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Localized knowledge spillovers and regional employment growth: evidence from Germany

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**Localized Knowledge Spillovers
and Regional Employment Growth:
Evidence from Germany**

by
Eckhardt Bode



Institut für Weltwirtschaft an der Universität Kiel
The Kiel Institute of World Economics

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July 1999

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Summary

The present paper aims at explaining the regional deconcentration of economic activities in (West) Germany during the past two decades. Using an idea-based endogenous growth model that encloses several innovative sectors, that subjects economic activity to externalities of agglomeration, and that allows for interregional labor migration, we test the hypothesis that human-capital intensive activities in (technical) manufacturing R&D, manufacturing management, and producer services continue to concentrate on agglomerations because of localized knowledge spillovers, while manufacturing production which does not benefit directly from knowledge spillovers deconcentrates because of agglomeration diseconomies. As an indicator of economic activities we use employment instead of value added since data on value added, resp. income, are not available from public statistics in Germany at a regionally and occupationally sufficiently disaggregated level. The empirical results on employment dynamics in 75 West-German regions during the time period 1976–1994 are in line with the hypothesis on spatial deconcentration of manufacturing production due to agglomeration diseconomies, but clearly reject the hypothesis on ongoing spatial concentration of high-skilled workers driven by knowledge spillovers. Thus, we conclude that in Germany localized knowledge spillovers may have been too weak to ensure endogenous growth. Finally, a number of shortcomings with respect to theory and data availability are discussed.

JEL: C21, O41, R11

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I. Regional deconcentration in Germany

In the past two decades, West Germany has experienced a marked regional decentralization of economic activity and population. Between 1976 and 1994, employment, value added and population have, on average, grown comparatively slow in regions where they were initially high. This process is evidenced by simple correlation coefficients between growth rates and the respective initial levels in 1976 (upper part of Table 1). For example, the correlation between regional employment growth and 1976 employment level is -0.4. The shift of economic activity from agglomerations to more peripheral regions is even more pronounced when correlation coefficients between growth rates and initial density are used as indicators (lower part of Table 1).¹ This process, which can be observed in other countries as well, has been described and analyzed in detail by several scholars (e.g. Bade 1987, Bröcker 1989, Bade and Ewers 1989, and Bode 1999 for Germany, or Glaeser et al. 1992 and Kim 1995 for the U.S.).

What are the driving forces behind this deconcentration of economic activity? Several theoretical explanations are at hand. Neoclassical growth theory would suggest that we observe convergence of regional income and productivity levels due to decreasing returns to capital (Barro and Sala-i-Martin 1992, 1995). There is, however, one major problem with the neoclassical approach: A theory that does not help much in explaining concentration of economic activity in space may not be taken too serious in explaining deconcentration.

Table 1 — Correlation between growth rates and initial levels of selected variables, 75 West German regions 1976 – 1994^a

	Growth rate			
	Employment	Per-capita income	Population	
1976 level				
Employment	-0.40 (0.00)			
Per-capita income		-0.16 (0.17)		
Population			-0.27 (0.02)	
Per square kilometer				
Employment	-0.54 (0.00)			
Gross value-added		-0.28 (0.01)		
Population			-0.31 (0.01)	

^a Pearson correlation coefficients, error probabilities of rejecting $H_0: r=0$ in parentheses. A description of regional disaggregation is given below.

¹ This does not result predominantly from suburbanization, as the regions have been defined such that regions with big cities include their suburban areas. For details see chapter III.2 and Bode (1998).

In this respect, theories that explicitly take into account economies and diseconomies of agglomeration may be more appropriate. One of these theories is new economic geography which describes a trade-off between those external economies.² As long as agglomerative forces, resulting, e.g., from internal or external economies of scale, dominate deglomerative forces, resulting, e.g., from high relative factor prices, congestion or transportation costs, firms and workers continue concentrating on agglomerations. With increasing exploitation of scale economies and decreasing transportation costs, however, net gains from agglomeration become weaker and, finally, turn negative. Beyond some critical point, deglomerative forces become dominant. Empirical work done, e.g., by Kim (1995) suggests that the U.S. economy has gone beyond this critical point. The same may be true in Germany.

Another theory that explicitly takes into account agglomeration economies is endogenous growth theory.³ It explains concentration processes by productivity-enhancing effects of dynamic positive externalities of agglomeration. More specifically, regional endogenous growth models frequently investigate a specific kind of positive localization externalities, namely localized knowledge spillovers among researchers. Due to localized knowledge spillovers, innovative actors tend to be more productive (i.e. more innovative) where they are highly concentrated. Deconcentration, in turn, may result from negative agglomeration externalities, taking either the form of negative localization externalities (decreasing R&D-productivity gains from localized knowledge spillovers) or of negative urbanization externalities (e.g. congestion costs). Empirical evidence suggests that "... R&D spillovers are present, their magnitude may be quite large, and social rates of return remain significantly above private rates" (Griliches 1992: 43).⁴ For Germany, Bode (1999) presents empirical evidence in favor of a positive impact of R&D spillovers on regional per-capita income growth and, thus, on regional concentration. This result, however, is conditional on the inclusion of deglomerative forces such as diseconomies of agglomeration into the regression. Since the deglomerative forces have been added to the regression function in a rather ad-hoc manner, the theoretical interdependencies between economies and diseconomies of agglomeration have been left unexplained theoretically by Bode (1999).

In the present paper we aim at going one step ahead by empirically investigating the trade-off between agglomerative and deglomerative forces, based on an endogenous growth model where innovative, human-capital intensive activities are subject to localized knowledge

² Recent surveys of the theoretical and empirical literature are given by Helpman (1998), Krugman (1998), and Krieger-Boden (1999).

³ For theoretical contributions see Romer (1990), Grossman and Helpman (1991), Aghion and Howitt (1992), Jones (1995) and related literature.

⁴ The majority of more recent empirical studies tends to confirm Griliches' conclusion. See, among others, Glaeser et al. (1992), Jaffe et al. (1993), Henderson et al. (1995), Audretsch and Feldman (1996), Cheshire and Carbonaro (1996), Fingleton and McCombie (1998), Klenow (1998), or Simon (1998).

spillovers, while production activities are subject to agglomeration diseconomies. More specifically, we test the hypothesis that human-capital intensive activities, namely technical R&D, manufacturing management, and high-quality producer services, continue to concentrate on agglomerations because of localized knowledge spillovers, while those activities that do not benefit directly from knowledge spillovers, namely manufacturing production and stock holding, tend to deconcentrate because of agglomeration diseconomies. The hypothesis is consistent with the observed pattern of regional deconcentration sketched above, if production activities were more important quantitatively than high-quality activities.

As an indicator of economic activities we have to use employment instead of value added since data on value added, resp. income, are not available from public statistics in Germany at a regionally and occupationally sufficiently disaggregated level. The paper is organized as follows. In section II the theoretical approach is outlined. Section III presents the empirical results, and section IV concludes.

II. Theory

A system of regional economies within a country is described by an endogenous growth model à la Romer (1990).⁵ To define a point of reference, we assume the regions to be initially isolated, i.e. trade and migration costs are prohibitively high (for whatever reason). Hence, there is no exchange of goods, workers, or ideas. The static equilibrium properties of the model are used to describe the determinants of wages of high and low-skilled workers at a certain point in time. More specifically, regional wage differences are traced to regional differences in factor supply, the stock of knowledge, and R&D productivity. Then, in a second step, we assume migration costs to decrease. Hence, workers will consider to move to other regions. The predictions of the model with respect to the pattern of relocation of workers immediately after the opening of regional borders are used to formulate the test hypothesis for the empirical investigation.

It should be noted that we are not interested in the Steady State properties of the growth model without and with migration. Instead, we concentrate on the static equilibrium and the first-round effects of the adjustment process towards a new equilibrium after the opening of regional borders. For a more convenient presentation of the model, we begin by outlining a growth model with only one innovative sector. Then, the model will be expanded to three in-

⁵ There is, of course, a number of open-economy models available in the literature that deal with questions similar to the present one; see, among others, Premer and Walz (1994), Walz (1995, 1999), Englmann and Walz (1995), Stadler (1995), Palivos and Wang (1996), or Keilbach (1998). It proved, however, extremely difficult to consistently derive our test hypothesis from these models. For this reason, we decided to set up a model that fits directly to our hypothesis.

novative sectors: technical R&D, managerial R&D and R&D in producer services – without fundamentally changing the equilibrium properties of the model.

1. The basic model with a single innovative sector

Assume a national economy consisting of R regional economies. Each regional economy r ($r = 1, \dots, R$) consists of three sectors: An innovative sector where new ideas (or blueprints) are developed, an intermediate good sector where a variety of intermediate goods is produced, and a final good sector where a homogeneous consumption good is produced. In the innovative sector, highly qualified workers develop \dot{N} innovative blueprints per instance of time using as inputs their own labor (H), and region-specific publicly available knowledge (Q) which determines their productivity:⁶

$$(1) \quad \dot{N}_r = dN_r / dt = \chi Q_r (N_r) H_r, \quad r = 1, \dots, R; \quad N_r = \int_{-\infty}^t \dot{N}_{r,v} dv;$$

χ is a constant productivity factor. For simplicity, we abstract from uncertainty of the innovation success. The blueprints which are protected against imitation by infinitely lived patents⁷ represent excludable innovative knowledge. As an unintended by-product of the innovation process, researchers produce knowledge that cannot be codified and patented. This knowledge spills over to other researchers in the respective region and improves their productivity in future research. Thus, in addition to a private good 'blueprint' each researcher produces some kind of a public good 'knowledge' that adds to the region-specific stock of knowledge (Q).

