$$t_2^C \rightarrow \eta\left(\omega^{\sigma\alpha-\sigma} - t^{1-\sigma\alpha-\sigma}\right) - t^{\sigma-1-\sigma\alpha} + \omega^{\sigma\alpha-\sigma} = 0. \tag{4.46}$$

Based upon these outcomes, the same implications hold for the case that one country is larger than its neighbor. The home-country and price index effect produce a relocation tendency towards the location with the larger market size. This implies an upward shift of the profit function in Figure 4.4. Hence, there exists a wage differential which totally compensates the effect of a difference in country sizes (for small deviations from symmetry).

Considering this situation from the viewpoint of the smaller country, it might be a political option to subsidize the local industry for initiating a relocation process due to a comparative cost advantage. In this context, Figure 4.7 shows the required wage rate in the smaller location (here, location 1) by means of the standard numerical example ($Y_2 = 1.1$).

As apparent, symmetry between locations in terms of firm number, and thus of the total industrial output, is only realizable either in the upstream sector or in the downstream sector. For low trade costs (to the left of the intersection), the wage rate is

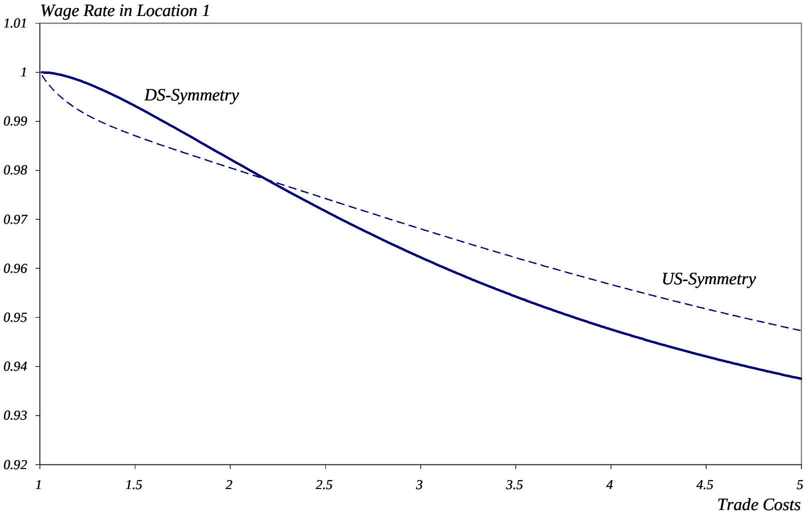

Figure 4.7: *Country size compensating wage rate*

higher, and thus the subsidy lower, for achieving downstream symmetry compared with the wage rate required to generate upstream symmetry. For high trade costs (to the right of the intersection), the situation is reversed. The trade cost value, where both curves intersect, converges to the break point level for a decreasing size asymmetry.

If we consider a situation of $t = 4$, for instance, a wage rate given on the upstream-symmetry curve produces an intermediate output, which is identical in both locations, but the downstream sector still shows a relocation tendency towards the larger country. If we further decrease the wage rate until the downstream-symmetry curve is reached, the upstream sector agglomerates in the smaller locations, whereas the downstream sector is equalized. For $t = 1.5$, for instance, a wage rate set on the upstream-symmetry level initiates a downstream agglomeration for the smaller country, while the upstream industry is evenly distributed. A wage rate below both curves implies agglomeration of upstream and downstream sectors in the smaller location.

Alternatively, it might be a political objective to equalize the total amount of manufactures as an aggregate; thus, to equalize the industrial employment in both countries: $n_1^u x_1^u + n_1^d x_1^d = n_2^u x_2^u + n_2^d x_2^d$. In the case of the standard example, the firm size can be neglected because it is the same in both locations and sectors. As a result of this policy, the upstream firm number in the smaller location is higher and the downstream firm number is lower than in the larger country. All in all, we face a situation of a relative upstream specialization in location 1, and a relative downstream specialization in location 2.

4.5 Concluding Remarks

As the Venables model reveals, vertical specialization only occurs in terms of a total specialization of the periphery in downstream activities. Thus, vertical specialization is a result of a successive relocation first of the upstream industry, thereafter of the downstream industry for decreasing trade costs. The inertia discussed in this paper quantifies this specialization effect, which is primarily controlled by the backward linkage. A perfect vertical specialization where one location focuses on upstream and the other location on downstream production is excluded.

If we return to the initial question of an industrial base and summarizing the main results, the strength of linkages quantified by the approach discussed in this paper differs from the existing literature. First, we obtain two values for the sectoral coherence with respect to forward and backward linkage, whereas the stronger one linkage, the weaker is the antagonistic one. Second, beside the commonly used parameter cost share, α, to quantify the linkage strength, we included the intermediate substitution elasticity, ς, as a further determinant.

The inertia of the downstream industry suggests itself for a criterion to identify industries being part of the industrial base. But as Section 4.3 revealed, the relationship is quite complex. As we have seen, a low break point does not unnecessarily imply a high inertia and vice versa. In fact, if we choose a high-α and a low ς-industry, for instance, the break point occurs for high trade cost values indicating an early agglomeration process. In contrast, the inertia also takes high values, which implies that the downstream industry slowly detaches from the periphery. Considering industries featuring a substitution elasticity even closer to the edge of the domain, the inertia may decrease again. Overall, a general attribution of industries to the industrial base critically depends upon the parameter constellation also in regard to the consumer substitution elasticity, fixed costs, and potential country size or wage rate asymmetries.

Having a comparative advantage either due to lower wages or higher labor productivity (lower production coefficient, a) does not inevitably mean agglomeration in the corresponding location, if the relative market size is too low. In consequence, low-cost locations do not benefit if the wage rate is above the curves exemplarily plotted in Figure 4.7. From the viewpoint of a larger country, this implies that as long as the wage rate in the smaller country is above both curves, the location with the larger market attracts the upstream and downstream sectors. For a wage rate in between the US- and DS-symmetry curves, the larger country releases the upstream sector for trade costs on the right of the intersection. On the left-hand side, where trade costs to the larger sales market become less relevant, the downstream industry becomes footloose and relocates before the upstream industry does.

4.6 Technical Appendix

Stability Analysis (Closed Economy)

As apparent in Figure 4.1 and provable by differentiating equations (4.17) and (4.19) at the equilibrium, the graph of N^d intersects N^u always from above, which confirms the global stability.

However, to prove the stability analytically, we assume an out-of-equilibrium adjustment process with the following characteristics:[10]

$$\begin{aligned} \dot{n^u} &= f\left(\pi^u\right)\ ,\ \partial f/\partial \pi^u > 0 \\ \dot{n^d} &= f\left(\pi^d\right)\ ,\ \partial f/\partial \pi^d > 0\ ,\ f(0) = 0. \end{aligned} \tag{4.47}$$

By substitution, the relative profit functions subject to the number of upstream and downstream firms can be expressed as:

$$\pi^u = \alpha w F^d \frac{\sigma}{\varsigma} \left(n^u\right)^{\frac{\alpha+\varsigma-1}{1-\varsigma}} n^d - wF^u \equiv K_1 \left(n^u\right)^{\frac{\alpha+\varsigma-1}{1-\varsigma}} n^d - wF^u \tag{4.48a}$$

$$\pi^d = \frac{\mu Y}{\sigma n^d} - wF^d \left(n^u\right)^{\frac{\alpha}{1-\varsigma}} \equiv K_2 \left(n^d\right)^{-1} - K_3 \left(n^u\right)^{\frac{\alpha}{1-\varsigma}}\ , \tag{4.48b}$$

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[10] Based upon Neary (2001) for the standard Dixit-Stiglitz model.

where K_1, K_2 and $K_3 > 0$. Totally differentiating the profit functions (4.48) yields:

$$d\pi^u = \underbrace{\left[\left(\frac{\alpha+\varsigma-1}{1-\varsigma}\right) K_1 \left(n^u\right)^{\frac{\alpha+\varsigma-1}{1-\varsigma}-1} n^d\right]}_{<0} dn^u + \underbrace{\left[K_1 \left(n^u\right)^{\frac{\alpha+\varsigma-1}{1-\varsigma}}\right]}_{>0} dn^d \tag{4.49a}$$

$$d\pi^d = \underbrace{\left[-K_2 \left(n^d\right)^{-2}\right]}_{<0} dn^d + \underbrace{\left[\left(\frac{\alpha}{\varsigma-1}\right) K_3 \left(n^u\right)^{\frac{\alpha}{1-\varsigma}-1}\right]}_{>0} dn^u. \tag{4.49b}$$

It is apparent at the sign of the partial derivative in (4.49a) that an increase in the number of upstream firms out of the zero-profit isocline, N^u, generates losses in this industry caused by the intermediate price index effect. Via the assumed adjustment process given by (4.47), the number of upstream firms decreases again, until they break even. A secondary effect works in the downstream sector. The decreasing intermediate price index reduces procurement cost for downstream firms, and makes them realize profits, which, in turn, attracts more downstream firms. The entry of new firms into the downstream market reduces their profits again via the price index effect (see equation (4.49b)), which retracts the number of downstream firms back to the zero-profit isocline (4.19). The overall result is a globally stable equilibrium indicated by the directional arrows in Figure 4.1.

Specified Equation System

For analytical traceability, the equation system is fully specified as follows:

$$n_1^d w_1^{1-\alpha} \left(P_1^u\right)^{\varsigma-1+\alpha} \left(w_1^{-\varsigma} - w_2^{-\varsigma} t^{1-\varsigma}\right) = n_2^d w_2^{1-\alpha} \left(P_2^u\right)^{\varsigma-1+\alpha} \left(w_2^{-\varsigma} - w_1^{-\varsigma} t^{1-\varsigma}\right) \tag{4.50}$$

$$\begin{aligned} &\mu Y_1 w_1^{\sigma(\alpha-1)} \left(P_1^u\right)^{\sigma-1} \left(P_1^d\right)^{\sigma-1} + \mu Y_2 w_1^{\sigma(\alpha-1)} \left(P_1^u\right)^{\sigma-1} \left(P_2^d\right)^{\sigma-1} t^{1-\sigma} \\ &\quad = \mu Y_1 w_2^{\sigma(\alpha-1)} \left(P_2^u\right)^{\sigma-1} \left(P_1^d\right)^{\sigma-1} t^{1-\sigma} + \mu Y_2 w_2^{\sigma(\alpha-1)} \left(P_2^u\right)^{\sigma-1} \left(P_2^d\right)^{\sigma-1} \end{aligned} \tag{4.51}$$

$$\left(P_1^u\right)^{1-\varsigma} = w_1^{1-\varsigma} n_1^u + \left(w_2 t\right)^{1-\varsigma} n_2^u \tag{4.52a}$$

$$\left(P_2^u\right)^{1-\varsigma} = \left(w_1 t\right)^{1-\varsigma} n_1^u + w_2^{1-\varsigma} n_2^u \tag{4.52b}$$

$$\left(P_1^d\right)^{1-\sigma} = w_1^{(1-\alpha)(1-\sigma)} \left(P_1^u\right)^{\alpha(1-\sigma)} n_1^d + w_2^{(1-\alpha)(1-\sigma)} \left(P_2^u\right)^{\alpha(1-\sigma)} t^{1-\sigma} n_2^d \tag{4.53a}$$

$$\left(P_2^d\right)^{1-\sigma} = w_1^{(1-\alpha)(1-\sigma)} \left(P_1^u\right)^{\alpha(1-\sigma)} t^{1-\sigma} n_1^d + w_2^{(1-\alpha)(1-\sigma)} \left(P_2^u\right)^{\alpha(1-\sigma)} n_2^d \tag{4.53b}$$

$$\alpha \frac{\sigma}{\varsigma} \frac{F^d}{F^u} \left[n_1^d w_1^{1-\alpha} \left(P_1^u\right)^{\alpha} + n_2^d w_2^{1-\alpha} \left(P_2^u\right)^{\alpha} \right] = n_1^u w_1 + n_2^u w_2 \tag{4.54}$$

$$\frac{\mu \left(Y_1 + Y_2\right)}{\sigma F^d} = n_1^d w_1^{1-\alpha} \left(P_1^u\right)^{\alpha} + n_2^d w_2^{1-\alpha} \left(P_2^u\right)^{\alpha} \tag{4.55}$$

Equation (4.50) represents the upstream output, where zero-profits implies a fixed firm size in both locations. Similarly, equation (4.51) holds for the downstream industry. Equations (4.52), (4.53) are the price indices; equations (4.54) and (4.55) are the market clearing conditions for the upstream and downstream sectors, respectively.

Symmetric Solution

From equating upstream and downstream firm numbers in both locations, the symmetric solution set can be found ($w_1 = w_2 = 1$, $F^u = F^d$):

$$n_s^u = \frac{\alpha \mu \left(Y_1 + Y_2\right)}{2 \varsigma F} \tag{4.56}$$

$$n_s^d = \frac{1}{\sigma} \left[\frac{\mu \left(Y_1 + Y_2\right)}{2F} \right]^{\frac{\alpha + \varsigma - 1}{\varsigma - 1}} \left[\frac{\alpha}{\varsigma} \left(1 + t^{1-\varsigma}\right) \right]^{\frac{\alpha}{\varsigma - 1}} \tag{4.57}$$

$$\left(P_s^u\right)^{1-\varsigma} = \left(1 + t^{1-\varsigma}\right) n_s^u \tag{4.58}$$

$$\left(P_s^d\right)^{1-\sigma} = \left(1 + t^{1-\sigma}\right) \left(P_s^u\right)^{\alpha(1-\sigma)} n_s^d \tag{4.59}$$

Corner Solutions

Due to variability of the corner solutions with respect to trade costs, we need to distinguish between two cases: i) $t < t^c$, and ii) $t > t^c$.

Setting peripheral firm numbers equal to zero, $\underline{n}^u = \underline{n}^d = 0$, yields:

$$\bar{n}^u = \frac{\alpha \mu \left(Y_1 + Y_2\right)}{\varsigma F} \tag{4.60}$$

$$\bar{n}^d = \left[\frac{\mu \left(Y_1 + Y_2\right)}{\sigma F} \right] \left(\bar{n}^u\right)^{\frac{\alpha}{\varsigma - 1}} \tag{4.61}$$

$$\left(\bar{P}^u\right)^{1-\varsigma} = \bar{n}^u \tag{4.62}$$

$$\underline{P}^u = \bar{P}^u t \tag{4.63}$$

$$\left(\bar{P}^d\right)^{1-\sigma} = \left(\bar{P}^u\right)^{\alpha - \alpha\sigma} \bar{n}^d \tag{4.64}$$

$$\underline{P}^d = \bar{P}^d t \tag{4.65}$$

The Break Point
Totally differentiating the equation system (4.50) – (4.55) at the symmetric equilibrium yields:

$$\frac{dn_s^d}{n_s^d} = (1-\varsigma-\alpha)\,\frac{dP_s^u}{P_s^u} \tag{4.66}$$

$$\frac{dP_s^d}{P_s^d} = \left[\frac{\sigma\alpha}{\sigma-1}\right]\left[\frac{1+t^{1-\sigma}}{1-t^{1-\sigma}}\right]\frac{dP_s^u}{P_s^u} \tag{4.67}$$

$$\frac{dP_s^u}{P_s^u} = \left[\frac{1-\varsigma}{1-\varsigma-\alpha}\right]\frac{\left(P_s^u\right)^{\varsigma-1}}{1-t^{\varsigma-1}}dn_s^u \tag{4.68}$$

$$\frac{dP_s^d}{P_s^d} = \left(1-t^{1-\sigma}\right)n_s^d\left(P_s^u\right)^{\alpha(1-\sigma)}\left(P_s^d\right)^{\sigma-1}\left\{\alpha\frac{dp_s^u}{P_s^u}+\left(\frac{1}{1-\sigma}\right)\frac{dn_s^d}{n_s^d}\right\}. \tag{4.69}$$

The downstream profit function can be expressed as:

$$\pi_1^d = \left(P_1^u\right)^{\alpha} = \left[\frac{x_1^d}{\sigma}-F\right]. \tag{4.70}$$

After substituting downstream demand (4.28a) and totally differentiating again, we obtain:

$$\begin{aligned} d\pi_s^d \;=\; & \left(\frac{1-\sigma}{\sigma}\right)\left(P_s^d\right)^{\sigma-1}\left(P_s^u\right)^{\alpha(1-\sigma)}\left\{\alpha\mu\left(Y_1+Y_2t^{1-\sigma}\right)\frac{dP_s^u}{P_s^u}\right. \\ & \left.-\,\mu\left(Y_1-Y_2t^{1-\sigma}\right)\frac{dP_s^d}{P_s^d}\right\}-\alpha F\left(P_s^u\right)^{\alpha}\frac{dP_s^u}{P_s^u} \end{aligned} \tag{4.71}$$

In the next step, we combine equations (4.66)–(4.69) and substitute them in (4.71). Now we rearrange the profit differential in such a way that $d\pi_s^d/dn_s^d$ results, which is the slope at n_s^d in Figure 4.4. Setting this expression equal to zero yields the break point condition (4.40).

Calibration Results

Table 4.1: *Comparative statics of critical trade cost values*

ζ	α											
		0.01		**0.05**		**0.1**		**0.2**		**0.5**		**0.6**
1.2	t^B	1.4597	t^B	2.1889	t^B	2.8059	t^B	3.7321	t^B	5.6541	t^B	6.1623
	t^C	1.0151	t^C	1.0782	t^C	1.1645	t^C	1.3767	t^C	3.9679	t^C	31.9998
	t^S	1.4599	t^S	2.1954	t^S	2.8455	t^S	4.0264	t^S	19.7892	t^S	243.0000
	FL	0.9524	FL	0.8000	FL	0.6667	FL	0.5000	FL	0.2857	FL	0.2500
	BL	0.0500	BL	0.2500	BL	0.5000	BL	1.0000	BL	2.5000	BL	3.0000
	Ω	0.2604	Ω	0.1587	Ω	0.1098	Ω	0.0725	Ω	0.0337	Ω	0.0062
	Θ	0.1059	Θ	0.1545	Θ	0.1577	Θ	0.1627	Θ	0.5127	Θ	1.3448
1.5	t^B	1.2745	t^B	1.6879	t^B	2.0395	t^B	2.5787	t^B	3.7321	t^B	4.0421
	t^C	1.0151	t^C	1.0782	t^C	1.1645	t^C	1.3767	t^C	3.9679	t^C	31.9998
	t^S	1.2747	t^S	1.6928	t^S	2.0635	t^S	2.7278	t^S	8.9927	t^S	62.8108
	FL	0.9804	FL	0.9091	FL	0.8333	FL	0.7143	FL	0.5000	FL	0.4545
	BL	0.0200	BL	0.1000	BL	0.2000	BL	0.4000	BL	1.0000	BL	1.2000
	Ω	0.2865	Ω	0.2152	Ω	0.1701	Ω	0.1212	Ω	0.0371	Ω	0.0048
	Θ	0.0655	Θ	0.1081	Θ	0.1204	Θ	0.1242	Θ	0.1372	Θ	0.0979
2.0	t^B	1.1881	t^B	1.4597	t^B	1.6879	t^B	2.0395	t^B	2.8059	t^B	3.0150
	t^C	1.0151	t^C	1.0782	t^C	1.1645	t^C	1.3767	t^C	3.9679	t^C	31.9998
	t^S	1.1884	t^S	1.4644	t^S	1.7079	t^S	2.1448	t^S	5.8140	t^S	36.7350
	FL	0.9901	FL	0.9524	FL	0.9091	FL	0.8333	FL	0.6667	FL	0.6250
	BL	0.0100	BL	0.0500	BL	0.1000	BL	0.2000	BL	0.5000	BL	0.6000
	Ω	0.2904	Ω	0.2285	Ω	0.1854	Ω	0.1319	Ω	0.0287	Ω	0.0015
	Θ	0.0427	Θ	0.0680	Θ	0.0737	Θ	0.0699	Θ	0.0323	Θ	0.0038
3.0	t^B	1.1300	t^B	1.3107	t^B	1.4597	t^B	1.6879	t^B	2.1889	t^B	2.3271
	t^C	1.0151	t^C	1.0782	t^C	1.1645	t^C	1.3767	t^C	3.9679	t^C	31.9998
	t^S	1.1303	t^S	1.3160	t^S	1.4795	t^S	1.7776	t^S	4.4156	t^S	32.1550
	FL	0.9950	FL	0.9756	FL	0.9524	FL	0.9091	FL	0.8000	FL	0.7692
	BL	0.0050	BL	0.0250	BL	0.0500	BL	0.1000	BL	0.2500	BL	0.3000
	Ω	0.2851	Ω	0.2211	Ω	0.1756	Ω	0.1168	Ω	0.0118	Ω	0.0001
	Θ	0.0267	Θ	0.0378	Θ	0.0373	Θ	0.0292	Θ	0.0028	Θ	0.0000
5.0	t^B	1.0904	t^B	1.2122	t^B	1.3107	t^B	1.4597	t^B	1.7850	t^B	1.8750
	t^C	1.0151	t^C	1.0782	t^C	1.1645	t^C	1.3767	t^C	3.9679	t^C	31.9998
	t^S	1.0908	t^S	1.2188	t^S	1.3333	t^S	1.5530	t^S	3.9996	t^S	32.0000
	FL	0.9975	FL	0.9877	FL	0.9756	FL	0.9524	FL	0.8889	FL	0.8696
	BL	0.0025	BL	0.0125	BL	0.0250	BL	0.0500	BL	0.1250	BL	0.1500
	Ω	0.2719	Ω	0.1960	Ω	0.1437	Ω	0.0789	Ω	0.0011	Ω	0.0000
	Θ	0.0159	Θ	0.0184	Θ	0.0150	Θ	0.0079	Θ	0.0000	Θ	0.0000
7.0	t^B	1.0732	t^B	1.1705	t^B	1.2483	t^B	1.3650	t^B	1.6180	t^B	1.6879
	t^C	1.0151	t^C	1.0782	t^C	1.1645	t^C	1.3767	t^C	3.9679	t^C	31.9998
	t^S	1.0738	t^S	1.1782	t^S	1.2742	t^S	1.4694	t^S	3.9700	t^S	31.9998
	FL	0.9983	FL	0.9917	FL	0.9836	FL	0.9677	FL	0.9231	FL	0.9091
	BL	0.0017	BL	0.0083	BL	0.0167	BL	0.0333	BL	0.0833	BL	0.1000
	Ω	0.2605	Ω	0.1737	Ω	0.1161	Ω	0.0507	Ω	0.0001	Ω	0.0000
	Θ	0.0114	Θ	0.0110	Θ	0.0075	Θ	0.0025	Θ	0.0000	Θ	0.0000
9.0	t^B	1.0631	t^B	1.1463	t^B	1.2122	t^B	1.3107	t^B	1.5227	t^B	1.5811
	t^C	1.0151	t^C	1.0782	t^C	1.1645	t^C	1.3767	t^C	3.9679	t^C	31.9998
	t^S	1.0638	t^S	1.1550	t^S	1.2414	t^S	1.4280	t^S	3.9681	t^S	31.9998
	FL	0.9988	FL	0.9938	FL	0.9877	FL	0.9756	FL	0.9412	FL	0.9302
	BL	0.0013	BL	0.0063	BL	0.0125	BL	0.0250	BL	0.0625	BL	0.0750
	Ω	0.2505	Ω	0.1545	Ω	0.0937	Ω	0.0314	Ω	0.0000	Ω	0.0000
	Θ	0.0088	Θ	0.0073	Θ	0.0041	Θ	0.0008	Θ	0.0000	Θ	0.0000

5 The Spatial Dynamics of the European Biotech Industry

5.1 Introduction

Significant changes in spatial concentration and specialization of European industries accompany the EU integration process. The empirical study of Midelfart-Knarvik et al. (2000) reveals that since the 1970s, medium and high-tech industries have been characterized by increasing dispersion. In this context, the geographical concentration of the pharmaceutical industry shows a particularly sharp decrease: 12% of the production was relocated from Germany and Italy to Denmark, the UK, Ireland and Sweden. Against the background of strong sectoral interdependencies between the biotech and pharmaceutical industries, changes in the economic geography of biotechnology may be expected as well.[1]

In the course of the EU enlargement in 2004, European industries did not only face enlarged sales markets; they also faced alternative production and research locations. In this context, it is debatable if the efforts of economic policy, especially in Germany, France and the UK, to establish a growing biotech landscape are endangered by a potential relocation to acceding countries in central and east Europe (CEE).[2] This risk appears to be imminent in the light of the dynamic economic growth, increasing foreign direct investments, and increasing high-tech exports from CEE countries. In contrast, the acceding countries show substantial deficits in research infrastructure, proprietary developments of products and processes, purchasing power and in the supply of highly qualified labor.

Against the background of these questions, this paper aims to make a quantitative contribution within this debate addressing to the central issue: *To what extent does the EU enlargement have an impact on the spatial formation of the European biotech industry?* Although the location and agglomeration of biotech firms have been analyzed in a wide range of scientific publications, the spatial dynamics of the European biotech industry

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[1] The term *biotech(nology)* follows the definition according to OECD (2005): 'The application of science and technology to living organisms, as well as parts, products and models thereof, to alter living or non-living materials for the production of knowledge, goods and services.' Analogously, a biotech company is: '... defined as a firm engaged in key biotechnology activities such as the application of at least one biotechnology technique (...) to produce goods or services and/or the performance of biotechnology R&D (...)'.

[2] With regard to the diffuse common definition of the term CEE, here it synonymously refers to the EU accession countries only.

as a whole appears to be a blind spot against the multitude of country studies.[3] Therefore, this paper aims to make a quantitative contribution using a numerical simulation of a standard model of the *New Economic Geography* (NEG). In combination with the empirical results of primary and secondary statistics, this approach allows to construct a scenario for the future development of the European biotech geography. This requires a consideration of the industrial structure and determinants of foreign trade.