The extent to which new knowledge spills over to other researchers, and to which it improves their future productivity, is an open question in growth-theoretic research up to now. Treating this process as a black box, Romer (1990) simply assumes knowledge to be a pure public good that spills over instantaneously to all other researchers in the economy. He further assumes R&D productivity to increase one-to-one with the number of innovations, i.e. $Q_r = N_r$. This assumption, however, may be too restrictive in the present context where we intend to compare several regions. As has been argued elsewhere on empirical grounds (Bode 1999), the productivity effects of knowledge spillovers may well differ across regions for several reasons. One reason may be that regions with a higher density of researchers and, thus, lower average distances between them realize higher intensities of knowledge spillovers because

⁶ The time index is omitted for simplicity.

⁷ Both the lack of uncertainty and the infinity of patent protection are very restrictive assumptions. However, results do not change fundamentally, if we assumed the innovation success to depend on a random event with a known probability distribution, and the market power granted by the patent to erode after some time (see, e.g., Aghion and Howitt 1992, 1998, Barro and Sala-i-Martin 1995).

communication between researchers is cheaper.⁸ With lower costs of communication, contacts between researchers can be expected to be more frequent, and new knowledge gained by single researchers in the course of R&D can be expected to spread faster, resp. more completely, among researchers than in regions with comparatively large average distances between researchers. Or, put differently, a given information may reach more researchers per instance of time in regions where distances between them are low than in regions where distances are high.

Since, up to now, there is no theoretically consistent and reliable explanation of regional differences in spillover intensities, the model should allow the productivity effects of knowledge spillovers to vary regionally. The only assumption we have to make here for analytical reasons is that in each region Q_r/N_r is constant over time – at least as long as factor supply is constant.

Each blueprint is sold competitively to potential intermediate good producers within the region. Having purchased a blueprint, an intermediate good producer i has the exclusive right to produce one variety of a heterogeneous intermediate good at constant marginal productivity:

$$(2) \quad x_{ir} = \eta B_{ir}, \quad i = 1, \dots, N_r.$$

For simplicity, we assume land (B) to be the sole input factor of this industry.

The consumption good Y , finally, which is produced using low-skilled labor (L), land (B_Y), and N_r varieties of the heterogeneous intermediate good as inputs according to

$$(3) \quad Y_r = L_r^\alpha B_{Yr}^\beta \left(\int_0^{N_r} x_{ir}^\gamma di \right), \quad \alpha + \beta + \gamma = 1,$$

is sold competitively to consumers. According to the love-of-variety approach (Dixit and Stiglitz 1977, Ethier 1982) this industry uses all N_r currently available varieties of the intermediate good. It faces constant returns to scale in a static environment, i.e. with the number of available varieties N_r being fixed, but increasing returns to scale in a dynamic environment, i.e. with the number of available varieties increasing. Each additional variety developed by the innovative sector and produced by the intermediate good industry raises total factor productivity in the final goods industry by intensifying the division of labor.⁹

⁸ For a search-theoretical analysis of knowledge spillovers see Jovanovic and Rob (1989).

⁹ (3) is restrictive in that the varieties of the intermediate good are assumed to be neither substitutes nor complements. Taken literally, (3) can at best be used to explain basic innovations. A more realistic theoretical description of the process of deepening of the division of labor was to assume the varieties to be substitutes (see, e.g. Grossman and Helpman 1991). Analytically, however, the two approaches make only little difference. Thus, the present approach may be justified as simplifying the formal analysis.

To obtain the equilibrium regional wage rates for high and low-skilled labor at time t , w_H and w_L , we assume factor supply to be fixed and the markets for blueprints, intermediate goods, labor, and land to be in equilibrium. For simplicity, we ignore the consumption side of the regional economy by assuming the output of the final good industry to be absorbed completely.

The price of the i -th variety of the intermediate good, p_i , follows from profit maximization of the intermediate good producer. Each producer chooses his output quantity x_i that maximizes his profit

$$\pi_{ir} = (p_{ir} - p_{Br} / \eta) x_{ir} = \gamma L_r^\alpha B_{Yr}^\beta x_{ir}^\gamma - p_{Br} x_{ir} / \eta$$

given the aggregate demand for his variety. The resulting price

$$(4) \quad p_{ir} = p_{Br} / \gamma \eta$$

depends only on the land price and on parameters that are assumed to be the same in all regions. It yields a maximum profit

$$(5) \quad \pi_{ir} = (1 - \gamma) p_{ir} x_{ir} = (1 - \gamma) \bar{p}_r \bar{x}_r.$$

Since all intermediate good producers i in region r face the same production and demand conditions, they will charge the same optimal price (\bar{p}_r) and produce the same quantity of their varieties (\bar{x}_r). Substituting (4) into the demand functions and the zero-profit condition of the final good industry, and taking the consumption good as numeraire yields

$$(6) \quad B_{Yr} = \beta p_{Br}^{-1} Y_r,$$

$$(7) \quad L_r = \left[\beta^\beta \gamma^\gamma (\gamma \eta)^\gamma \right]^{-1/\alpha} N_r^{-(1-\gamma)/\alpha} p_{Br}^{(1-\alpha)/\alpha} Y_r,$$

$$(8) \quad \bar{x}_r = [\gamma (\gamma \eta)] N_r^{-1} p_{Br}^{-1} Y_r.$$

The market for (homogeneous) land is cleared, if aggregate demand by the intermediate good industry, given by (2) and (8)

$$(9) \quad N_r B_{Yr} = N_r x_{ir} / \eta = \gamma^2 p_{Br}^{-1} Y_r,$$

and the final goods industry, given by (6), sums up to the exogenously given supply, i.e., if $B_r = B_{Yr} + N_r B_{Ir}$. The resulting equilibrium land price is

$$(10) \quad \begin{aligned} p_{Br} &= (\beta + \gamma^2) B_r^{-1} Y_r \\ &= \Psi B_r^{-1} Y_r, \end{aligned}$$

$\Psi := (\beta + \gamma^2)$. Substituting (10) into (6) and (9) yields $B_{rr} = \beta B_r / \Psi$ and $N_r B_{rr} = \gamma^2 B_r / \Psi$, respectively. The allocation of land between the final and the intermediate good sector within a region depends only on production technology and the supply of land, but not on land prices, or the number of varieties of the intermediate good.

(10) is also used to determine equilibrium final output Y , and prices w_L , p_B , and \bar{p} as functions of exogenously given supply of low-skilled labor (L), land (B), and total factor productivity in the consumption good industry $N^{1-\gamma}$.¹⁰

$$(11) \quad Y_r = \Delta \Psi^{\alpha-1} N_r^{1-\gamma} L_r^\alpha B_r^{1-\alpha},$$

$$(12) \quad w_{Lr} = \alpha \Delta \Psi^{\alpha-1} N_r^{1-\gamma} L_r^{\alpha-1} B_r^{1-\alpha},$$

$$(13) \quad p_{Br} = \Delta \Psi^\alpha N_r^{1-\gamma} L_r^\alpha B_r^{-\alpha},$$

$$(14) \quad \bar{p}_r = (\gamma \eta)^{-1} \Delta \Psi^\alpha N_r^{1-\gamma} L_r^\alpha B_r^{-\alpha};$$

$\Delta := \beta^\beta \gamma^\gamma (\gamma \eta)^\gamma$. Using (8) and (11), the optimal quantity per variety of the intermediate good is

$$(15) \quad \bar{x}_r = \gamma (\gamma \eta) \Psi^{-1} N_r^{-1} B_r.$$

In the innovative sector, profit maximization requires

$$(16) \quad w_{Hr} = \chi Q_r(N_r) c_{Nr},$$

where w_{Hr} denotes the wage rate of high-skilled workers and c_{Nr} are the production costs of a blueprint.

At the market for innovative blueprints which is assumed to be perfectly competitive the supply of blueprints meets demand by potential intermediate good producers. To purchase a blueprint, each producer has to borrow money at the capital market at an interest rate ρ_r .¹¹

¹⁰ Note that, with $x_{rr} = \bar{x}_r$, the production function of the consumption good industry (3) becomes $Y_r = L_r^\alpha B_{Yr}^\beta N_r \bar{x}_r^\gamma = N_r^{1-\gamma} L_r^\alpha B_{Yr}^\beta (N_r \bar{x}_r)^\gamma$, where total factor productivity $N^{1-\gamma}$ represents the productivity effects of technical progress. It can only be realized when the number of varieties of the intermediate good (N) increases but not when the input quantity (x) of each intermediate good increases while N is constant.

¹¹ We assume the interest rate to be region-specific, but exogenously given. It is determined at the national, resp. international capital markets, but corrected by a federal government for reasons of regional assistance. For details, see below. The only thing we have to assume here is that actors in the regions expect the interest rate to be constant over time.

The credit is served by monopoly profits. The standard no-arbitrage condition equating the instantaneous rate of return from intermediate good production to the interest rate is

$$(17) \quad (\pi_{ir} + \dot{c}_{Nir}) / c_{Nir} = \rho_r,$$

where π_{ir} is monopoly profit of the i -th intermediate good producer.

It is clear from (16) that the unit costs (c_{Nr}) are constant when w_H and Q grow at the same rates. Equating (16) and (17), and using (5), (8), (11) and (14) yields the wage rate of high-skilled labor

$$(18) \quad \begin{aligned} w_{Nr} &= (1-\gamma)\gamma\chi\Delta\Psi^{\alpha-1}Q_r\rho_r^{-1}N_r^{-\gamma}L_r^\alpha B_r^{1-\alpha} \\ &= (1-\gamma)\gamma\chi\Delta\Psi^{\alpha-1}(Q_r/N_r)\rho_r^{-1}N_r^{1-\gamma}L_r^\alpha B_r^{1-\alpha} \end{aligned}$$

which does not directly depend on the number of researchers in the region but on their productivity χQ_r , resp. $\chi Q_r/N_r$, and, thus, on the intensity of research in the past. Note that, with Q_r/N_r being constant over time by assumption, both wage rates, w_L and w_H , depend positively on $N^{1-\gamma}$, the total factor productivity in the final good industry.