As the study of Midelfart-Knarvik et al. (2000) demonstrated and intensely discussed in the regional economic literature, the impact of inter-industrial linkages on agglomeration dynamics has significantly increased.[4] In this regard, central and east European locations attract downstream sectors to an increasing degree. This implies also a stronger relocation of the biotech industry in its essential capacity as an upstream supplier for the pharmaceutical and medical sectors. Therefore, this paper aims to fertilize the discussion of spatial restructuring within the context of sectoral interdependencies between the biotech and pharmaceutical industries.

Figure 5.1 represents the approach of this analysis. In the first steps, comprised in Sections 5.2, the paper provides the analytical base and legitimization of the model assumptions underlying the numerical simulation in Section 5.3. Because of the central importance of the vertical integration of the biotech industry within the pharmaceutical supply chain, the sectoral interdependencies are the focus in characterizing the real object of investigation in Section 5.2.1. In Section 5.2.2, based upon the specification of real economic facts of the preceding segment, the paper identifies the structure of international trade within the European biotech industry as a major determinant of its spatial formation.

In this context, the article refers to the results of an online survey, conducted by the department *Innovation and Growth* of the University of Lueneburg and supported by two major industrial associations.[5] A detailed presentation of the survey results associated with an extensive analysis of the biotech industry and its foreign trade activities are discussed in Kranich (2007a) and in a working paper for the survey results only in Kranich (2007b).

Based upon the empirically established model assumptions, Section 5.3 sets up a standard NEG model incorporating vertical linkages (Venables (1996)). This model provides the basis for the simulation study of the EU-15+10 enlargement. Finally, Section 5.4 discusses the results and draws conclusions for: i) potential industrial development paths; ii) economic policy in terms of location and research promotion; and iii) for further research concerning the spatial dynamics of the European biotech industry.

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[3] See for country studies e.g. Dohse (2000) for Germany, Corrolleur et al. (2003) in the context of France, Cooke (2001) for UK.

[4] See Porter (2005), Markusen and Melvin (1984), Amiti (1998), Hummels et al. (1998) as an exemplary listing of empirical studies concerning vertical linkages.

[5] National Association of the Pharmaceutical Industry e.V. (BPI), German Association of Biotechnology Industries (DIB).

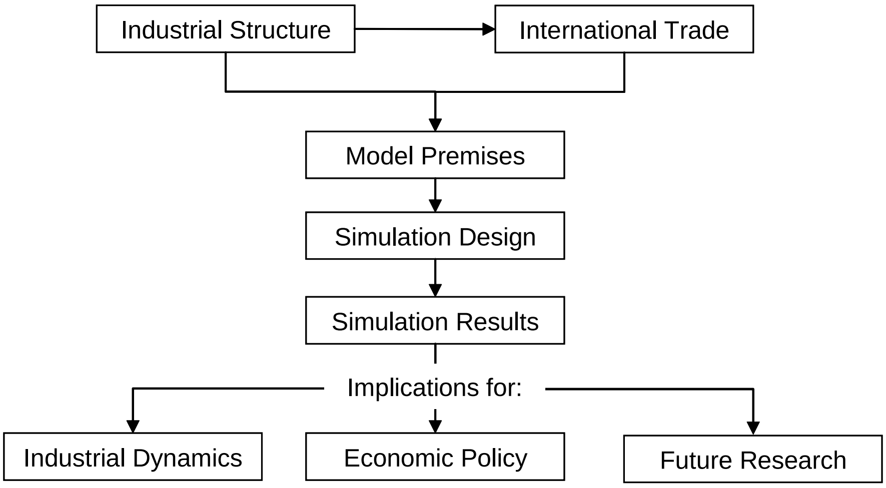

Figure 5.1: *Structure and approach*

5.2 The European Biotech Industry

5.2.1 Industrial Structure and Vertical Integration

In 2004, the European biotechnology industry counted about 2,200 firms generating a total turnover of €22 billion.[6] Germany, the UK, and France occupied the leading positions in terms of firm number (see Figure 5.2.1). Furthermore, with respect to turnover, Denmark and Switzerland joined the leading group, which can be traced back to the presence of large multinational corporations. In general, it is apparent that the leading west European agglomeration areas are also occupied by the larger part of biotech companies. This conclusion corresponds also with the results of Allansdottir et al. (2000). The authors draw a similar picture of the spatial concentration of the European biotechnology using patent statistics. The study reveals that the most innovative regions in terms of patents are in Germany, France, the UK, the Netherlands and Italy. Another remarkable result is that the leading positions correlate to the spatial concentration of downstream sectors (material sciences, organic chemicals, pharmaceuticals and polymers).Furthermore, several studies emphasize the role of local universities and research institutions as well as the supply of a highly educated workforce for the emergence and growth of biotech clusters.[8]

Summarizing, these results allow the conclusion that: i) the local conditions in R&D infrastructure and capacities; ii) the size of sales markets; and iii) the connection to the (pharmaceutical) downstream sector play an important role for the spatial formation of

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[6] EuropaBio (2006)

[7] Monetary values in million €.

[8] See e.g., Audretsch and Stephan (1996), Feldman (2000), Stuart and Sorenson (2003).

Table 5.1: *European biotechnology industry (2004)*[7]

Country	**Firms**	**Turnover**	**R&D Exp.**	**Employees**
Austria	44	481	345	2,842
Belgium	84	606	315	3,654
Denmark	117	5,396	824	18,461
Finland	66	568	91	2,160
France	223	2,197	589	9,142
Germany	572	3,421	1,244	24,134
Greece	5	2	2	131
Hungary	16 [a]	38 [a]	-	394[b]
Ireland	41	982	277	2,900
Italy	51	286	284	2,654
Norway	41	81	80	931
Netherlands	51	286	284	2,654
Poland	13[c]	180[d]	-	946[c]
Portugal	17	36	8	256
Spain	81	260	214	2,201
Sweden	138	854	367	3,942
Switzerland	90	2,367	795	1,990
Czechia	63[e]	-	-	-
UK	457	4,522	1,557	21,134
Total	**2,266**	**67,733**	**9,816**	**101,156**

[a] Data from EuropaBio (2006).

[b] Rough estimation based upon Proventa (2004).

[c] See OECD (2006).

[d] Polish Information and Foreign Investment Agency: Biotechnology Sector in Poland 2004.

[e] See South Moravian Innovation Center (2007).

biotechnology. In this context, the relevance of location factors depends upon the level of geographical aggregation. In international terms, the degree of industrialization, the consumer as well as the downstream market size, and the connection to global markets determine the extent of national biotech industries. On the national level, only few regions benefit from the local presence of biotech firms. In contrast, the occurrence of regional clustering is restricted to national agglomeration areas characterized by high performing endowments of research facilities and highly skilled labor.

Turning to the cross-sectional orientation of the European biotech industry, Figure 5.2 shows the percentage of firms with respect to the fields of biotechnological application. In this context, Pharmaceuticals and Enabling Technologies (platform technologies), with 37% and 24%, respectively, are the outstanding categories. Overall, the figure indicates the superior importance of the pharmaceutical sectors for the biotech industry, which legitimates the simplification of the simulated supply chain in Section 5.3, consisting of the pharmaceutical industry as a single downstream sector for the biotech industry.

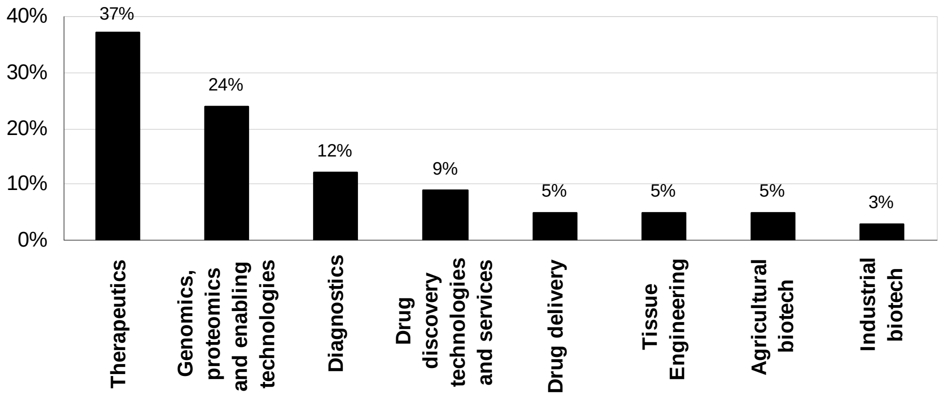

Figure 5.2: *Percentage of firms with respect to biotech applications in Europe (2005)*[9]

A common attribute of the majority of biotech firms is the small and medium firm size. According to the survey of OECD (2006), the share of companies with less than 50 employees lies between 63% (Belgium) and 86% (Germany). Only few large *Life Science Corporations* (LSC) dominate the biotechnology industry in Europe.[10] These firms attend different markets, primarily for pharmaceuticals but also for chemicals, health care and consumer goods. In Germany, for instance, approximately 30 firms covering a share in total biotech sales of nearly 70% occupy this category.

Also in contrast to the majority of core biotech firms, the LSCs are vertically integrated in all stages of the value-added chain from R&D until distribution. In addition, these companies interact with biotech core firms in ways such as the purchase of intermediate inputs, contract research, sales cooperation, and license agreements. In general, the representative core biotech firm is small or medium sized, operating as an intermediate supplier of products, knowledge (licenses and patents) or external knowledge production

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[9] See Ernst & Young (2006).

[10] Life Sciences are qualified as "…any of the branches of natural science dealing with the structure and behaviour of living organisms" (WordNet: http://wordnet.princeton.edu/perl/webwn?s=life%20science). In these categories particularly fall biochemistry, nutritional sciences, medical technology, pharmacy, environmental technology. The term *Life Science Corporation* (LSC) follows the definition of Ernst & Young (2000), which is also used by the German Federal Statistical Office (2002): large corporations of the Life Science Industry are firms with more than 250 employees, which do not focus on biotechnology as the only business segment, but undertake intensive R&D efforts for products and processes of modern biotechnology or achieved an annual turnover of more than €10 million with modern biotech products. In contrast, *core biotech firms* primarily work with the use of modern biotechnological processes and firm size is smaller than the thresholds of the LSCs.

(contract research) for the pharmaceutical and medical industries. The vertical separation of these upstream and downstream sectors is relatively stable while both industries have recently experienced a period of horizontal consolidation. In this context, Pisano (1990) considers the vertical division of labor between core biotech and established firms in the pharmaceutical industry. The paper concludes that, though both sectors show a tendency for vertical integration due to transaction costs and the need for technology adaptation by the downstream sector, these endeavors are limited by capital restraints of the core biotech firms and a longsome know-how accumulation process within established downstream firms.[11]

In addition, any more arguments for vertical separation may be supplemented. Since the 1980s, public technology promotions, on one hand, and the increasing availability of venture capital, on the other hand, have advanced the emergence and growth of biotechnology out of the fundamental research in academic facilities. Due to high fixed cost in R&D and production, as well as the extensive research risk, only a few core biotech firms succeeded in becoming established as fully integrated units. The technological gap of the LSCs with respect to biotechnology forwarded their demand for biotech products and services, especially in the form of contract research, and strengthened the division of labor between both sectors. Since the industrial consolidation in the course of the collapse of the stock market bubble in 2001, many biotech companies had financial shortages. In consequence, the firm population decreased by market exits, mergers and acquisitions. Another result was the adjustment of the business models to a stronger focus on services and technologies rather than proprietary development, production and distribution. Finally, these factors resulted in an increased vertical separation between core biotech and life science industries at increased sectoral interdependencies.[12]

Based upon these results and the findings of existing literature, the relationship between the core biotech industry and LSCs is characterized by: i) the demand for biotech intermediate products and services of the life science industry; ii) the LSCs as competitors for fully integrated biotech firms; iii) the make or buy decision of LSCs with respect to biotech services and intermediates; and iv) the intensity of competition within the biotech industry.

In consequence, an increasing independence of the LSCs from the core biotech industry may be expected for the future, assuming an unchanged market condition. The crucial factor for this development is the tendency of the LSCs to (re-)integrate biotech R&D as a core competence, which is primarily dependent upon the (anticipated) market size for biotech products and applications. This mainly concerns activities, which could not be integrated in default of technological knowledge but are of strategic importance for (pharmaceutical) corporations. In contrast, activities with a high degree of homogeneity, low economies of scale, or minor demand (i.e., specialized services) may be unaffected by the integration propensity of LSCs. Furthermore, a reduction of public technology

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[11] See also Audretsch (2001).

[12] See Kranich (2006) for a theoretical discussion of allocation in vertically linked industries.

promotion and hence a reduction of subsidization of core biotech firms would decrease cost advantages of outsourcing biotech activities, which finally reinforces the integration tendency of the life science industry.[13]

Concerning the opposite dependency of the biotech core industry upon the LSCs, it is necessary to differentiate with respect to different firm types, again. Generally, the increasing concentration in the downstream sector implies a further shifting of market power to the LSCs from the biotech core firms in their capacity as either intermediate suppliers or fully integrated competitors. In this context, it is noted that with respect to market segment and degree of differentiation, the impact of increasing concentration on the biotech sector may vary. On one hand, the field of biotech products and services are quite heterogeneous, with the result that, on closer examination, the industry disaggregates into separate submarkets with frequently oligopolistic structures. Because of the wide range of biotechnological applications and the innovative potential, customers in different industries prefer a certain degree of diversity in terms of products, processes and suppliers. In consequence, it may be a successful business strategy to focus on a few segments rather than to compete on a homogenous or large-scale production. A vertical acquisition of core biotech companies by LSCs is an exception and conceivable, if the take-over: i) represents an opportunity for vertical restraint with respect to downstream competitors; ii) grants access to strategically important know-how, licenses and patents; or iii) is beneficial due to strong complementarities between intermediates and final products and services.[14]

5.2.2 International Trade

For evaluating the impact of international trade on the German biotech industry, our department conducted an online survey in 2006. The target audience contained 810 firms consisting of German biotech core companies, equipment suppliers, and LSCs that were compiled by address files of the industrial associations, as well as Internet and database search. The subject matters of the survey were led by the central questions: To what extent are biotech firms involved in foreign trade? What significance do the emerging countries Brazil, Russia, India, China (frequently abbreviated *BRIC*) and the Eastern EU accession states have in terms of sales market, research and production location?

In this context, the survey was structured into five parts: A) The location factors of German biotech firms within Germany; B) International activities of the industry in terms of R&D, production and sales; C) Opportunities and risks of globalization for the interviewed firm with a focus on BRIC and eastern Europe; D) Opportunities and risks due to globalization for the overall German biotech industry; and E) Information about the interviewed firm with respect to size, business focus, region and age.

The firm survey was accompanied by an expert survey with 106 persons from industry,

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[13] This hypothesis was also confirmed by experts in personal interviews.

[14] See e.g., Martin (1993), pp. 242-260 for a discussion of vertical integration.

politics, industrial associations and science.[15] Both questionnaires were identical except for firm specific questions. The online survey represents the first study concerning the internationalization of (German) biotech firms. Because the survey primarily asked for qualitative evaluations, the significance of the results cannot be statistically proved. Nevertheless, the outcome appears to be valid in consideration of the feedback rates, which are 12% of firms and 27% of experts, as well as the representative cross section in terms of application field, firm size and firm age. The expert survey was conceived to check the answers of firms from a different point of view, especially concerning country evaluation and interpretation of firm response.

In the context of this paper, the online survey confirms the major importance of the location factors for biotech firms (Germany), as discussed in the previous subsection. For international activities, the survey concludes that the most important determinants are: i) the enlargement of sales markets; ii) the unification of admission standards (the reduction of market entry barriers); and iii) the access to technological knowledge of research institutions.

The study reveals that biotech companies participate in international trade with a high degree. About 66% of the firms generate a turnover of at least 30% abroad, where 34% of the firms gain more than 70% of their annual turnover by the export business. Despite the high trade intensity, the majority of firms (41%) realize only less than 10% of their turnover beyond Europe. This implies that the foreign sales of the German biotech industry focuses on Western Europe as indicated in Table 5.2, which shows the rankings of foreign countries preferred by German biotech firms. The percentages in brackets represent the relative frequency of firms, which established a relationship to the corresponding country. In this regard, the indications summarize the foreign activities in terms of their varying intensity. In respect of sales, for instance, the foreign activities range from pure exporting, sales corporations to own subsidiaries; concerning R&D this contains (bilateral) contract research or own foreign R&D facilities. With respect to sales, the most important destinations are in Western Europe: Switzerland, Austria, the UK, France and the Netherlands.Regarding the foreign engagement in terms of production, the results confirm the statements of trade theory, where the trade volume is determined by spatial closeness and the market size of foreign trade partners. This explains the high relevance of the west European countries, on one hand, and the importance of North America, where the USA represents the largest global pharmaceutical market, on the other hand. In terms of production, it is apparent that West European countries are under-represented. which can be traced back to their geographical closeness to Germany in which the largest part of manufacturing for the European market is located. Furthermore, countries featuring a large (expected) market size but are distant from Europe, e.g., USA or China, tend to be supplied by local production. For R&D, the biotechnological leader, the United States, is closely followed by China, Russia and

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[15] The addresses of experts have been provided by the German Association of Biotechnology Industries (DIB).

Table 5.2: *Ranking of the most important countries for German biotech companies with respect to R&D, production and sales activities*[17]

Pos.	Sales	Production	R&D
1	Switzerland (55%)	USA (9%)	USA (17%)
2	Austria (51%)	China (7%)	China (14%)
3	USA (50%)	UK (5%)	Russia (14%)
4	Others Europe (43%)	Slovakia (4%)	Austria (14%)
5	UK (42%)	Hungary (4%)	Netherlands (12%)
6	France (39%)	Netherlands (3%)	UK (12%)
7	Netherlands (38%)	Brazil (3%)	Hungary (11%)
8	Canada (34%)	Canada (3%)	Switzerland (10%)
9	Japan (33%)	Others America (3%)	Japan (9%)
10	Belgium (31%)	India (3%)	Australia (5%)

Western Europe. This implies that R&D activities follow not only the research potential and infrastructure, but also the market size and manufacturing, which explains the relatively strong correlation to the production ranking. This relocation dependency may be an evidence for strong vertical linkages between R&D and production (or downstream sectors).

In the survey we explicitly asked for an evaluation of the BRIC and CEE countries in terms of their competitive position and biotech market potential. The majority (60%) of the survey participants consider the role of competitors from the emerging countries China and India as relevant. In contrast, about 69% attribute a meaningful market potential to those countries. Overall, the questioned firms plan to expand their sales activities in the emerging BRIC (65%), followed by 32% and 9% that intend to establish R&D or production capacities.

Regarding the EU accession states, about 63% of the responding firms assess the competitive risk from the CEE countries as unimportant or almost unimportant. With respect to the market potential, a clear rating is not available. About 48% of the firms assess the market size as relevant – opposed to 45%, which see no potential in Eastern Europe. Nonetheless, 61% of German biotech firms plan an extension of sales in the CEE countries, as well as 32% in R&D and 9% in production. The importance of the CEE countries, in terms of biotech upstream activities, particularly concerns Hungary and Slovakia, as also shown in Table 5.2.

These results raise the question: What factors are responsible for the relatively weak position of the CEE countries compared to the BRIC states?

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[17] The data contain any kind of activities from pure export to own (sales) establishments in relative frequency. Multiple answers were possible.

At first, the economic potential in the CEE countries is restricted in several ways: the low market size and purchasing power, the below-average research infrastructure in comparison with Western Europe, as well as the scarce supply of highly qualified biotechnologists. Furthermore, the Eastern European research locations are suffering from two dilemmas: First, the geographical closeness to the industrialized European core implies that highly skilled R&D can be undertaken without leaving the core. The case is different in China and India, where the immense market potential and the spatial (and political) distance requires a local establishment. Second, the European integration process promotes the interregional mobility of workers. The income and professional perspectives are significantly better in Western Europe, which makes high skilled specialists leave peripheral regions to look for job opportunities in the core.[18]

With respect to the pharmaceutical industry as a downstream sector for biotech companies, further barriers for development occur. Although the pharmaceutical industry has recently been characterized as a dynamic development, the total market size accounts just for 6% of the European Union. In this context, Poland plays with €3.8 billion, the largest part of the CEE countries, followed by Hungary (€1.9 billion), Czech Republic (€1.6 billion), and Slovenia (€672 m).[19] In 2003, the local pharmaceutical industry in the CEE countries achieved revenues of €5.3 billion (2003). The largest Eastern European manufacturer with 202 firms is Poland, ahead of Hungary with 102 firms. A major part of sales growth can be attributed to the imports of multinational corporations (via sales branches) and locally produced generics. Therefore, it can be concluded that local manufacturing predominantly supplies local markets so that the competitive risk from the CEE countries is relatively low. Competitive advantages in labor costs have a lower impact due to high capital and technology intensity in the biotech and pharmaceutical sectors, which was also confirmed in personal expert interviews. According to expert opinions (survey and interviews), the expansion of international biotech activities in the CEE countries is currently constrained to production and services of standardized products and processes, especially in the field of clinical testing and automatic screening.

Opposed to these dampening factors for an eastward relocation, the spatial formation of the biotech industry is also dependent upon the dynamics of the pharmaceutical sector. Although this downstream sector is currently weakly established in the CEE states, it sensitively responds to national wage differences. Figure 5.3 shows the labor unit costs of the pharmaceutical industry (2004) for Poland, Czechia, Hungary and Slovakia compared to the EU-25 average, compared to about one-fourth in the eastern accession states. These cost advantages imply a motive for an eastward relocation of pharmaceutical firms. In the course of the EU integration process, trade barriers between European countries have fallen, which has made it profitable to attain the large Western Euro-

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[18] This corresponds also with the results of empirical studies; see e.g., OECD (2002).

[19] EUROSTAT database.

[21] Data source: EUROSTAT, industry code: NACE DG244 (Manufacture of pharmaceutical, medicinal-chemical and botanical products), indicator code: v91210 (Labor cost per employee -Unit labor cost-).

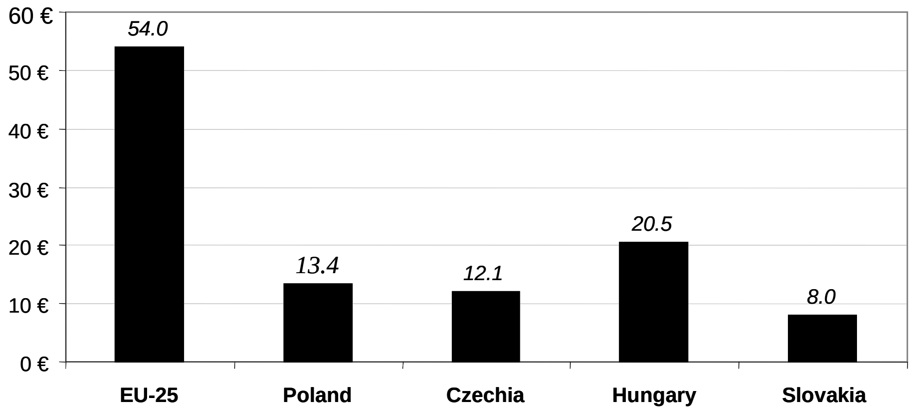

Figure 5.3: *Labor unit costs of the pharmaceutical industry in the largest CEE countries in comparison with the EU-25 average (2004)*[21]

pean pharmaceutical markets from distant low cost locations. A spatial shifting of the pharmaceutical industry, characterized as being the relevant market for biotech firms, involves also a relocation tendency of the corresponding upstream sector via vertical linkages. This linkage driven development may entail increasing spatial technology diffusion that could (partially) compensate the technological gap of the CEE research facilities. Against this background, the next section introduces a modeling framework for quantifying the spatial dynamics of the European biotech industry from this vertical linkage perspective.

5.3 Simulation

5.3.1 The Model

The New Economic Geography, initially introduced by Krugman (1991), provides explanations for industrial agglomeration based upon increasing returns and imperfect competition. Based upon classical economic geography models (e.g., Christaller (1933), Lösch (1940), the first proceedings, commonly referred to as the *core-periphery model*, explains industrial agglomeration with respect to regional mobility of workers. Later on, the theoretical debate was extended by the implementation of vertical linkages as a further agglomerative force, as discussed in Section 5.1, where Krugman and Venables (1995) as well as Venables (1996) provided seminal papers.

For modeling the European biotech industry, this paper picks up the latter model roughly illustrated in this section. The Venables model considers a simple supply chain consisting of an upstream sector providing a downstream sector with intermediate products while this downstream sector supplies consumer with final products. Both such vertically linked industries are spread across two spatially separated locations (see Figure 5.4). Both industries produce a continuum of differentiated goods by the use of labor,

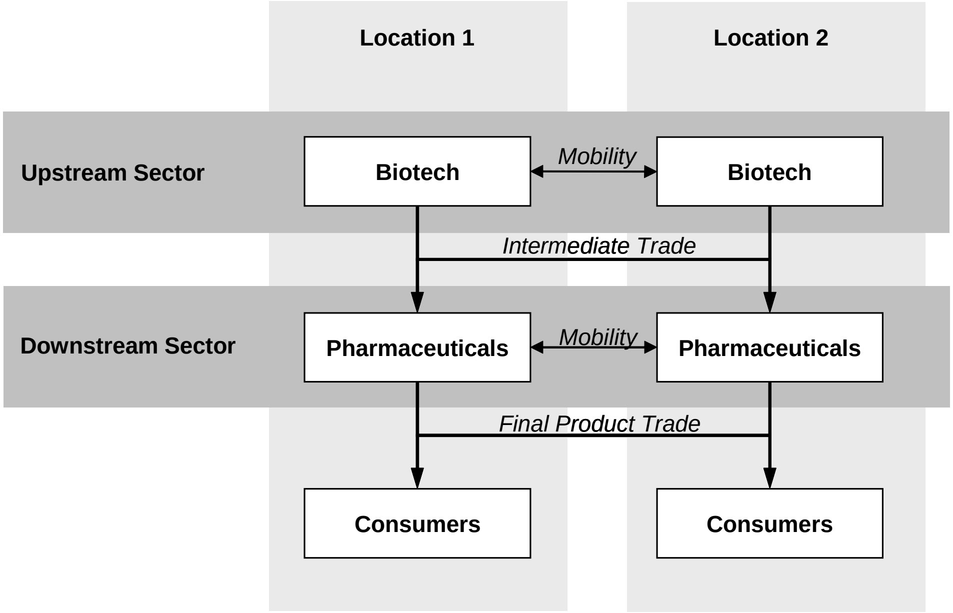

Figure 5.4: *Schematic diagram of the Venables model*

while the downstream sector additionally employs the output of the upstream sector as a further input factor. The downward arrows between sectors and consumers indicate these commodity flows. Both types (intermediate and final products) are internationally tradable signified by the sectoral cross-links labeled by *trade*. The firms in both industries are competitive monopolists, so that due to increasing returns and (technical) preference structure, one firm produces only one differentiated variety.