The growth dynamics of the model can be explored by differentiating equations (11)-(14) and (18) with respect to time. Under the above assumptions, and noting that Q_r/N_r is constant over time, we obtain

$$(19) \quad \hat{Y}_r = \hat{w}_L = \hat{w}_{Nr} = \hat{p}_{Br} = \hat{p}_{ir} = (1-\gamma)\hat{N}_r = (1-\gamma)\chi(Q_r/N_r)H_r.$$

All factor prices (except the interest rate) are growing with the same positive rate, which is $(1-\gamma)$ times the rate of technical progress. As a consequence, income and factor prices grow faster, *ceteris paribus*, in regions with a larger number of researchers and/or a higher R&D productivity.

Turning to the determinants of regional wage differences in the static context, we observe from (12) and (18) that wage rates of both low and high-skilled workers depend positively on the technological level N . *Ceteris paribus*, wages are higher in technologically advanced regions than in regions that lag behind technologically.

Moreover, the model reflects both economies and diseconomies of agglomeration. Economies of agglomeration result from R&D productivity if we assume that regions with a higher density of researchers realize higher intensities of knowledge spillovers, i.e. a higher value of Q_r/N_r . In a static context, the benefits of these agglomeration economies accrue only to high-skilled workers (equation 18) whose wage rate will, *ceteris paribus*, be higher in regions with higher R&D productivity than in regions with lower productivity. Low-skilled workers

(equation 12) do benefit only indirectly via a higher N as a result of a faster rate of technical progress in the past. Dynamically, however, all workers benefit from higher R&D productivity to the same extent (equation 19).

Diseconomies of agglomeration result from the scarcity of land. In general, the model implies that both low and high-skilled workers will earn higher wages in regions where land is more abundant, provided regional differences in labor supply and technology are not too strong. However, if we compare regions of equal geographical size, regions with a higher number of low-skilled workers per unit of land will have, *ceteris paribus*, a higher land price and a higher wage rate of high-skilled labor, while the wage rate of low-skilled labor will be lower.

Taken together, the regional structure of wage rates of high and low-skilled workers at a given point in time depends on the relative technological level attained in the respective regions, and on the relative importance of economies and diseconomies of agglomeration. For low-skilled workers, an agglomeration is less favorable than a peripheral region (of comparable geographical size), provided they are not compensated for agglomeration diseconomies by the productivity effects of a higher level of technology. For high-skilled researchers, an agglomeration is generally more favorable than a peripheral region, provided (i) the agglomeration is not lagging behind too far technologically, (ii) their productivity does not suffer too much from congestion, and (iii) the region-specific interest rate is not too high.

2. Three innovative sectors

In the bulk of the theoretical and empirical growth literature technical R&D is assumed to be the only relevant source of technological progress. This point of view is very restrictive since in highly developed countries there are other activities that are equally capable of developing innovative ideas, concepts, products, or processes which foster productivity and growth. To mention only one example, think of new management and organization concepts that increase the motivation of workers and their incentives to contribute more actively to the company's success than the traditional Tayloristic organization does (Bickenbach and Soltwedel 1998). In the present investigation, therefore, we prefer a broader view to technological innovations by including not only technical but also organizational and institutional innovations.

The simplest way to do so in a growth theoretic context is to assume all innovative sectors to work in the same way the R&D sector does in traditional endogenous growth models. Assume that there is not a single, but three innovative sectors for technical R&D (RD), management techniques (M), and producer services (S)

$$(20) \quad \dot{N}_r = \chi_r Q_r (N_r) H_r, \quad t = RD, M, S; r = 1, \dots, R.$$

For simplicity, we assume that each of the three sectors uses his own sector-specific high-skilled workers and knowledge. There is no exchange of workers or knowledge between the sectors. In each sector, R&D produces excludable knowledge that can be sold on a sector-specific market for new ideas,¹² and non-excludable knowledge as an external effect, that spills over to other researchers in the region and sector. Note that R&D productivity may differ between the sectors. For technical reasons again, we have to assume that Q_{ir}/N_{ir} is region-specific but constant over time as long as factor supply is constant.

The three intermediate good sectors that translate ideas into intermediate goods work in the same way than before, but their productivities may differ:

$$(21) \quad \begin{aligned} x_{RDir} &= \eta_{RD} B_{RDir}, & i=1, \dots, N_{RD}, \\ x_{Mjr} &= \eta_M B_{Mjr}, & j=1, \dots, N_{Mr}, \\ x_{Skr} &= \eta_S B_{Skr}, & k=1, \dots, N_{Sr}. \end{aligned}$$

The consumption good sector, finally, uses all varieties of all three intermediate goods according to

$$(22) \quad Y_r = L_r^\alpha B_{Yr}^\beta \left(\int_0^{N_{RD}} x_{RDir}^\gamma di \right) \left(\int_0^{N_{Mr}} x_{Mjr}^\delta dj \right) \left(\int_0^{N_{Sr}} x_{Skr}^\varepsilon dk \right),$$

$$\alpha + \beta + \gamma + \delta + \varepsilon = 1; \quad N_{ir} = \int_{-\infty}^t \dot{N}_{iv} dv; \quad i=RD, M, S.$$

Each intermediate good is a necessary input, but they are incomplete substitutes.

The wage rates in the four labor market segments for low and high-skilled workers in static equilibrium can be determined in the same way as in the preceding chapter. The results are very similar, the only notable differences being that¹³

$$\Psi = \beta + \gamma^2 \text{ has to be replaced by } \tilde{\Psi} = \beta + \gamma^2 + \delta^2 + \varepsilon^2,$$

$$\Delta = \beta^\beta \gamma^\gamma (\gamma\eta)^\gamma \text{ by } \tilde{\Delta} = \beta^\beta (\gamma\eta_{RD})^\gamma (\delta\eta_M)^\delta (\varepsilon\eta_S)^\varepsilon, \text{ and}$$

$$\text{total factor productivity } N_r^{1-\gamma} \text{ in (11)-(14) and (18) by } \Theta_r := N_{RD}^{1-\gamma} N_{Mr}^{1-\delta} N_{Sr}^{1-\varepsilon}.$$

¹² Of course, many new management ideas and services cannot be patented. However, there are other ways of protecting immaterial innovations against imitation. One is to ensure the own competence in implementing the innovation in final use to be steadily higher than that of potential imitators. But anyway, even if the innovation becomes worthless after some time, or monopoly power of the innovator, resp. the intermediate good or service producer deteriorates, the idea of the present model will still work. For details see the quality-ladder models of endogenous growth following Aghion and Howitt (1992), and the discussion in Barro and Sala-i-Martin (1995: 223 ff.).

¹³ A more detailed description of the model is available from the author upon request.

The equilibrium wages at an arbitrary point of time now read

$$(23) \quad w_{Lr} = \alpha \tilde{\Delta} \tilde{\Psi}^{\alpha-1} \Theta_r L_r^{\alpha-1} B_r^{1-\alpha},$$

$$(24) \quad w_{RD r} = (1-\gamma) \gamma \chi_{RD} \tilde{\Delta} \tilde{\Psi}^{\alpha-1} \Theta_r (Q_{RD r} / N_{RD r}) \rho_r^{-1} L_r^{\alpha} B_r^{1-\alpha},$$

$$(25) \quad w_{Mr} = (1-\delta) \delta \chi_M \tilde{\Delta} \tilde{\Psi}^{\alpha-1} \Theta_r (Q_{Mr} / N_{Mr}) \rho_r^{-1} L_r^{\alpha} B_r^{1-\alpha},$$

$$(26) \quad w_{Sr} = (1-\varepsilon) \varepsilon \chi_S \tilde{\Delta} \tilde{\Psi}^{\alpha-1} \Theta_r (Q_{Sr} / N_{Sr}) \rho_r^{-1} L_r^{\alpha} B_r^{1-\alpha}.$$

3. Factor mobility

Assume now that, in a system of regions where each region is described by the above model with three innovative sectors, the costs of interregional migration are somewhat reduced. Suddenly, both low and high-skilled workers will be able to move to their most favored regions, provided the individual costs of migration do not exceed the expected returns. We assume the (social and natural) migration costs to differ between individual workers such that there will always be only a fraction of the total workforce that is willing to migrate. The central question is: Which regions will attract high-skilled workers, and which low-skilled?

To answer this question we have to define the conditions and incentives for interregional migration by a migration function. The function employed here is a most simple one borrowed from standard text books on regional growth (e.g. Richardson 1973, Walz 1999):

$$g_{\kappa t} = f_{\kappa} (w_{\kappa t} / \bar{w}_{\kappa}), \quad \kappa = L, RD, M, S; r = 1, \dots, R.$$

It states that the growth rate of employment (g) of low ($\kappa = L$) and high-skilled labor (H) in region r and period t due to migration will be the higher the higher the respective wage rate is in r ($w_{\kappa t}$) relative to the national average (\bar{w}_{κ}) at the beginning of the period.¹⁴ For practical reasons, however, this simple function is modified in order to avoid misspecification of the empirical model due to omitted variables. From the empirical migration literature we know that there are other factors than wages that determine migration flows (Bode and Zwing 1998). Thus, we add a vector (\mathbf{X}) of additional variables which potentially influence the interregional movement of workers:

$$(27) \quad g_{\kappa t} = f_{\kappa} (w_{\kappa t} / \bar{w}_{\kappa}, \mathbf{X}_{\kappa t}), \quad \kappa = L, RD, M, S; r = 1, \dots, R.$$

¹⁴ For convenience we define g as $g_{L,t} = L_{t+1}/L_t$ and $g_{H,t} = H_{t+1}/H_t$.

4. Test hypotheses

By substituting the regional wage rates (23) - (26) into (27) we get

$$g_{Lr} = f_L \left(\alpha \tilde{\Psi}^{\alpha-1} \Theta_r L_r^{\alpha-1} B_r^{1-\alpha} \bar{w}_L^{-1}, \mathbf{X}_{Lr} \right),$$

$$g_{RDri} = f_H \left((1-\gamma) \gamma \chi_{RD} \tilde{\Delta} \tilde{\Psi}^{\alpha-1} \Theta_r (Q_{RDri} / N_{RDri}) \rho_r^{-1} L_r^{\alpha} B_r^{1-\alpha} \bar{w}_{RD}^{-1}, \mathbf{X}_{RDri} \right),$$

$$g_{Mri} = f_H \left((1-\delta) \delta \chi_M \tilde{\Delta} \tilde{\Psi}^{\alpha-1} \Theta_r (Q_{Mri} / N_{Mri}) \rho_r^{-1} L_r^{\alpha} B_r^{1-\alpha} \bar{w}_{M}^{-1}, \mathbf{X}_{Mri} \right),$$

$$g_{Sri} = f_H \left((1-\varepsilon) \varepsilon \chi_S \tilde{\Delta} \tilde{\Psi}^{\alpha-1} \Theta_r (Q_{Sri} / N_{Sri}) \rho_r^{-1} L_r^{\alpha} B_r^{1-\alpha} \bar{w}_{S}^{-1}, \mathbf{X}_{Sri} \right), \quad r = 1, \dots, R.$$

Assuming that $f_k(w_{kri} / \bar{w}_k, \mathbf{X}_{kri}) = a_k \ln(w_{kri} / \bar{w}_k) + \mathbf{b}_k \ln \mathbf{X}_{kri}$ (with $a_k > 0$) is an appropriate approximation of (27), and realizing that the national average wage rates \bar{w} are constant across regions, the logged migration functions read

$$(28a) \quad d \ln L_r = C_L + a_L \ln \Theta_r + a_L(\alpha-1) \ln L_r + a_L(1-\alpha) \ln B_r + \mathbf{b}_L \ln \mathbf{X}_{Lr},$$

$$(28b) \quad d \ln H_{RDri} = C_{RD} + a_{RD} \ln(Q_{RDri} / N_{RDri}) - a_{RD} \ln \rho_r + a_{RD} \ln \Theta_r \\ + a_{RD} \alpha \ln L_r + a_{RD}(1-\alpha) \ln B_r + \mathbf{b}_{RD} \ln \mathbf{X}_{RDri},$$

$$(28c) \quad d \ln H_{Mri} = C_M + a_M \ln(Q_{Mri} / N_{Mri}) - a_M \ln \rho_r + a_M \ln \Theta_r \\ + a_M \alpha \ln L_r + a_M(1-\alpha) \ln B_r + \mathbf{b}_M \ln \mathbf{X}_{Mri},$$

$$(28d) \quad d \ln H_{Sri} = C_S + a_S \ln(Q_{Sri} / N_{Sri}) - a_S \ln \rho_r + a_S \ln \Theta_r \\ + a_S \alpha \ln L_r + a_S(1-\alpha) \ln B_r + \mathbf{b}_S \ln \mathbf{X}_{Sri},$$

where $C_L := a_L \left[\ln(\alpha \tilde{\Psi}^{\alpha-1}) - \ln \bar{w}_L \right]$, $C_{RD} := a_{RD} \left[\ln((1-\gamma) \gamma \chi_{RD} \tilde{\Delta} \tilde{\Psi}^{\alpha-1}) - \ln \bar{w}_{RD} \right]$, $C_M := a_M \left[\ln((1-\delta) \delta \chi_M \tilde{\Delta} \tilde{\Psi}^{\alpha-1}) - \ln \bar{w}_M \right]$, and $C_S := a_S \left[\ln((1-\varepsilon) \varepsilon \chi_S \tilde{\Delta} \tilde{\Psi}^{\alpha-1}) - \ln \bar{w}_S \right]$ are constants.

Using the four equations (28a-d) the central hypothesis will be tested empirically for a cross-section of West-German regions. The hypothesis holds that the three human-capital intensive activities continue concentrating on agglomerations because of localized knowledge spillovers, while those activities that do not benefit directly from knowledge spillovers, namely manufacturing production and distribution, tend to deconcentrate because of agglomeration diseconomies. The hypothesis will not be rejected, if the regressions show

- significantly positive parameters of the R&D productivity terms $\ln(Q_i/N_i)$ in equations (28b-d) for highly qualified workers, indicating that researchers benefit from agglomeration economies due to productivity-enhancing knowledge spillovers;
- a significantly negative parameter of the low-skilled labor force (L) in (28a).

By contrast, zero, or negative parameters of the R&D productivity terms $\ln(Q_i/N_i)$ in equations (28b-d) will indicate that regional differences in R&D productivity are negligible, or that the intensity of spillovers declines in the course of technological progress. A positive parameter of $\ln L$ in (28a) will indicate that diseconomies of agglomeration may be negligible.

III. Empirical estimation

1. Specification of the empirical model

The first thing to be done in the empirical part is to describe the variables of the theoretical model by appropriate statistical indicators. This task is not trivial in the present context since some of the variables of the model cannot be observed directly and, thus, have to be approximated by available statistics.

The dependent variables, the growth rates of regional employment of low-skilled and the three kinds of high-skilled workers, are approximated by data from public social-security insurance statistics which are the only source in Germany from which regional, sectoral, and occupational sufficiently disaggregated data are available. H_{RD} , the number of highly qualified technical researchers, is indicated by the number of engineers, natural scientists, and mathematicians with academic education employed in manufacturing industries. On average, this group of workers accounts for 1.5 per cent of total workforce in manufacturing industries, and for 0.7 per cent of the whole regional workforce (Table 2). H_M , the number of highly qualified workers developing innovative management techniques, is indicated by the number of persons employed by manufacturing industries as managers, business consultants, ADP and marketing specialists. As indicator of H_S , the number of highly qualified persons developing innovative producer services, we use high-skilled workers in service industries that produce services predominantly for corporate clients. More specifically, the indicator comprises workers with characteristics similar to those taken as indicators for H_{RD} and H_M (engineers, natural scientists, mathematicians, managers, business consultants, ADP, marketing specialists) employed in producer service industries.¹⁵ Finally, to measure L , the numbers of low-skilled

¹⁵ It should be noted that the German social-security insurance system does not cover the whole workforce. Self-employed, as well as employees with an income above or below critical levels are only covered if they

workers in final good industry, we use the number of employees in manufacturing industries engaged in production and stock holding. On average, this group of workers, who are mostly medium or low skilled, accounts for about 70 per cent of total workforce in manufacturing industries, and 31 per cent of the whole regional workforce (Table 2).

The growth rates cover the time period 1976 – 1994 which is defined as one period. Accordingly, the explanatory variables are from 1976, resp. 1977.

As concerns statistical indicators of the explanatory variables, B_n is approximated by land used for housing and business (except agriculture and traffic) which is available from statistical offices by the Bundesländer. Unfortunately, the statistics do not allow to isolate land used predominantly by firms from land used for housing.

The interest rate, ρ , is indicated by regional capital costs, as calculated by Deitmer (1993). The data were calculated by correcting a nationwide identical interest rate for region-specific local corporate-tax rates and certain public investment grants.¹⁶

For total factor productivity $\Theta_i = N_{RD}^{1-\gamma} N_M^{1-\delta} N_{SF}^{1-\varepsilon}$, the weighted average of the regional state-of-the-art in technologies, there is no indicator available from public statistics. We can neither observe the numbers of intermediate-good varieties entering final good production nor their respective output elasticities empirically. In the literature, this problem is solved using different approaches. Firstly, we may follow authors like Heitger et al. (1992) or Bretschger and Schmidt (1999) by simply using regional per-capita income as an indicator of Θ , stressing the hypothesis that technological progress is the only source of income growth in

Table 2 — Shares of employees in the four sectors in manufacturing and in total employment in 1976 – means and standard deviations for 75 West-German regions

	Share in			
	manufacturing employment		total employment	
	Mean	Std Dev	Mean	Std Dev
L	0.724	0.047	0.314	0.075
H_{RD}	0.015	0.009	0.007	0.004
H_M	0.023	0.007	0.010	0.003
H_S	—	—	0.022	0.008

participate voluntarily in the system. Moreover, the statistic is not corrected for differences in individual working time. The indicator of H_S , in particular, is somewhat ambiguous since the share of self-employed, and of persons with an income above the critical level in total workforce is pretty high in service industries.

¹⁶ For details see Deitmer (1993), and Asmacher et al. (1987).

the long run. I.e., we may assume $\Theta_r = (Y_r / P_r)^\zeta$, where P denotes regional population and ζ is a constant proportionality factor. Using this assumption, equation (28a) (taken as an example) becomes

$$(29a) \quad d \ln L_{rt} = C_L + a_L(\alpha - 1) \ln L_{rt} + a_L(1 - \alpha) \ln B_{rt} + a_L \zeta \ln(Y_r / P_r) + b_L \ln X_{Lrt},$$

or, replacing Y by the production function (22),

$$(30a) \quad d \ln L_{rt} = C_L + a_L(\alpha - 1 + \alpha \zeta) \ln L_{rt} + a_L(1 - \alpha + \beta \zeta) \ln B_{rt} \\ + a_L \zeta \ln(N_{RDrt} x_{RDrt}^\gamma N_{Mrt} x_{Mrt}^\delta t N_{Srt} x_{Srt}^\epsilon) - a_L \zeta \ln P_{rt} + b_L \ln X_{Lrt}.$$

The term $N_{RDrt} x_{RDrt}^\gamma N_{Mrt} x_{Mrt}^\delta N_{Srt} x_{Srt}^\epsilon$ may be approximated by an estimate of the regional stock of fixed assets.¹⁷

Secondly, we may make use of the fact that Θ is total factor productivity (TFP) in the final goods industry, i.e.

$$(31) \quad \Theta_{rt} = Y_{rt} L_{rt}^{-\alpha} B_{rt}^{-\beta} (N_{RDrt} x_{RDrt})^{-\gamma} (N_{Mrt} x_{Mrt})^{-\delta} (N_{Srt} x_{Srt})^{-\epsilon}.$$

Substituting (31) into (28a) yields

$$(32a) \quad d \ln L_{rt} = C_L - a_L \ln L_{rt} + a_L(1 - \alpha - \beta) \ln B_{rt} \\ + a_L \ln Y_{rt} - a_L \ln[(N_{RDrt} x_{RDrt})^\gamma (N_{Mrt} x_{Mrt})^\delta (N_{Srt} x_{Srt})^\epsilon] + b_L \ln X_{Lrt}$$

where $(N_{RDrt} x_{RDrt})^\gamma (N_{Mrt} x_{Mrt})^\delta (N_{Srt} x_{Srt})^\epsilon$ may be approximated by the stock of fixed assets.¹⁸

The question which of the three specifications (29), (30), or (32) should be preferred can hardly be answered on theoretical grounds alone. On the one hand, per-capita income is a very crude indicator of TFP. From this perspective, specifications (30) or (32) may be more preferable. On the other hand, however, (30) and (32) contain many variables that depend on a region's scale. As a consequence, the statistical significance of the estimators may be difficult to assess because of multicollinearity which inflates standard deviations. From this perspective, (29) may yield more clear-cut results. Since the problem cannot be solved a priori, we

¹⁷ Data on fixed assets at the regional level in Germany are available from Deitmer (1993).