The market supply attends to a representative private household, which demands not only the whole consumer good continuum, but also a homogenous outside good, which can be considered, since these goods are not in the focus of this model. The allocation between both sectors is characterized by mutual interdependencies, which are also referred to as *forward* and *backward linkages*. The forward linkage, also called demand linkage, describes the dependency of the upstream industry upon the downstream industry: the larger the downstream sector, the larger is the relevant market for the intermediate sector. The backward linkage, also described as cost linkage, results from the *price index effect*: the more firms produce in the upstream sector, the higher is the competitive pressure implying decreasing intermediate prices, which finally decrease the procurement costs of the downstream industry. It is applied for both mechanisms: the larger is one sector, the larger is the other.

In the framework of the NEG, the spatial distance between locations is represented by trade costs (usually Samuelson iceberg costs), which are dependent upon the value of goods exported from location r to location s. Trade costs involve not only transportation costs but also every cost arising from international trade. These include tolls and import taxes, insurance rates, labor and storage costs, etc., and additionally efforts caused by lingual and cultural differences or varying legal conditions but are difficult to quantify. Against this background, not only local market size and production costs influence the location decision of firms, but also the amount of trade costs. The higher the trade costs, the stronger firms tend to locate at the larger market for reducing the costs of spatial transfers. In contrast, at low trade costs, local cost advantages become more important than local market size.

The model results in two spatial distribution functions, v^u and v^d, where the first one describes the spatial spreading of the upstream industry, and the second one of the downstream industry.[22] The distribution of an industry is measured by the ratio of sectoral output in location s to the corresponding output in location r. For an example, if v^u takes the value 5, the total output of the upstream industry in location s is five times higher than the output of the same industry in location r, implying that the upstream industry geographically concentrates in s.

In this context, Equation (5.1) represents the spatial distribution of the upstream industry dependent upon several exogenous parameters and the distribution of the downstream industry, v^d:

$$v^u = \frac{v^d \left[t^\sigma - (\alpha^u)^{\sigma-1} \omega^\sigma\right] - t\left[(\alpha^u)^{\sigma-1} \omega^\sigma - t^{-\sigma}\right]}{\left[t^\sigma - (\alpha^u)^{1-\sigma} \omega^{-\sigma}\right] - v^d t \left[(\alpha^u)^{1-\sigma} \omega^{-\sigma} - t^{-\sigma}\right]} \tag{5.1}$$

Equation (5.1) reveals two mechanisms. First, it contains the forward linkage, which implies that the distribution of the downstream sector positively determines the distribution of the upstream sector. Second, we find parameters representing the production situation in both locations: α and ω. The first one is the ratio of production coefficients in location s to location r reflecting productivity differences. The second one, ω, defines the ratio of wages in both locations and can be interpreted as the wage differential.[23] In general, the location with lower production costs is the location with a smaller consumer market, and thus, with a lower concentration of downstream firms. This, in turn, reduces the motivation of upstream firms to move to the firm location characterized by cost advantages. The tension between those opposing mechanisms is determined by the level of trade costs, t, with the result that, at a certain degree of trade integration, one force exceeds the other one. In the extreme, where international (intermediate) trade is costless, the upstream industry totally agglomerates in the country with lower production costs.

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[22] The superscripts are mnemonics for *upstream* and *downstream*.

[23] The parameter σ represents the constant elasticity of substitution. The higher the value the more homogenous are the differentiated intermediate and final products. Because this variable is not of major importance for this paper, it is henceforth neglected.

Equation (5.2) describes the spatial distribution of the downstream industry with respect to the distribution of the upstream industry.

$$v^d = \frac{\eta^d \left[t^\sigma - \left(\alpha^d\right)^{\sigma-1} \left(\xi^d\right)^\sigma\right] - t \left[\left(\alpha^d\right)^{\sigma-1} \left(\xi^d\right)^\sigma - t^{-\sigma}\right]}{\left[t^\sigma - \left(\alpha^d\right)^{1-\sigma} \left(\xi^d\right)^{-\sigma}\right] - \eta^d t \left[\left(\alpha^d\right)^{1-\sigma} \left(\xi^d\right)^{-\sigma} - t^{-\sigma}\right]} \tag{5.2}$$

Similarly as in equation (5.1), the outcome is dependent upon the backward linkage and local production and cost conditions. In this context, the variable x_i defines the relative downstream costs that are the procurement costs for intermediates in the ratio of location s to r, again:

$$x_i^d = \omega^{1-\mu} \left[\frac{t^{1-\sigma} + \omega^{-\sigma} \left(\alpha^u\right)^{1-\sigma} v^u}{1 + \omega^{-\sigma} \left(\alpha^u\right)^{1-\sigma} v^u t^{1-\sigma}}\right]^{\frac{\mu}{1-\sigma}} . \tag{5.3}$$

This expression depends upon the wage differential, trade costs, the size of consumer market, μ, and finally upon the distribution of the upstream industry, v^u. The level of trade costs determines the relevance of the upstream industry distribution. With decreasing trade costs, the concentration of the downstream industry becomes increasingly independent of the location of upstream firms. Under specific conditions, a potential outcome is the total geographic specialization, where upstream and downstream industries totally agglomerate in different locations.

The interaction of mechanisms summarized in the functions (5.1) and (5.2) allocate an equilibrium distribution of both sectors, where the intersection of the corresponding graphs defines one or multiple equilibrium states. In the following subsection, we adapt the modeling framework to the case of the European biotech and pharmaceutical industries.

5.3.2 Simulation Design

Within the simulation study, the Venables model is utilized to analyze the impact of the European enlargement in 2004 (EU15+10) upon the European biotech industry. In doing this, the following facts, presented in Section 5.2, are explicitly taken into account: i) the strong focus of biotech firms on upstream activities incorporating R&D and the production of intermediates; ii) the dominance of the pharmaceutical industry as a major application field; iii) the great importance of inter-European trade; and iv) the spatial concentration of industries in the Western European countries. Based upon these facts, we make the following assumptions:

- The biotech core industry is considered an upstream sector of the pharmaceutical industry as indicated in Figure 5.4.
- Both sectors have access to the same labor market.

- Because only a singular supply chain is modeled, the partial-analytical version of the Venables model is used implying exogenous wages and income.
- We summarize the Western European countries (AT, BE, CH, DE, DK, FR, GB, IT, NL) to one location, referred to as the core region, and the residual European states (E, FI, GR, IE, PT, NO, SE) to a second location, defined as the peripheral region.[24]

This approach allows not only an analysis within a two-location version but also a modeling of the European Eastern enlargement by adding the CEE countries to the periphery. All in all, this simulation design raises several problems: i) the Venables model does not incorporate R&D activities so that corresponding expenditures fall in production fixed costs; ii) capital as an important input factor, especially in the pharmaceutical industry due to high development costs of new agents, are neglected; iii) the model does not involve the decisive public research infrastructure; and iv) the agglomeration forces are ascribed to vertical linkages only, but not to factor mobility, for instance.

Nonetheless, this approach features convincing advantages with respect to the present case. The markets for biotech products and services as well as pharmaceuticals are fragmented to a high degree, which can be traced back to the relative low substitutability between products on the one hand, but also to the distinctive consumer preference for diversity, on the other hand. In addition, due to patents and property rights, temporary niche markets appear, which almost few firms provide. The choice of monopolistic competition sufficiently takes account for the structures in both sectors. Furthermore, both industries are characterized by increasing returns, principally in R&D and production. It may be held again to the missing implementation of explicit R&D activities and associated demand effects that the Venables model describes basic agglomeration dynamics of vertically linked industries; this is also valid in the biotech and pharmaceutical industries. The simulation results, which can be interpreted as agglomerative potential, will be completed by the impact of entrepreneurial R&D and public research policy.

5.3.3 Simulation Results

Figure 5.5 and Figure 5.6 illustrate the simulation outcomes as well as the comparative-static analysis based upon the simulation parameters in Table 5.3. Figure 5.5 shows the distribution of sectoral output in the ratio core to periphery with respect to trade costs. Here, v^B stands for the distribution of the *biotech* instead of *upstream* industry and v^P for *pharmaceutical* in terms of the *downstream* industry. Both marks indicate the calibrated trade costs level for the period before and after the EU Eastern enlargement in 2004. This means for 'EU-15' that before the European enlargement in 2004, both

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[24] The countries are assigned to the categories by means of their spatial distances and the annual turnover of the pharmaceutical industry (2004).

industries very spatially concentrated in the same degree: the biotech and pharmaceutical industries were 5.8 times stronger agglomerated in the European core compared to the periphery. The trade cost values for 'EU-15' and 'EU-25' are indirectly determined from the real ratio of sectoral turnovers for 2003 and 2005, while the distributions are functions of trade costs.

The Eastern enlargement implies for the European Union not only a larger common economic area, but also a simultaneous convergence of legal conditions, an increasing expansion of transportation infrastructure, an abolition of tolls and import regulations, and decreasing average trade costs with increasing trade volume. With decreasing trade costs, the spatial concentration of both sectors, characterized by a decreasing ratio, declines to the benefit of the peripheral countries. Furthermore, the biotech industry shows a stronger relocation to the periphery compared to the pharmaceutical industry, apparent at the divergence of the sectoral distribution on the left hand side of the figure. This implies that the pharmaceutical sector features an increasing relative specialization at a decreasing spatial concentration in comparison to the upstream sector. The reason for this development is the stronger sales market orientation of the pharmaceutical industry: the expenditures for respective products in the Western European states are almost five

Table 5.3: *Simulation parameters*

Variable	**Description**	**Value**	**Comments**
η^d	Relative expenditures for pharmaceutical output	5.6709 4.7018	Pharmaceutical turnover, ratio Core: Periphery (before and after enlargement)
α	Relative production coefficients	0.9110 0.8914	Calculated from the average factor productivity, ratio Core: Periphery, (before and after enlargement)[a]
ω	Wage differential	1.2638 2.3552	Labor unit costs, ratio Core: Periphery, (before and after enlargement)
μ	Cost share of downstream industry for intermediates	0.0716	Ratio of biotech wage bill + purchases of goods and services to total costs of the biotech industry[b]
σ	Substitution elasticity	9.5300	See Hummels (1999), Table 4

[a] Here the ratio of locations is inversed because the gross value-added per each output unit is equal to the reciprocals of the production coefficients. Average factor productivity = input / output = (production value – gross value added) / production value. It is assumed the same productivity for biotech and pharmaceutical industry.

[b] The costs of biotech industry are calculated from data of Ernst&Young (2004).