¹⁸ A third possibility were to simply calculate Θ from (31) as $\hat{\Theta}_{rt} = Y_{rt} L_{rt}^{-\alpha} B_{rt}^{-\beta} (\text{fixed assets}_{rt})^{1-\alpha-\beta}$, applying some kind of a growth accounting approach (see, e.g. Denison 1985, Maddison 1987, Temple 1999). This alternative, however, is less preferable because it needs a-priori information on the values of α and β . Although the literature provides us with some ideas about the magnitudes of production elasticities (see, e.g., Barro et al. 1995, Diehl and Gundlach 1998) we cannot expect to obtain consistent regression results if we assumed α and β to take certain values on the one hand, but estimated them as parameters on the other hand.

will test all three specifications to be able to compare the results qualitatively and quantitatively.

Another set of variables that cannot be observed empirically is R&D productivities (Q_i/N_i) which, according to the model, depend on the intensities of localized knowledge spillovers. Even worse, growth theory does not give us useful ideas of how to approximate these variables. There is only one notable exception in the literature, namely Park (1998) who analyses theoretically the impact of government-financed (basic) research on industrial R&D productivity and growth within a Romer-type model. He concludes that knowledge spillovers from universities generally foster R&D productivity and growth. Since the intensity of these spillovers can be expected to be sensitive to spatial distance,¹⁹ we hypothesize that R&D productivity depends positively on the potential of university research in spatial proximity to the respective region.²⁰

With respect to other potential determinants of R&D productivities, the specification must necessarily be somewhat ad-hoc. Referring to the search-theoretic work by Jovanovic and Rob (1989), we use the density of high-skilled workers (per square kilometer) within the respective labor market segment as a second indicator of spillover intensity.²¹ A short average distance between researchers within a region is hypothesized to enhance communication and, thus, knowledge exchange. Thirdly, previous empirical studies indicate that the sectoral structure of regional industries may have an impact on the intensity of knowledge spillovers.²² Their results show that inter-industry knowledge spillovers foster productivity more than spillovers within industries.²³ Accordingly, we hypothesize that R&D productivities depend negatively on the degree of sectoral concentration of research. And finally, the empirical results obtained by Niebuhr (1998) indicate that there may be – contrary to the assumption in the theoretical part – interregional knowledge spillovers among neighboring regions. In order to test whether our assumption of no interregional exchange of ideas is too restrictive, we add the potential of

¹⁹ For empirical support of this hypothesis, see, e.g. Herden (1992), Herden and Heydebreck (1991), Reinhard and Schmalholz (1996), Jaffe (1989), Zucker et al. (1994a, 1994b), Audretsch and Stephan (1996), and Anselin et al. (1997).

²⁰ As an indicator of university research we use scientific personnel at public universities and Fachhochschulen (colleges) published by the Wissenschaftsrat (1987). Excluded are universities and "Fachhochschulen" for arts and music. Note that this statistic covers the number of planned jobs, with is not necessarily identical with the number of scientists actually employed.

²¹ Somewhat related to this hypothesis, Rauch (1993) has presented empirical evidence on positive productivity effects of geographic concentration of human capital.

²² Most available evidence refers to the U.S.; see Glaeser et al. (1992), Henderson et al. (1995), Henderson (1997), Feldman and Audretsch (1999), and Kelly and Hageman (1999), among others. However, there are also a few studies for Germany; see Büttner (1997), and Bode (1999).

²³ Although one might expect intuitively that technologically specialized researchers should be able to make better use of information originating from researchers with similar specialization than of information originating from researchers with completely different specialization, the empirical evidence is different.

researchers in the respective innovative sectors in neighboring regions as a final determinant of R&D productivity.

Assuming the productivities Q_i/N_i ($i = RD, M, S$) to have a log-linear functional form we get

$$\ln(Q_{it}/N_{it}) = \phi_{i1} \ln UR_{it} + \phi_{i2} \ln HD_{it} + \phi_{i3} \ln SH_{it} + \phi_{i4} \ln PH_{it}.$$

UR denotes the potential of researchers at universities in region r and its neighboring regions (for an exact definition of this variable see below), HD the number of researchers in the respective sector i per square kilometer, SH the sectoral concentration of research in i , approximated by the share of researchers in those two industries in the region's total R&D employment in i that have the largest absolute numbers of researchers, and PH the distance-weighted sum of researchers in sector i in neighboring regions of r (r') (see below).

The last set of explanatory variables to be determined statistically is the vector of non-wage determinants of interregional migration (\mathbf{X}). Although these determinants are not covered by the present growth model the empirical migration literature, surveyed, i.e., by Greenwood (1975, 1985), and Bode and Zwing (1998), strongly suggests to not ignore them because wage differences alone cannot explain empirical migration patterns to a sufficient extent. Apart from wage differences, one important determinant of migration is differences in regional employment opportunities, i.e. in employment growth dynamics and unemployment. Migrants tend to prefer regions with high growth rates of employment and low unemployment rates. Another determinant of migration is urbanization externalities, i.e. a multifaceted supply of consumer goods and services by private and public suppliers. As a consequence, we assume \mathbf{X} to be

$$(33) \quad \mathbf{X}_{\kappa r} = f_{\mathbf{X}\kappa}(\hat{E}_{\kappa r}, u_r, PD_r) = e^{b_{\kappa 1} \hat{E}_{\kappa r}} (1 - u_r)^{b_{\kappa 2}} PD_r^{b_{\kappa 3}} \quad \kappa = L, RD, M, S; r = 1, \dots, R,$$

where $\hat{E}_{\kappa r}$ denotes the growth rate of regional employment outside the κ -th sector, $(1-u)$ the (un)employment rate (defined as the share of persons employed in the regional population aged 15 to 65),²⁴ and PD the number of inhabitants per square kilometer.²⁵

²⁴ Instead of registered unemployment, we use this broader indicator, including both registered unemployed and persons that are not active in the labor market officially, in order to avoid the well-known problems of official labor market statistics which cover only a fraction of persons who are really willing to work.

²⁵ Empirically, the multifaceted nature of urbanization economies has often been condensed in a single explanatory variable, namely population size (Glaeser 1998). However, in order to make regions comparable in size, population density (i.e. the number of inhabitants on a representative square kilometre) is more adequate than absolute population. No one would expect a spacious, loosely settled peripheral region to exhibit the same extent of urbanization economies than a geographically small, but densely settled agglomeration with the same number of inhabitants.

In summary, Version I (assuming $\Theta_r = (Y_r / P_r)^{\epsilon}$) of the empirical model to test the central hypothesis reads²⁶

$$(34a_i) \quad d \ln L_{ri} = C_L + a_L \zeta \ln(Y_{ri} / P_{ri}) + a_L(\alpha - 1) \ln L_{ri} + a_L(1 - \alpha) \ln B_{ri} \\ + b_{L1} \hat{E}_{Lri} + b_{L2} \ln(1 - u)_{ri} + b_{L3} \ln PD_{ri} + \mu_{Lr},$$

$$(34b_i) \quad d \ln H_{RDri} = C_{RD} - a_{RD} \ln \rho_{ri} + a_{RD} \zeta \ln(Y_{ri} / P_{ri}) + a_{RD} \alpha \ln L_{ri} + a_{RD}(1 - \alpha) \ln B_{ri} \\ + a_{RD} \phi_{RD1} \ln UR_{ri} + a_{RD} \phi_{RD2} \ln HD_{RDri} \\ + a_{RD} \phi_{RD3} \ln SH_{RDri} + a_{RD} \phi_{RD3} \ln PH_{RDri} \\ + b_{RD1} \hat{E}_{RDri} + b_{RD2} \ln(1 - u)_{ri} + b_{RD3} \ln PD_{ri} + \mu_{RDri},$$

$$(34c_i) \quad d \ln H_{Mri} = C_M - a_M \ln \rho_{ri} + a_M \zeta \ln(Y_{ri} / P_{ri}) + a_M \alpha \ln L_{ri} + a_M(1 - \alpha) \ln B_{ri} \\ + a_M \phi_{M1} \ln UR_{ri} + a_M \phi_{M2} \ln HD_{Mri} \\ + a_M \phi_{M3} \ln SH_{Mri} + a_M \phi_{M3} \ln PH_{Mri} \\ + b_{M1} \hat{E}_{Mri} + b_{M2} \ln(1 - u)_{ri} + b_{M3} \ln PD_{ri} + \mu_{Mri},$$

$$(34d_i) \quad d \ln H_{Sri} = C_S - a_S \ln \rho_{ri} + a_S \zeta \ln(Y_{ri} / P_{ri}) + a_S \alpha \ln L_{ri} + a_S(1 - \alpha) \ln B_{ri} \\ + a_S \phi_{S1} \ln UR_{ri} + a_S \phi_{S2} \ln HD_{Sri} \\ + a_S \phi_{S3} \ln SH_{Sri} + a_S \phi_{S3} \ln PH_{Sri} \\ + b_{S1} \hat{E}_{Sri} + b_{S2} \ln(1 - u)_{ri} + b_{S3} \ln PD_{ri} + \mu_{Sri}.$$

The residuals μ_k are assumed to have the usual properties, namely normal distribution with zero mean and constant variance, and no spatial autocorrelation, or heteroscedasticity. Moreover, we assume the regression parameters to be stable, i.e. to take the same value in all regions.