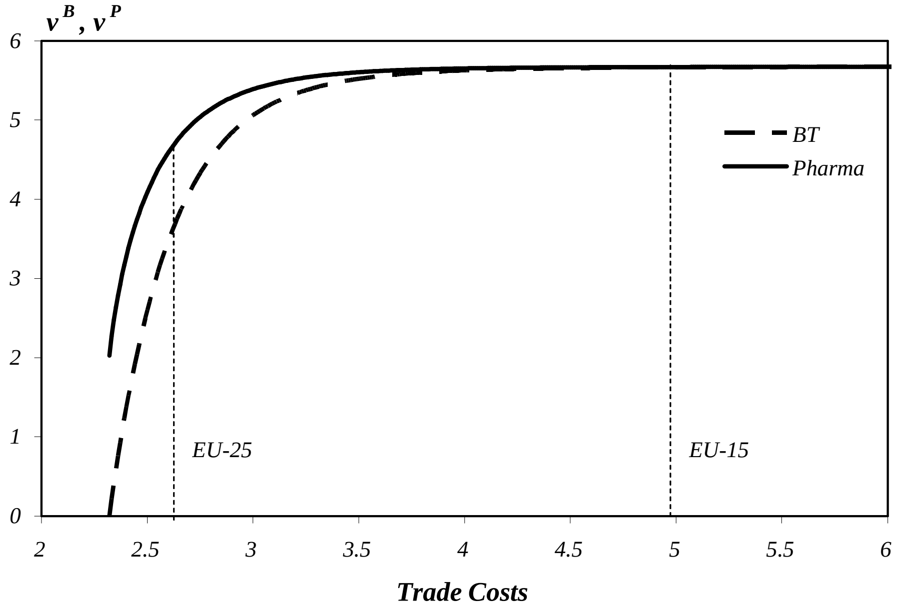

Figure 5.5: *Relative distribution (Core to Periphery) of pharmaceutical and biotech industry (measured in the relative turnover), before and after EU enlargement, with respect to trade costs.*

times higher than in the periphery (see Table 5.3, first line).[25]

Figure 5.6 shows the simulation results with respect to a change in the relative wages (again, core to periphery). The European enlargement is associated with an increasing wage differential from 1.2 to 2.3, in consequence of the accession of the CEE countries. It is apparent that the current and the past wage differential lie in a relatively inelastic range of the sectoral distribution function. The spatial concentration does not respond to an increasing (decreasing) wage differential until the value is above 3.5 (below 0.5). Only in a situation beyond these values, the figure shows relative specialization and tendency to a symmetric outcome (increasing asymmetry). In the course of economic integration, a convergence of wages and income is expected within the EU, which corresponds with a limiting wage differential of 1.With respect to Figure 5.6, the economy moves from a wage ratio of 2.3 leftward to 1 without affecting the spatial distribution of both sectors. The reason for the rigidity is the strong forward linkage between biotech and pharmaceutical linkages, which more than compensate differences in local production costs. This means that the dependency of the biotech industry upon the pharmaceutical industry, which primarily orientates on the larger core market, has a stronger impact on the location decision than lower wages in the periphery.

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[25] Multiple equilibria, a central feature of NEG models, do not occur in this parameter setting. For trade costs (basically defined to be greater than 1) which are below 2.3, the model loses its validity: countries become more and more regions.

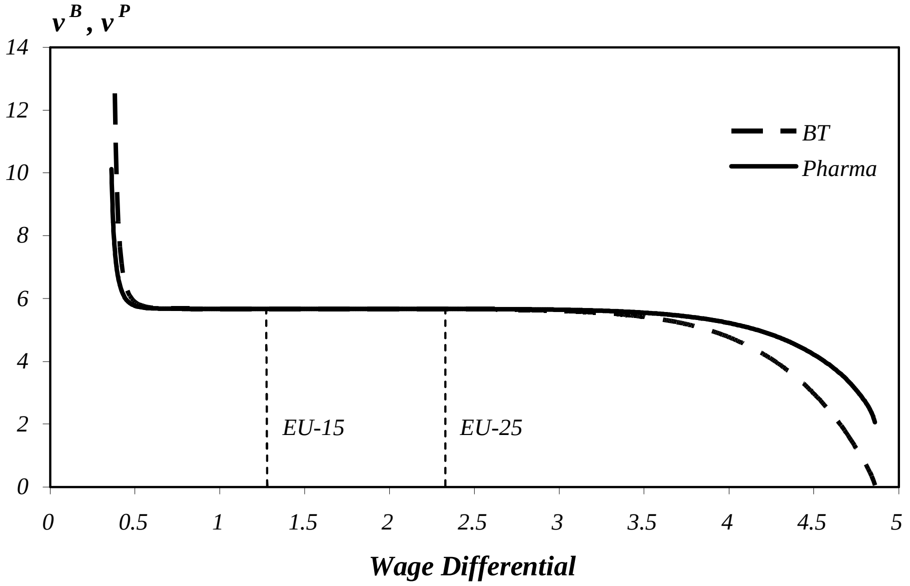

Figure 5.6: *Relative distribution (Core to Periphery) of pharmaceutical and biotech industry, before and after EU enlargement, with respect to wage differential*

5.4 Discussion and Conclusions

Considering the simulation, the results provide two central messages. First, the strong vertical linkages between biotech and pharmaceutical industries compensate the dispersive impact of wage differentials across European countries. Because the European core features the larger consumer market, it primarily determines the downstream sector distribution, which exerts a strong attraction for the biotech industry. Wage differentials within the real parameter domain do not have an impact on the concentration of both the biotech and pharmaceutical industries. The second implication is the sensitivity of sectoral distribution with respect to the level of trade costs. The simulation shows that a further decrease results in an increasing relocation of both industries to the European periphery. In the face of this outcome, the concerns, that public investments in the core get lost by a relocation of the biotech industry, appear to be justified. However, this conclusion requires a further discussion. One point of critics is addressed to the simulation design. In this context, the partial-analytical approach implying exogenous income and wages may provide a relevant dampening effect for the industrial relocation. On one hand, there is the limited supply of highly qualified labor and the research infrastructure in the periphery, which is not included in the model but represents crucial location determinants, as shown in the previous section. The supply of skilled labor and R&D facilities in the CEE countries are restricted by mobility as well as low capacities for public investments in the capital-intensive biotech and pharmaceutical research. On the other hand, a further limitation stems from the model design: the periphery is considered as one common location implying a homogeneous economic area.

In reality, the periphery disaggregates into spatially separated countries arranged like a ring around the core. Some peripheral countries are quite distant from each other so that the underlying assumption of costless intra-regional trade is questionable. Nevertheless, this argument may be countered by several empirical studies concerning the exports of peripheral countries, e.g., the Eastern European states.[26] The largest part of the peripheral exports concentrates on trading with the core while the intra-peripheral flows of trade are relatively low. Without these distortions, the spatial production network would be much more filigree; furthermore, the market size of the periphery would be significantly reduced, which works against dispersion.

Summarizing and turning back to the central question posed in Section 5.1, a restrained relocation tendency from the European core to the periphery results for both, the biotech and pharmaceutical industries. Restrictions in labor, infrastructure, and technology supply considerably dampen the industrial shifting. Along with the low peripheral market size (for both sectors), only moderate changes arise in the spatial distribution.

Against the background of these results: What can be concluded for economic policy? Baldwin et al. (2003) summarized central issues of the NEG with regard to economic policy. Nonlinearities, thresholds, and discontinuities determine agglomeration, and thus an efficient economic political intervention. As shown in the previous section, the current wage differential is in an inelastic range of sectoral distribution, which also will not be left at complete convergence. Public intervention via price or factor cost subsidization for promoting industrial agglomeration potentially requires enormous expenditures in which legitimization is questionable with respect to proportionality and economic efficiency. Therefore, it is important to note that, with decreasing trade costs, the efficiency of agglomeration stimulating instruments is increasing.

From the viewpoint of regional policymakers, political options are even more restricted due to financial and hierarchical constraints. In addition to lower public budgets, a conflict of regional and supra-regional interests develops. While industrial agglomeration is desirable for local policy, on the national or supra-national level, these ambitions lead to industrial dispersion and a loss of spatial efficiency due to lower economies of scale. The solutions proposed for this dilemma refer to spatial specialization implying the emergence of industry- or technology-specific clusters. The basic idea is to compensate missing spatial economies of scale by competitive advantages due to specialization. This approach is debatable with respect to the following facts:

- Biotech products and services find use only in few applications, which are dominated by the medical and pharmaceutical sectors.
- The biotech industry disaggregates in many small-scale niche markets and technology fields, which are not inevitably interconnected. This implies that endogenous

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[26] See e.g., Ando and Kimura (2007).

agglomeration tendencies by spillover effects are lower as they would be for a more homogenous industry.

- The vertical linkages between biotech and pharmaceutical industries are strong in such a way that the upstream industry primarily orientates on the location of the downstream industry. The pharmaceutical industry is agglomerated in the European core as a result of larger sales markets. A spatial separation of the sectors implies an immense subsidization of peripheral regions, public investments in a highly qualified labor supply and sufficient infrastructure.
- Without supra-national coordination, regional (national) politics may be conflicting what is associated with a loss of spatial efficiency and common welfare.

In the context of these conditions, a final and general recommendation for economic policy is not possible because the political trade-off between spatial economies of scale and regional equality depends upon the aversion to asymmetry of the European population. As demonstrated by Charlot et al. (2006), the industrial core is almost able to compensate the periphery for welfare losses resulting from agglomeration. This implies inter-regional transfers as realized by the European Regional Development Fund (ERDF), for instance. The related question is: For what purposes should these interregional investments be applied? With respect to the present case, a promotion of peripheral industries is reasonable if these industries do not only feature comparative cost advantages, but also low trade costs and major economic importance in terms of output and employment. For Eastern Europe, this may concern industries with a relative high labor intensity, distinctive product or process standardization, and large-scale production. However, a further consideration of an optimal European technology mix requires a comprehensive analysis of the European industries and may be subject for future research. In this context, the outcomes of this paper suggest a further consideration of public technology promotion in their capacity as location factor, potential spillover effects between biotech firms as a relevant agglomeration force on the regional level, as well as the international mobility of biotech researchers as a destabilizing impact for the European periphery.

What can finally be concluded for the theoretical background? First, simulation and empirical results confirm the statements of the NEG. Models of the classical trade theory predict that regional differences in terms of production costs tend to converge and economic activities to disperse. In contrast, modern approaches by the NEG as well as the New Trade Theory emphasize agglomeration based upon increasing returns and imperfect markets and the corresponding differences regarding wages, income and factor endowments. However, this paper reveals that the core-periphery structure of European industries may remain, in spite of increasing trade integration and decreasing wage differentials. Exogenous asymmetries between countries, e.g., in terms of country size, suggest an attractive field for future research - despite the loss of analytical convenience given by symmetric countries. Second, the reason for the success of the NEG is the potential to provide quantitative statements compared with alternative location theories. In consequence, case studies and econometric analysis of the spatial formation of industries may be complemented by a stronger use of numerical simulations, especially in the context of multi-country frameworks.

6 Concluding Remarks

For covering the spectrum of modeling results presented in all four papers, this chapter draws the main conclusion in terms of location and innovation policies. Beside the general legitimization of political intervention, a major point of discussion is the industrial-base concept. In this context, the pharmaceutical industry is exemplarily considered to be a potential candidate of the European industrial base.

Location Policy

Political intervention requires legitimization based upon market failure and welfare losses. A unilateral location policy, whether in form of a subsidy for mobile agents as discussed in Chapter 3 or a subsidization of local firms as briefly described in Chapter 4, produces an *artificial* comparative advantage. This advance implies a long run welfare gain due to agglomeration in the corresponding location. However, this approach is questionable in respect of three concerns. First, an efficient intervention is subject to thresholds and must be financed. This especially applies for the case of size asymmetries (the location is initially smaller than its neighbor) or for peripheral locations (hysteresis effect). Finally, an efficient subsidy may overburden the financing sources, here the tax base. Second, the welfare distribution might be undesired on a supra-regional or supra-national level. Third, as the simple policy game in Section 3.5 reveals, a situation, where not only one location is following a subsidization policy but also the rivaling neighbors, may at best entail a constellation of subsidies, which are canceling out each other. In the worst case, multilateral competing policies originate a subsidy race. Given these political and economic risks, single-handed efforts need to be scrutinized in regard to feasibility, effectiveness, and superordinate effects.

By reasonable appraisal, the problem of spatial allocation has to be reconsidered either on a superordinate level or during inter-regional negotiation, respectively. In this regard, the welfare implications in Chapter 3 convey a clear message representative for the class of core-periphery models. For decreasing trade costs, agglomeration turns out to be a welfare superior state compared with dispersion. However, agglomeration implies winners and losers due to an uneven distribution of consumer utility and real income. In this way, policymakers face a trade-off between spatial efficiency and distributive justice. For a figurative illustration, whereas efficiency determines the size of the whole cake to be shared, equity describes differences in size of its pieces. The problem is the more asymmetric the pieces, the bigger is the cake.

The second paper draws a pessimistic picture with regard to agglomeration winners and losers. On one hand, bigger locations tend to attract R&D and production; on the other hand, inhabitants in the industrialized core benefit from agglomeration, whereas the peripheral regions experience a loss in real income. This result can be traced back to the strong assumption of R&D localization so that production is impregnably bound to the R&D sector. Relaxing this assumption would have a dampening influence. An implementation of spillover effects or of a research infrastructure (public good), for instance, might imply regional specialization of knowledge creation and manufacturing, which also has different welfare implications.

Nonetheless, for low trade costs, agglomeration rents become sufficiently high that a compensating transfer between winning and losing factor groups appears to be possible. Thus, the question for the need of political intervention rather becomes a question of an equitable distribution of agglomeration rents and compensating transfers. In consequence, it is debatable what kind of transfers might be adequate for compensating the periphery. First of all the question arises: Who should receive and who decides how to spend the transfers? The first point regards peripheral administrative institutions vs. private households; the second is related to (productive) governmental spending in contrast to consumer spending.

Based upon the welfare results, it is obviously not reasonable to utilize compensation transfers for investments, which again establish comparative advantages in the periphery for turning around the agglomeration process. But for all that, the models presented in the previous chapters display only a small and simplified part of the whole picture. We considered only two locations and two possible equilibrium states: perfect dispersion and total agglomeration. In multi-country (and multi-sector) versions changes in the spatial formation of industries, and thus, of social welfare are smooth so that Pareto comparisons as conducted in the second paper are no longer sufficient to be an analytical instrument. In this context, if agglomeration and welfare are not clear-cut conditions, they might substantiate political intervention in order to decelerate or to stop concentration processes. In this way, transfers do not have a compensating character; in fact, they act as a political control mechanism.

Another concern are the assumptions made with respect to the character of transfers. For the purpose of Hicks and Kaldor compensations, it is sufficient to consider hypothetical rather than real transfers. However, a *real* compensation requires real transfers, but these have in turn a redistributive impact for the mobile workforce, and thus, of the industrial landscape. This increases the complexity of the problem because political intervention produces reorganizing feedback.

The Industrial Base

One aspect of location policy is the notion that industries differ in terms of their relocation behavior. Whereas some industries are comparatively footloose, other industries seem to be stronger bounded to one particular place, which raises the idea of an industrial base. In this context, it might be a political objective to identify such strategic industries and also to evaluate these candidates by means of their macroeconomic relevance, e.g., in terms of output, employment, and value added. In this regard, these considerations are inevitably connected with horizontal and vertical specialization.

As a central result of the NEG (and trade theory), horizontal specialization occurs only in presence of sufficient comparative advantages. On the contrary, vertical specialization is merely a result of the inertia of downstream industries during a process of relocation.

As one of the central concerns of the third paper, we can conclude that the industrial base is characterized by four categories of impact factors: i) the inertia of the downstream industry; ii) comparative advantages in terms of wages, technology, and productivity; iii) policy interventions, which induce comparative advantages by subsidization, tax, or trade policies; and iv) R&D intensity and the degree of R&D localization.

In contrast to first-nature characteristics, which primarily comprise industries with a naturally given localization, e.g., mining, agriculture, and forestry, the points mentioned above concern second-nature characteristics, which are related to agglomeration economies due to increasing returns.[1] Considering the inertia as an exogenous and technological description of industries, the concept elaborated here rather includes a bilateral relation between sectors but neglects multilateral input-output networks. Instead, the production function has to be extended by a continuum of intermediate sectors. As a result, the inertia becomes a function of a multitude of cost shares and substitution elasticities: $\Theta\left(\alpha_j, \varsigma_j\right)$, whereas j counts the intermediate sectors. Analogically, the non-linear complexity increases as well, which might be the subject of future research. The indications for an industrial base mentioned above mainly argue for downstream industries close to consumer markets. Finally, a downstream industry may also be inert to relocation if it is essentially dependent upon an upstream R&D sector, and if this sector is strongly localized. From this perspective, the question arises whether the pharmaceutical industry in the fourth paper is a potential candidate for being part of the Western European industrial base.

The Pharmaceutical Industry: Part of the Industrial Base?

Starting from the concept of the industrial inertia, the pharmaceutical industry, with respect to the biotech intermediate sector, shows a Θ-value of 0.0026 based upon the assumptions made in Chapter 5. However, the inertia is relatively low due to the high substitution elasticity of biotech input, which simply has been equalized with the substitution elasticity for pharmaceutical products. The fact that this category is not further differentiated between proprietary and generic medicaments suggests also in regard to Proposition 2.6 in Chapter 2 that the substitution elasticity for biotechnological products and services might be lower than the assumed value of $\sigma = \varsigma = 9.53$. In consequence, the inertia might take higher values but probably not too high values. However, the pharmaceutical industry makes an exception compared with other industries: the biggest part of input comes from intra-industry trade. This implies that except from the strategic biotech sector, no major vertical linkages exist; the pharmaceutical industry is primarily characterized by horizontal linkages. In this regard, the inertia concept is invalid

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[1] See Krugman (2003) for a discussion of first and second nature geography.

because vertical specialization is not possible anymore. Nevertheless, the trade-off between market size and production costs plays an important role. As argued, the spatial concentration within the Western European core rather than in the periphery is determined by larger sales markets. Although lower labor costs imply a relocation tendency for upstream firms to the acceding countries, as the standard Venables model predicts, Chapter 3 shows a different scenario. In face of existing asymmetries, the European core benefits from an upstream migration due to higher real wages for the scientific workforce. All in all, we face two contrarily operating forces: a dispersive shift due to industrial linkages and high wage differentials on one hand, and an agglomeration tendency due to highly-skilled mobility and spillover effects in R&D on the other hand. Although these findings argue for a strategic industry, an ultimate evaluation as to whether the pharmaceutical industry participates in the industrial base is not possible. Nonetheless, the first paper presented in Section 2.4 offered a potential way to adapt the vertical differentiation approach to the standard VL model of Krugman and Venables (1995) and also to include the horizontal-trade attribute of the pharmaceutical industry discussed above.

Innovation Policy

Major legitimization of innovation promoting policy intervention is according to Klodt (1995): i) positive externalities in knowledge creation and adaption; ii) public good characteristics; iii) entrepreneurial risk aversion; and iv) capital market failure. In contrast, parallel research, patent race, and monopolization of sales markets provide arguments for an impeding research policy.

As the first essay reveals, product R&D in monopolistic-competitive industries tends to be too high compared with the social optimum. Here, the legitimization for public intervention is the argument of market monopolization due to increasing returns. Including tax funding, most policy instruments fail to contain welfare losses. Only the relatively severe alternative of price regulation seems to be a way out of the dilemma.

However, international trade sheds a different light on these results, as demonstrated in the second paper. An explicit welfare statement, as made in the first paper, is not possible due to the problem of interregional aggregation. Nonetheless, the consumer utility depends upon where agglomeration takes place. Thus, the focus of political analysis deflects from market imperfections to a distribution of welfare across locations and factor groups.

Furthermore, as demonstrated in the second paper, R&D and especially the mobility of research production has a destabilizing impact on the spread of industries and local welfare. In this context, it might be a unilateral political objective to increase the welfare in the home location by subsidizing R&D, and, thus, to achieve local agglomeration advantages. In this way, R&D promoting policy instruments stepped into the shoes of direct export promotion, which is widely prohibited in the course of the GATT agreements and the common market. Finally, innovation policy utilized as a location policy instrument produces the same problems as discussed in the beginning of this chapter.

How does the picture look like if location policy conversely is a supporting element of innovation policy? In this case, an innovation and technology policy requires a legitimization as discussed above. As a broad consensus, the majority of literature concerning this question finds that, in most cases, a public research promotion is not justified. Nonetheless, recent policy takes on substantial efforts to support research, development, and improvement of products, processes and technologies. In this context, the German Federal Government as well as the Governments of the Federal States, for instance, is sponsoring support programs especially for high technologies like biotechnology, nanotechnology, microsystem or mechatronic technologies. These technological fields are (partially) in the phase of fundamental research, which provides the justification for corresponding political endeavors. The present work does not intend to evaluate this practice; rather, it will be discussed if the NEG provides new insights how to combine elements of location and innovation policies.

The underlying idea is quite simple. High-tech industries are substantially characterized by internal and external economies of scale. Internal scale economies arise from high fixed costs due to long-term development and approval procedures, research risks, and high-value laboratory facilities. In addition, labor market pooling for highly-skilled, spillover effects, and strong vertical linkages for technology adaption provide arguments for external economies of scale, and, thus, for agglomeration advantages. The question remains, whether a given spatial distribution is sufficient for a successful and internationally competitive development of new technologies. Furthermore, are policymakers in position to accelerate technological progress by politically enhanced agglomeration?

The NEG basically supports this view – with some restrictions. Agglomeration advantages of R&D critically depend upon the modeling assumptions. In Chapter 3, for instance, due to the scientific labor market settings, the quality of products manufactured in the core was the same as in the dispersion. Further on, the R&D output depends upon the population of scientists, the productivity in the research process, and the technological potential (see Chapter 2.5), respectively. Thus, these factors also determine the extent of agglomeration economies. The next point concerns the degree of concentration and specialization. In this context, it is a decisive issue whether one R&D related core implies higher agglomeration economies rather than several specialized centers. In this regard, the strength of these vertical linkages plays a major role and how these R&D adaptors are distributed in space.

Bibliography

Allansdottir, A., Bonaccorsi, A., Gambardella, A., Mariani, M., Orsenigo, L., Pammolli, F. and Riccaboni, M.: 2000, Innovation and competitiveness in european biotechnology, *Enterprise Papers 7*, European Commission.

Alonso-Villar, O.: 2005, The effects of transport costs revisited, *Journal of Economic Geography* **5**(5), 589–604.

Amiti, M.: 1998, New trade theories and industrial location in the EU: A survey of evidence, *Oxford Review of Economic Policy* **14**(2), 45–53.

Amiti, M.: 2005, Location of vertically linked industries: agglomeration versus comparative advantage, *European Economic Review* **49**(4), 809–832.

Anderson, S. P., de Palma, A. and Thisse, J.-F.: 1992, *Discrete Choice Theory of Product Differentiation*, The MIT Press, Cambridge, MA and London.

Ando, M. and Kimura, F.: 2007, Fragmentation in europe and east asia: Evidences from international trade and FDI data, *in* P. B. Ruffini and J. K. Kim (eds), *Corporate Strategies in the Age of Regional Integration*, Cheltenham UK.

Audretsch, D.: 2001, The role of small firms in U.S. biotechnology clusters, *Small Business Economics* **17**, 3–15.

Audretsch, D. B. and Feldman, M. P.: 1996, R&D spillovers and the geography of innovation and production, *American Ecnomic Review* **86**(3), 630–640.

Audretsch, D. and Stephan, P.: 1996, Company-scientist locational links: The case of biotechnology, *American Economic Review* **86**(3), 641–652.

Baldwin, R. E.: 1999, Agglomeration and endogenous capital, *European Economic Review* **43**(2), 253–280.

Baldwin, R. E. and Krugman, P.: 2004, Agglomeration, integration and tax harmonisation, *European Economic Review* **48**(1), 1–23.

Baldwin, R., Forslid, R., Martin, P., Ottaviano, G. and Robert-Nicoud, F.: 2003, *Economic Geography and Public Policy*, Princeton University Press, Princeton.

Baldwin, R., Martin, P. and Ottaviano, G.: 2001, Global income divergence, trade and industrialization: The geography of growth take-off, *Journal of Economic Growth* **6**.

Baldwin, R. and Robert-Nicoud, F.: 2000, Free trade agreements without delocation, *Canadian Journal of Economics* **33**(3), 766–786.

Berliant, M., Reed, R. R. and Wang, P.: 2006, Knowledge exchange, matching, and agglomeration, *Journal of Urban Economics* **60**(1), 69–95.

Brakman, S. and Heijdra, B. (eds): 2004, *The Monopolistic Competition Revolution in Retrospect*, Cambridge University Press, Cambridge UK.

Carrincazeaux, C., Lung, Y. and Rallet, A.: 2001, Proximity and localisation of corporate r&d actvities, *Research Policy* **30**, 777–789.

Chamberlin, E.: 1933, *The Theory of Monopolistic Competition*, Harvard University Press, Cambridge MA.

Charlot, S., Gaigne, C., Robert-Nicoud, F. and Thisse, J.-F.: 2006, Agglomeration and welfare: The core-periphery model in the light of Bentham, Kaldor, and Rawls, *Journal of Public Economics* **90**, 325–347.

Christaller, W.: 1933, *Die zentralen Orte in Süddeutschland*, Gustav Fischer Verlag, Jena.

Combes, P.-P. and Overman, H. G.: 2004, The spatial distribution of economic activities in the European Union, *in* V. Henderson and J. Thisse (eds), *Handbook of Regional and Urban Economics*, Vol. 4, Amsterdam, North Holland, pp. 2845–2910.

Cooke, P.: 2001, Biotechnology clusters in the U.K.: Lessons from localisation in the commercialisation of science, *Small Business Economics* **17**, 43–59.

Corrolleur, F., Mangematin, V. and Torre, A.: 2003, French biotech start-ups and biotech clusters in France. The importance of geographic proximity, *in* G. Fuchs and B. Luib (eds), *Biotechnology in Comparative Perspective - Growth and Regional Concentration*, Routeledge, London.

Crescenzi, R., Rodriguez-Pose, A. and Storper, M.: 2007, The territorial dynamics of innovation: a Europe - United States comparative analysis, *Journal of Economic Geography* **7**(6), 673–709.

Dixit, A. K. and Stiglitz, J.: 1977, Monopolistic competition and optimum product diversity, *American Economic Review* **67**, 297–308.

Dixit, A. and Norman, V.: 1980, *The Theory of International Trade*, The MIT Press, Cambridge UK.

Dohse, D.: 2000, Technology policy and the regions — the case of the BioRegio contest, *Research Policy* **29**(9), 1111–1133.

Ernst & Young: 2000, Gründerzeit – Zweiter Biotechnologie-Report, *Report*, Ernst & Young Deutsche Allgemeine Treuhand AG, Stuttgart.

Ernst & Young: 2006, Zurück in die Zukunft – Deutscher Biotechnologie-Report, *Report*, Ernst & Young Deutsche Allgemeine Treuhand AG, Stuttgart.

Ernst&Young: 2004, Per Aspera ad Astra – Deutscher Biotechnologie–Report 2004, *Report*, Ernst & Young Deutsche Allgemeine Treuhand AG, Stuttgart.