2. Definition of regions and spatial interdependencies

What is the proper definition of a regional economy? In general, there should be particular strong economic ties between the areas within a region, but only weak ties between areas of different regions. In Germany, none of the major levels of administrative and statistical units meets these requirements. The 10 West-German *Bundesländer*, on the one hand, differ considerably in size and economic density. While the city-states of Hamburg and Bremen cover only the cores of metropolitan areas but not their suburbs, other *Länder* comprise several economic cores as well as peripheral regions with only weak economic ties to those cores. The 326 West-German *Landkreise*, on the other hand, are too small to constitute economically

²⁶ To save space, the two other systems of equations, referred to as Version II (Y replaced by eq. 22), and Version III (TFP derived from eq. 22 as an indicator of Θ), are outlined in Appendix 1. Descriptive statistics for all variables used in the regressions are given in Appendix 2 (Tables A1 and A2).

meaningful regions. Attempting to overcome these deficiencies, the *Bundesanstalt für Landeskunde und Raumordnung* (BfLR) developed so-called *Raumordnungsregionen* (planning regions) each comprising several *Landkreise* that are linked by comparatively high commuting flows. However, due to political resistance from a couple of *Bundesländer*, especially the city-states, it was not possible to define *Raumordnungsregionen* across borders of *Bundesländer* even in the presence of high commuting flows (Böltken 1996). Thus, we defined a slightly different set of 75 West-German²⁷ regions by aggregating those *Landkreise* that can be supposed to be linked by intensive economic ties (Figure 1). 29 of those regions, which we call agglomerations, comprise (i) at least one core city (at least 100,000 inhabitants and population density of at least 1,000 inhabitants per square kilometer) and (ii) their hinterlands characterized by higher commuting flows to the respective core city than to other *Landkreise*.²⁸ The remaining 46 regions, which we call peripheral regions, are organized according to commuting patterns as well.

Two variables in the set of explanatory variables aim at describing interregional knowledge spillovers, namely the potential of research at universities and *Fachhochschulen* (*UR*), and of highly qualified workers (*PH_i*). The former is defined as the sum of scientific personnel at universities and *Fachhochschulen* in region *r* and its neighboring regions, weighted by the inverse geographical distances between the economic centres of *r* and the respective neighbors. The distance weights are normalized to one. Formally, *UR* can be expressed as

$$(35) \quad UR_r = \sum_{t=1}^{R_r} \frac{H_{Ur} e^{-\vartheta_U D_{rt}}}{\sum_{t=1}^{R_r} e^{-\vartheta_U D_{rt}}},$$

where R_r denotes the number of neighboring regions of *r* (including *r*), H_{Ur} the specific personnel, and ϑ_U a distance decay parameter.

The latter three variables, PH_{it} , are defined similarly, the only exception being that region *r* is not element of R_r , i.e.

$$(36) \quad PH_{it} = \sum_{t=1}^{R_r} \frac{H_{it} e^{-\vartheta_{PH} D_{rt}}}{\sum_{t=1}^{R_r} e^{-\vartheta_{PH} D_{rt}}} \quad t = RD, M, S.$$

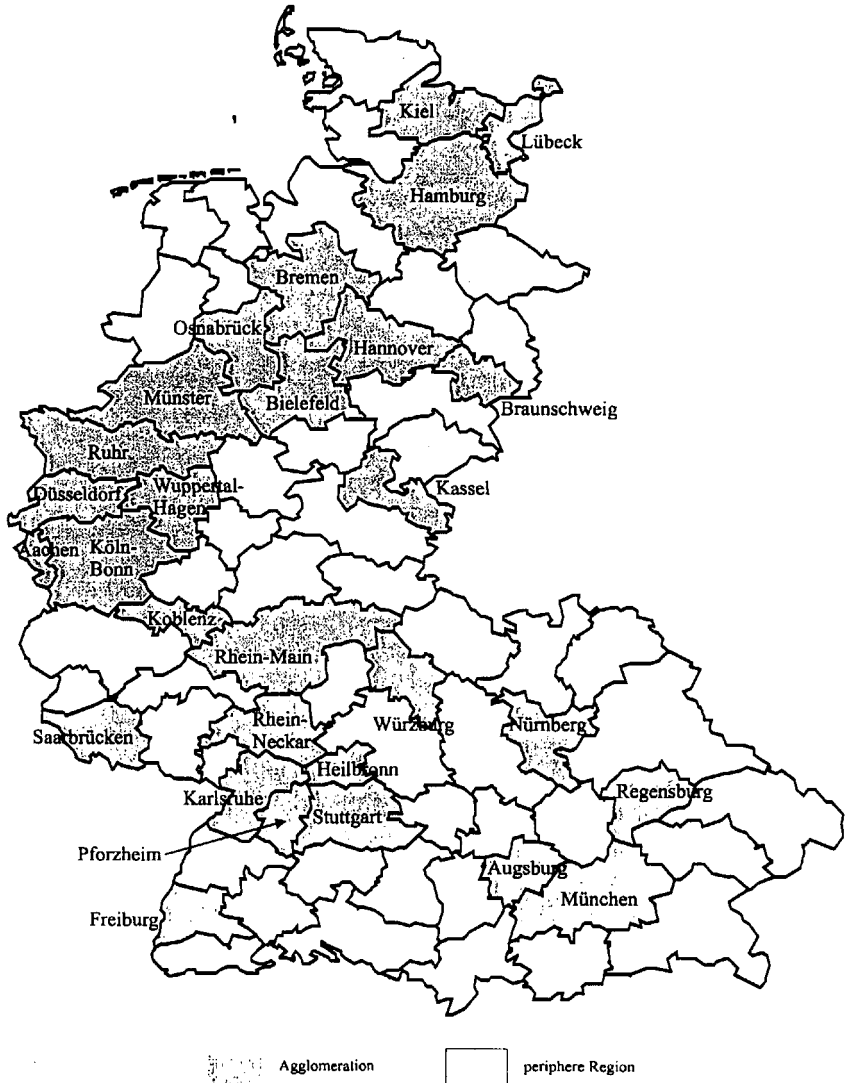
A problem frequently arising when distance decay parameters of potential variables like (35) and (36) are estimated non-linearly is that the estimators $\hat{\vartheta}$ take unplausibly low values. This

²⁷ East German regions had to be excluded from analysis because data are not available for a sufficiently long period of time.

²⁸ Unfortunately, commuter flows is the only indicator of economic ties uniquely available from public statistics for German *Landkreise*. More preferable indicators, such as intensity of trade, or capital links between firms, cannot be determined statistically.

happens most often when the number of neighboring regions is not restricted to a (region-specific) sub-sample of all regions under investigation. From test calculations as those plotted in

Figure 1 — Regional structure of West-Germany, 75 regions



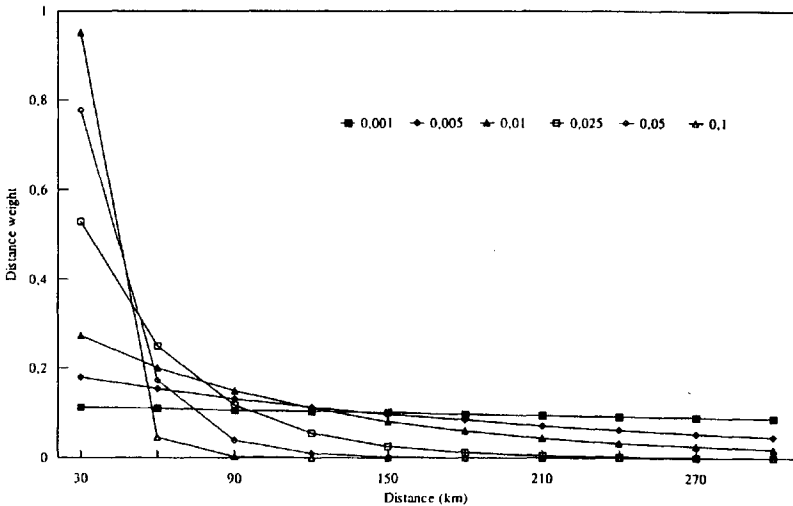
Source: Bode (1998).

Figure 2 we may infer that parameters less than $\hat{\theta} = 0.005$ are unplausible since they suggest distance decay to be almost zero.

This problem did occur in the current investigation as well. The decay parameters were estimated to be far below 0.005, even after R_r was restricted to regions within a distance of 150 km from r . Although these results already seem to indicate that cross-border effects, namely knowledge spillovers, are negligible we restrict the maximum distance to 150 km and θ to either 0.025 or 0.05 and estimate (34) linearly.

To analyze the properties of regression residuals, we ran several statistical tests of the assumptions of regression theory, namely homoscedasticity, parameter stability, as well as the absence of spatial autocorrelation and spatial lag dependence. Homoscedasticity is tested for by Breusch-Pagan as well as by Chow-(F-)tests based on several sub-samples of regions (rich vs. poor, north vs. south, agglomerations vs. peripheral regions).²⁹ The sub-samples are used

Figure 2 — Distance weights in dependence of distance and selected decay parameters^a



^a Distance weights are calculated according to eq. (35) as $e^{-\theta D_{rt}} / \sum_{t=1}^R e^{-\theta D_{rt}}$, assuming $R=10$ and distance decay parameters as given in the legend.

Source: Own calculations.

²⁹ See Bode (1998) for details.

as well to test parameter stability by the usual F-tests. Spatial autocorrelation is tested by Moran's I and LM-tests, using different spatial weights matrices; tests for spatial lag dependence are based on the LM principle.³⁰

In several regressions the tests indicated heteroscedasticity and/or spatial dependencies. Heteroscedasticity most often resulted from outliers, i.e. from – mostly peripheral – regions with exceptional high or low growth rates of employment in the respective sectors due to very special circumstances. One of such regions, for example, is Paderborn, where Nixdorf (now Siemens-Nixdorf), a very rapidly expanding producer of computers, is located; another frequent outlier is Wolfsburg where Volkswagen is located. These outliers have been neutralized by dummies in order to ensure homoscedasticity. Spatial dependencies usually resulted from spatial lag dependence. They were controlled for by adding a spatially lagged endogenous variable to the model (Anselin 1988). Since OLS produces biased estimates in the presence of a spatially lagged dependent variable, the respective models had to be estimated by a maximum likelihood (ML) approach.³¹

3. Regression results

In Table 4 the results are given of the empirical estimation for low-skilled workers (equations 34a_{I-III}). The first column reports results (estimated parameters and p-values) for Version I using real per-capita income as proxy of TFP, the second refers to Version II where Y is substituted by the production function, and the third to Version III where TFP is assumed to be $YL^{-\alpha}B_V^{\beta}(AS)^{-1}$.

In summary, the empirical results do not reject the hypothesis that low-skilled employment is negatively affected by agglomeration diseconomies. As was hypothesized, their employment growth depends negatively on the number of low-skilled workers ($\ln L$) and positively on the availability of land ($\ln B$). This result is most obvious in Version I. Both parameters are highly significant, according to the prob-values: The probabilities of erroneously rejecting the hypotheses that the parameters equal zero are only 1 per cent, and 2 per cent, which is much lower than the usual critical level of 5 per cent. Moreover, the parameters are of the same absolute magnitude, as the theoretical model suggests.³² From this we may conclude that there are ag-

³⁰ See Anselin (1988) for a detailed description of test statistics. We test for spatial autocorrelation among direct neighbors as well as for effects originating from agglomerations only. Furthermore, we test for spatial autocorrelation among regions within a distance of no more than 150 km. Each of the tests is done using spatial weights matrices with different distance decay parameters. See Bode (1998; 1999) for details.

³¹ See Anselin (1988) for details.

³² Recall from equation (34a) that the parameter of $\ln L$, $\alpha_L(\alpha-1)$, should equal that of $\ln B$, $\alpha_L(1-\alpha)$, except for the sign. The error probability of the respective F-test is less than 2 per cent.

glomeration diseconomies at work: The higher the geographic density of low-skilled workers, the less attractive is a region for those workers, resp. activities.

Table 3 — Regression results for low-skilled workers, equations (34aI-III)a

Equation	(34aI)		(34aII)		(34aIII)	
Method	ML		OLS		ML	
Explanatory variables	parm	prob ^b	parm	prob ^b	parm	prob ^b
C	0.67	0.61	0.69	0.14	0.32	0.31
lnL	-0.09	0.01 **	-0.02	0.78	-0.06	0.19
lnB	0.08	0.02 **	0.14	0.00 **	0.11	0.02 **
lnρ	—	—	—	—	—	—
TFP:						
ln(Y/P)	-0.03	0.78	—	—	—	—
lnY	—	—	—	—	-0.05	0.40
lnP	—	—	-0.11	0.14	—	—
lnAS	—	—	-0.03	0.51	-0.01	0.79
R&D productivity:						
lnUR	—	—	—	—	—	—
lnHD	—	—	—	—	—	—
lnSH	—	—	—	—	—	—
lnPH	—	—	—	—	—	—
additional determinants of migration:						
dlnE ^c	1.07	0.00 **	0.94	0.00 **	1.06	0.00 **
ln(1-u)	-0.01	0.95	-0.18	0.20	-0.04	0.76
lnPD	-0.04	0.23	7E-4	0.98	-0.03	0.48
spatial lag	-0.44	0.02 **	—	—	-0.40	0.04 **
No. of Dummies	0	—	0	—	0	—
R ² _{adj.} (pseudo- R ²)	(0.72)	—	0.68	—	(0.72)	—
lnL	80.51	—	—	—	80.96	—
SSR	0.51	—	0.53	—	0.50	—
F	—	—	23.54	0.00**	—	—
Homoscedasticity ^d	o	—	o	—	o	—
Parameter stability ^d	o	—	o	—	o	—
No autocorrelation ^d	o	—	o	—	o	—

^a Cross-section OLS, resp. maximum likelihood (ML) regressions for 75 West German regions 1976–1994; dependent variable: *dlnL*. Definitions of the variables are given in the text. — ^b Error probability of rejecting H_0 : parameter=0; two-tailed test. *: Different from zero with a probability of at least 90 per cent; **: Different from zero with a probability of at least 95 per cent. — ^c Growth rate of regional employment excluding workers covered by the dependent variable. — ^d o: H_0 of homoscedasticity, parameter stability, or no spatial autocorrelation is not rejected by the tests at the 95% level. For details of the tests, see text.

Source: Own estimations.

The estimated effect of total factor productivity on low-skilled employment growth is ambiguous. In Version I, per-capita income, $\ln(Y/P)$, has no significant impact on employment growth (prob = 0.78). In Versions II and III, nearly all parameters of the TFP indicator also appear to be insignificant. However, their standard deviations and, thus, their prob-values, are seriously inflated by multicollinearity³³ which makes it impossible to determine the statistical significance of individual effects of the variables. Moreover, a closer look at the parameter values, which remain unbiased in the presence of multicollinearity, reveal some inconsistencies that seriously question the reliability of these indicators.

- Comparing the results of Version II to those of Version I, the parameter of $\ln L$ should be $a_L(\alpha - 1 + \alpha\zeta) > a_L(\alpha - 1)$, while that of $\ln B$ should be $a_L(1 - \alpha - \beta\zeta) < a_L(1 - \alpha)$. The former requirement is met, the latter is not.
- In Version III, the parameters of $\ln L$ and $\ln P$ should be $a_L > 0$, but are, in fact, estimated to be negative.

Thus, apart from multicollinearity, the parameters of the TFP indicators in Versions II and III seem to reflect effects that are not part of the model. Obviously, these indicators are not very useful in the present context.

Among the non-wage determinants of regional employment growth of low-skilled workers, only the overall growth of regional employment ($d\ln E$; excluding low-skilled workers) shows a significant effect. Its parameter is about 1,³⁴ suggesting that employment of low-skilled workers grows at roughly the same rate than overall employment. This result may be surprising since we know from empirical observation that, in (West-) Germany as a whole, this group of workers has grown slower than overall employment (see, e.g. Bade 1996, 1997). However, we have to keep in mind that, firstly, most regions in the data set are peripheral regions where the numbers of these jobs have tended to decline less than in agglomerations. Secondly, there are other variables in the model, such as initial employment ($\ln L$) and the spatially lagged endogenous variable, that explain below-average employment growth of low-skilled workers. From this perspective we may conclude that, in general, employment growth of low-skilled workers follows overall employment growth, with the deviations from the general tendency being explained pretty well by negative agglomeration economies, and by the lagged-endogenous variable.

³³ Although the individual probability values of the parameters of low-skilled workers ($\ln L$), income ($\ln Y$), population ($\ln P$) and fixed assets ($\ln AS$) in Versions II and III indicate that they are not statistically different from zero (prob > 0.05), there is a significant impact on employment growth of all three variables taken together in the respective equations ($\ln L$, $\ln P$, $\ln AS$ in Version II; $\ln L$, $\ln Y$, $\ln AS$ in Version III), as evidenced by F-tests on joint significance.

³⁴ The parameter is not significantly different from 1.

The latter variable has a significantly negative parameter indicating that there has been some interregional reallocation of low-skilled employment over short and medium distance (up to 150 km). In the literature, this process is frequently referred to as suburbanization³⁵ and decentralization.

For the three segments of high-skilled workers, the regression results are clearly not in favor of the central test hypothesis.³⁶ According to the empirical results, high R&D productivity seems to repel rather than attract researchers (Table 4). This interpretation is suggested, in particular, by the estimated negative impact of the initial density of high-skilled workers ($\ln HD$) on employment growth. In contrast to the hypothesis which holds that higher density enhances the intensity of intraregional knowledge spillovers among researchers and, thus, improves their productivity, the effect on employment growth is significantly negative in all three sectors, the innovative technical, managerial, and service activities.³⁷

Moreover, interregional spillovers, as indicated by the potential of researchers in neighboring regions ($\ln PH$), also appear to affect high-skilled employment negatively rather than positively. The respective parameters are, however, insignificant in two of the three sectors. Thus, we have to conclude that R&D productivity tends to decline rather than to increase with increasing intraregional R&D density and interregional potential for knowledge spillovers.

At best, the spillover hypothesis may hold for the transmission of knowledge by universities. The potential of university research ($\ln PH$) seems to have some positive effects on R&D productivity and growth, at least in the producer services and the management sectors, although the latter is only of weak statistical significance. The effects of the sectoral specialization in regional research ($\ln SH$), finally, are estimated to be negligible.

Another result that further weakens the empirical relevance of the underlying theoretical approach is that the parameters of most of the other determinants of the regional wage rates, namely the interest rate ($\ln \rho$), total factor productivity ($\ln(Y/P)$), the supply of low skilled workers ($\ln L$), and of land ($\ln B$) are either insignificant, or have the wrong signs, if compared to the theoretical model. For example, the parameters of $\ln L$ and $\ln B$ should both be positive and sum up to 1. This theoretical prediction is not met in a single equation.

³⁵ Although the definition of regions for the present purpose is such that most of the short-distance reallocation of jobs in the course of suburbanization is an intraregional phenomenon, we may not have been fully successful in excluding all effects of suburbanization from the empirical analysis.

³⁶ Because of the above mentioned inconsistencies of results obtained for Versions II and III we concentrate on estimations of Version I. Results for the other Versions are listed in Appendix 3.

³⁷ All three parameters are different from zero. This result is robust to a variation of TFP indicators. See Tables A3 – A5 in Appendix 3.