Ethier, W.: 1982, National and international returns to scale in the modern theory of international trade, *American Economic Review* **72**, 389–405.

EuropaBio: 2006, Biotechnology in Europe: 2006 comparative study, *Report*, The European Association for Bioindustries, Brussels.

Eurostat: 2008, *Science, Technology and Innovation in Europe*, Eurostat Statistical Books, Luxembourg.

Eurostat and OECD: 2005, *The Measurement of Scientific and Technological Activities: Guidelines For Collecting and Interpreting Innovation Data (Oslo Manual)*, third edition edn, Eurostat Statistical Books, Paris.

Feldman, M.: 2000, Where science comes to life: University bioscience, commercial spinoffs, and regional economic development, *Journal of Comparative Policy Analysis: Research and Practice* **2**, 345–361.

Feldman, M. P.: 1994, *The Geography of Innovation*, Kluwer, Dordrecht et al.

Feldman, M. P.: 1999, The new economics of innovation, spillovers and agglomeration: A review of empirical studies, *Economics of Innovation and New Technology* **8**, 5–25.

Flam, H. and Helpman, E.: 1987, Vertical product differentiation and north-south trade, *The American Economic Review* **77**(5), 810–822.

Forslid, R.: 1999, Agglomeration with human and physical capital: an analytically solvable case, *CEPR Discussion Paper 2102*, Centre for Economic Policy Research.

Forslid, R. and Ottaviano, G. I.: 2003, An analytically solvable core-periphery model, *Journal of Economic Geography* **3**(3), 229–240.

Forslid, R. and Wooton, I.: 2003, Comparative advantage and the location of production, *Review of International Economics* **11**(4), 588–603.

Fujita, M.: 1988, A monopolistic competition model of spatial agglomeration: Differentiated product approach, *Regional Science and Urban Economics* **18**, 87–124.

Fujita, M. and Krugman, P.: 1995, When is economy monocentric?: von Thünen and Chamberlin unified, *Regional Science and Urban Economics* **25**, 505–528.

Fujita, M., Krugman, P. and Mori, T.: 1999, On the evolution of hierachical urban system, *European Economic Review* **43**, 209–251.

Fujita, M., Krugman, P. R. and Venables, A. J.: 1999, *The Spatial Economy: Cities, Regions, and International Trade*, The MIT Press, Cambridge MA, London.

Fujita, M. and Mori, T.: 1997, Structural stability and evolution of urban systems, *Regional Science and Urban Economics* **27**, 399–442.

Fujita, M. and Mori, T.: 2005, Frontiers of the new economic geography, *Papers in Regional Science* **77**(5), 377–405.

Fujita, M. and Thisse, J.-F.: 2003, Does geographical agglomeration foster economic growth? and who gains and loses from it?, *The Japanese Economic Review* **54**(2).

Gabszewicz, J. and Thisse, J.: 1979, Price competition, quality and income disparities, *Journal of Economic Theory* **20**, 340–359.

Gabszewicz, J. and Thisse, J.: 1980, Entry (and exit) in a differentiated industry, *Journal of Economic Theory* **22**, 327–338.

German Federal Statistical Office: 2002, Unternehmen der Biotechnologie in Deutschland – Ergebnisse einer Pilotstudie für das Jahr 2000, *Annual report*, Federal Statistical Office, Wiesbaden.

Greenaway, D. and Torstensson, J.: 2000, Economic geography, comparative advantage and trade within industries: Evidence from the OECD, *Journal of Economic Integration* **15**(2), 260–280.

Grossman, G. and Helpman, E.: 1991a, Quality ladders in the theory of growth, *Review of Economic Studies* **58**, 43–61.

Grossman, G. M. and Helpman, E.: 1991b, *Innovation and Growth in the Global Economy*, MIT Press, Cambridge MA.

Head, K. and Mayer, T.: 2004, The empirics of agglomeration and trade, *in* V. Henderson and J. Thisse (eds), *Handbook of Regional and Urban Economics*, Vol. 4, Amsterdam, North Holland.

Hicks, J.: 1940, The valuation of social income, *Economica* **7**, 483–499.

Hotelling, H.: 1929, Stability in competition, *Economic Journal* **39**, 41–47.

Hummels, D.: 1999, Toward a geography of trade costs, *GTAP Working Paper 17*.

Hummels, D., Ishii, J. and Yi, K.: 2001, The nature and growth of vertical specialization in world trade, *Journal of International Economics* **54**(1), 75–96.

Hummels, D. and Klenow, P. J.: 2005, The variety and quality of a nation's exports, *American Economic Review* **95**(3), 704–723.

Hummels, D., Rapoport, D. and Yi, K.: 1998, Vertical specialization and the changing nature of world trade, *Economic Policy Review* **4**(2), 79–99.

Jaffe, A. B., Trajtenberg, M. and Henderson, R.: 1993, Geographic localization of knowledge spillovers as evidenced by patent citations, *The Quarterly Journal of Economics* **108**(3), 577–598.

Jinji, N.: 2003, Strategic policy for product R&D with symmetric costs, *Canadian Journal of Economics* **36**(4), 993–1006.

Kaldor, N.: 1939, Welfare propositions of economics and interpersonal comparisons of utility, *Economic Journal* **49**, 54–551.

Klodt, H.: 1995, *Grundlagen der Forschungs- und Technologiepolitik*, Verlag Franz Vahlen, München.

Kranich, J.: 2006, The strength of vertical linkages, *Working Paper Series in Economics 20*, University of Lueneburg, Lueneburg.

Kranich, J.: 2007a, *Biotechnologie und Internationalisierung – Eine Bestandsaufnahme der deutschen Branche*, VDM Verlag, Saarbrücken.

Kranich, J.: 2007b, Biotechnologie und Internationalisierung. Ergebnisse der Online-Befragung, *Working Paper Series in Economics 45*, University of Lueneburg.

Krugman, P.: 1979, Increasing returns, monopolistic competition, and international trade, *Journal of International Economics* **9**, 469–480.

Krugman, P.: 1980, Scale economies, product differentiation, and the pattern of trade, *American Economic Review* **70**, 951–959.

Krugman, P.: 1991, Increasing returns and economic geography, *Journal of Political Economy* **99**, 483–499.

Krugman, P.: 1993, On the number and location of cities, *European Economic Review* **37**, 392–298.

Krugman, P.: 2003, First nature, second nature, and metropolitan location, *Journal of Regional Science* **33**(2), 12–1444.

Krugman, P. and Venables, A. J.: 1995, Globalization and the inequality of nations, *The Quarterly Journal of Economics* **110**, 857–880.

Lancaster, K.: 1966, A new approach to consumer theory, *Journal of Political Economy* **74**, 132–157.

Lösch, A.: 1940, *Die räumliche Ordnung der Wirtschaft*, Gustav Fischer Verlag, Jena.

Lucas, R. E.: 1988, On the mechanics of economic development, *Journal of Monetary Economics* **22**, 3–42.

Ludema, R. D. and Wooton, I.: 2000, Economic geography and the fiscal effects of regional integration, *Journal of International Economics* **52**(2), 331–357.

Markusen, J.: 1989, Trade in producer services and other specialized intermediate inputs, *American Economic Review* **79**, 85–95.

Markusen, J. and Melvin, J.: 1984, The theory of international trade and its Canadian application, *The Canadian Journal of Economics* **18**(4), 929–931.

Martin, P.: 1998, Can regional policies affect growth and geography in europe?, *The World Economy* **21**(6), 757–774.

Martin, P. and Ottaviano, G.: 1999, Growing locations: Industry locations in a model of endogenous growth, *European Economic Review* **43**.

Martin, S.: 1993, *Advanced Industrial Economics*, Blackwell, Oxford, UK and Cambridge, USA.

Midelfart-Knarvik, K. H. and Overman, H. G.: 2002, Delocation and european integration: Is structural spending justified?, *Economic Policy* **17**(35), 321–359.

Midelfart-Knarvik, K., Overman, H., Redding, S. and Venables, A.: 2000, The location of European industry, *Economic Papers 142*, European Commission.

Neary, P. J.: 2001, Of hype and hyperbolas: Introducing the new economic geography, *Journal of Economic Literature* **39**, 536–561.

OECD: 2002, International mobility of the highly skilled, *Policy Brief, July 2002*, OECD.

OECD: 2005, *A Framework for Biotechnology Statistics*, OECD, Paris.

OECD: 2006, *OECD Biotechnology Statistics – 2006*, OECD, Paris.

Ottaviano, G.: 1996, Monopolistic competition, trade, and endogenuous spatial fluctuations, *CEPR Discussion Paper 1327*, Centre for Economic Policy Research.

Ottaviano, G.: 2002, Regional policy in the global economy: Insights from the new economic geography, *HWWA discussion paper No. 211*, Hamburgisches Welt–Wirtschafts–Archiv, Hamburg.

Ottaviano, G. and Puga, D.: 1998, Agglomeration in the global economy: A survey of the 'new economic geography', *The World Economy* **21**(6), 707–731.

Park, L.-H.: 2001, Strategic R&D policy under vertically differentiated oligopoly, *Canadian Journal of Economics* **36**(4), 967–987.

Pisano, G.: 1990, The governance of innovation: Vertical integration and collaborative arrangements in the biotechnology industry, *Research Policy* **20**, 237–249.

Porter, M.: 2005, *The Competitive Advantage of Nations*, Free Press, New York.

Proventa: 2004, Human biotechnology in Hungary, an industry overview, *Report*, PROVENTA Capital Advisors GmbH, Bad Homburg.

Puga, D. and Venables, A.: 1996, The spread of industry, spatial agglomeration and economic development, *Journal of the Japanese and International Economies* **10**(4), 440–464.

Rivera-Batiz, F.: 1988, Increasing returns, monopolistic competition and agglomeration economies in consumption and production, *Regional Science and Urban Economics* **18**, 125–153.

Robert-Nicoud, F.: 2002, A simple model of agglomeration with vertical linkages and perfect capital mobility. Chapter 1 in *New Economic Geography: Welfare, Multiple Equilibria and Political Economy. PhD Thesis*, London School of Economics.

Romer, P.: 1987, Growth based on increasing returns due to specialization, *American Economic Review* **77**, 56–62.

Romer, P. M.: 1990, Human capital and growth: Theory and evidence, *Carnegie-Rochester Conference Series* **32**, 251–286.

Rothschild, R.: 1987, The theory of monopolistic competition - Chamberlin, E.H. influence on industrial organization theory over 60 years, *Journal of Economic Studies* **14**(1), 34–54.

Schmalensee, R.: 1992, Sunk costs and market structure. a review article, *Journal of Industrial Economics* **40**(2), 125–134.

Segerstrom, P. S., Anant, T. and Dinopoulos, E.: 1990, A schumpeterian model of the product life cycle, *The American Economic Review* **80**(5), 1077–1091.

Shaked, A. and Sutton, J.: 1982, Relaxing price competition through product differentiation, *Review of Economic Studies* **49**, 3–14.

Shaked, A. and Sutton, J.: 1983, Natural oligopolies, *Econometrica* **51**, 1469–1484.

Shaked, A. and Sutton, J.: 1987, Product differentiation and industrial structure, *Journal of Industrial Economics* **36**, 131–146.

Skinner, A.: 1986, Chamberlin, Edward - the theory of monopolistic competition - a reorientation of the theory of value, *Journal of Economic Studies* **13**(5), 27–44.

South Moravian Innovation Center: 2007, Czech biotech report 2007, *Report*, South Moravian Innovation Center.

Spencer, B. J. and Brander, J. A.: 1983, International R&D rivalry and industrial strategy, *Review of Economic Studies* **50**(4), 707–722.

Straubhaar, T.: 2000, International mobility of the highly skilled: Brain gain, brain drain or brain exchange, *Technical Report 88*, HWWA.

Stuart, T. and Sorenson, O.: 2003, The geography of opportunity: Spatial heterogeneity in founding rates and the performance of biotechnology firms, *Research Policy* **32**, 229–253.

Sutton, J.: 1991, *Sunk Costs and Market Structure*, The MIT Press, Cambridge.

Sutton, J.: 1998, *Technology and Market Structure*, The MIT Press, Cambridge/MA, London.

Symeonidis, G.: 2003, Comparing cournot and bertrand equilibria in a differentiated duopoly with product R&D, *International Journal of Industrial Organization* **21**(1), 39–55.

Tirole, J.: 1988, *The Theory of Industrial Organization*, The MIT Press, Cambridge MA, London.

Venables, A.: 1996, Equilibrium locations of vertically linked industries, *International Economic Review* **37**, 341–359.

Waltz, U.: 1996, Transport costs, intermediate goods, and localized growth, *regional Science and Urban Economics* **26**, 335–360.

Yeats, A.: 1998, Just how big is global production sharing?, *Working Paper 1871*, World Bank Policy Research.

Zhou, D., Spencer, B. J. and Vertinsky, I.: 2002, Strategic trade policy with endogenous choice of quality and asymmetric costs, *Journal of International Economics* **56**, 205–232.