Table 4 — Regression results for employment growth in three sectors of high-skilled workers, equations (34b)–(34d) ^a

Equation	(34b)		(34c)		(34d)	
Dependent variable	$d\ln H_{RD}$		$d\ln H_M$		$d\ln H_S$	
Method	ML		OLS		ML	
Explanatory variables	parm	prob ^b	parm	prob ^b	parm	prob ^b
C	-6.05	0.09*	-3.00	0.25	-4.92	0.01 **
$\ln \rho$	0.11	0.81	0.43	0.29	0.31	0.31
TFP:						
$\ln(Y/P)$	0.42	0.16	0.13	0.53	0.27	0.11
$\ln Y$	—	—	—	—	—	—
$\ln P$	—	—	—	—	—	—
$\ln AS$	—	—	—	—	—	—
R&D productivity:						
$\ln L$	0.36	0.00 **	0.06	0.30	-0.14	0.02 **
$\ln B$	-0.38	0.00 **	-0.10	0.11	0.07	0.21
$\ln UR$	0.08	0.07 *	0.04	0.20	0.18	0.00 **
$\ln HD$	-0.22	0.00 **	-0.17	0.08 *	-0.41	0.00 **
$\ln SH$	-0.07	0.49	-0.01	0.89	-0.04	0.78
$\ln PH$	-0.02	0.61	-0.01	0.78	-0.14	0.00 **
additional determinants of migration:						
$d\ln E^c$	1.41	0.00 **	1.27	0.00 **	0.95	0.00 **
$\ln(1-u)$	0.23	0.57	0.23	0.50	0.40	0.15
$\ln PD$	-0.03	0.75	0.08	0.51	0.56	0.00 **
spatial lag	-0.77	0.00 **	—	—	0.24	0.03 **
No. of Dummies	1		3		2	
R^2_{adj} (pseudo- R^2)	(0.64)		0.61		(0.73)	
$\ln L$	20.82		.		57.40	
SSR	2.42		1.15		0.94	
F	.		9.79	0.00 **	.	
Homoscedasticity ^d	o		o		o	
Parameter stability ^d	o		o		N=S ^c	
No autocorrelation ^d	o		o		o	

^a Cross-section OLS, resp. maximum likelihood (ML) regressions for 75 West German regions 1976–1994. Definitions of the variables are given in the text. — ^b Error probability of rejecting H_0 : parameter=0; two-tailed test. *: Different from zero with a probability of at least 90 per cent; **: Different from zero with a probability of at least 95 per cent. — ^c Growth rate of regional employment excluding workers covered by the dependent variable. — ^d H_0 of homoscedasticity, parameter stability, or no spatial autocorrelation is not rejected by all tests at the 95% level. For details of the tests, see text. — ^e N=S: Parameters differ significantly between northern and southern German regions.

Source: Own estimations.

With respect to the non-wage determinants of high-skilled employment growth the results are fairly mixed. Whereas unemployment, $\ln(1-u)$, seems to have no significant effect on employment growth in any of the three innovative activities,³⁸ the parameters of overall employment growth ($d\ln E$) are highly significant and of plausible magnitude. Although the point estimates range from 1.41 for technical R&D to 0.95 for services, none of the parameters is significantly different from 1. Thus, there are, in general, no signs of an exogenously increasing regional concentration of high-skilled workers in regions with above-average economic prosperity.

Finally, urbanization externalities ($\ln PD$) obviously do not generally foster regional concentration of high-skilled workers. Quite interestingly, the only significantly positive effects are obtained for high-skilled service workers. This result, however, should be taken with care since there are some significant differences in the parameter estimates between northern and southern German regions, as indicated by the test on parameter stability ($N \neq S$).

IV. Conclusions

The aim of the present paper is to identify empirically the driving forces behind the regional deconcentration of economic activities in (West) Germany during the past two decades. Using an idea-based endogenous growth model similar to that of Romer (1990) that is modified to distinguish several innovative sectors, and to introduce externalities of agglomeration, we test the hypothesis that human-capital intensive activities in (technical) manufacturing R&D, manufacturing management, and producer services, continue to concentrate on agglomerations because of localized knowledge spillovers, while those activities that do not benefit directly from knowledge spillovers, namely manufacturing production and stock holding, tend to deconcentrate because of agglomeration diseconomies. Since data on income or wages are not available at a regionally and sectorally sufficiently disaggregated level in Germany, we introduce a theoretical migration function to the growth model assuming that regional wage differences induce workers to move to regions where localized knowledge spillovers are intensive and, thus, R&D productivity is high.

The empirical results, which are based on cross-section regressions for 75 West-German regions during the time period 1976–1994, reveal that the spatial deconcentration has been fuelled not only by low-skilled workers and jobs moving to peripheral regions in order to escape agglomeration diseconomies in the centers, but also by high-skilled, innovative workers, resp. jobs. In contrast to the test hypothesis, the positive effects of localized knowledge

³⁸ Again, the standard deviations of the parameters are inflated by multicollinearity between the unemployment rate on the one hand and per-capita income and population density on the other hand (Table A2 in Appendix 2).³⁹ Thus, the p-values are somewhat overstated.

spillovers on R&D productivity obviously have been too weak to ensure endogenous growth (of regional employment). Instead, the results suggest that R&D is subject to diminishing rather than constant returns to scale, as endogenous growth models like Jones (1995) assume.

One possible reason for the mismatch between the endogenous growth model developed for the present purpose and empirics may be that the theoretical model is misleading. However, since our results are in contrast to a big deal of previous empirical research on this topic, several shortcomings of the present approach should be kept in mind. Firstly, the approach is lacking a detailed theoretical analysis of potential determinants of R&D productivity, such as localized knowledge spillovers. Since this aspect is still treated as a black box in endogenous growth theory, statistical indicators of R&D productivity are necessarily ad-hoc. Secondly, employment figures may be not too reliable as indicators of the spatial allocation of economic activities. Due to the severe regulation of labor markets in Germany, knowledge spillovers may predominantly affect prices rather than quantities at the labor markets. From this perspective it would be interesting to separately analyse the impact of knowledge spillovers on wages, and that of regional wage differences on the reallocation of workers in order to get an idea as to where the model doesn't work. Such an analysis, however, deserves detailed data on regional wages which are not available for Germany up to now. And finally, there may be substantial heterogeneity within the labor market segments which have been assumed to be homogeneous here because of data shortage. Within producer service industries, for example, the degree of specialization of high-skilled workers may be very different. Probably, the benefits from knowledge spillovers vary substantially between workers depending on their specialization. The observed deconcentration of high-skilled workers may be fuelled mainly by the comparatively low-specialized among these activities while those with a high specialization, indeed, may still need spatial proximity to other specialists.

Hopefully, future refinements of endogenous growth theory, and of public statistics, will enable us to address at least some of these shortcomings in more detail.

Appendix 1 – Additional regression equations

Version II of the system of equations (assuming $\Theta_r = (L_r^\alpha B_r^\beta AS_r / P_r)^\zeta$) where fixed assets $AS_r \approx N_{RD,r} x_{RD,r}^\gamma N_{M,r} x_{M,r}^\delta N_{S,r} x_{S,r}^\epsilon$ are used as an indicator of intermediate inputs reads

$$(34a_{II}) \quad d \ln L_n = [C_L + a_L \beta \zeta \ln(\beta / \Psi)] + a_L (\alpha - 1 + \alpha \zeta) \ln L_n + a_L (1 - \alpha + \beta \zeta) \ln B_n \\ + a_L \zeta \ln AS_r - a_L \zeta \ln P_r + b_{L1} \hat{E}_{L_n} + b_{L2} \ln(1 - u)_n + b_{L3} \ln PD_n + \mu_{L_r},$$

$$(34b_{II}) \quad d \ln H_{RDn} = [C_{RD} + a_{RD} \beta \zeta \ln(\beta / \Psi)] - a_{RD} \ln \rho_n + a_{RD} \alpha (1 + \zeta) \ln L_n \\ + a_{RD} (1 - \alpha + \beta \zeta) \ln B_n + a_{RD} \zeta \ln AS_r - a_{RD} \zeta \ln P_n + a_{RD} \phi_{RD1} \ln UR_n \\ + a_{RD} \phi_{RD2} \ln HD_{RDn} + a_{RD} \phi_{RD3} \ln SH_{RDn} + a_{RD} \phi_{RD3} \ln PH_{RDn} \\ + b_{RD1} \hat{E}_{RDn} + b_{RD2} \ln u_n + b_{RD3} \ln PD_n + \mu_{RD_r},$$

$$(34c_{II}) \quad d \ln H_{Mn} = [C_M + a_M \beta \zeta \ln(\beta / \Psi)] - a_M \ln \rho_n + a_M \alpha (1 + \zeta) \ln L_n \\ + a_M (1 - \alpha + \beta \zeta) \ln B_n + a_M \zeta \ln AS_r - a_M \zeta \ln P_n + a_M \phi_{M1} \ln UR_n \\ + a_M \phi_{M2} \ln HD_{Mn} + a_M \phi_{M3} \ln SH_{Mn} + a_M \phi_{M3} \ln PH_{Mn} \\ + b_{M1} \hat{E}_{Mn} + b_{M2} \ln(1 - u)_n + b_{M3} \ln PD_n + \mu_{M_r},$$

$$(34d_{II}) \quad d \ln H_{Sn} = [C_S + a_S \beta \zeta \ln(\beta / \Psi)] - a_S \ln \rho_n + a_S \alpha (1 + \zeta) \ln L_n \\ + a_S (1 - \alpha + \beta \zeta) \ln B_n + a_S \zeta \ln AS_r - a_S \zeta \ln P_n + a_S \phi_{S1} \ln UR_n \\ + a_S \phi_{S2} \ln HD_{Sn} + a_S \phi_{S3} \ln SH_{Sn} + a_S \phi_{S3} \ln PH_{Sn} \\ + b_{S1} \hat{E}_{Sn} + b_{S2} \ln(1 - u)_n + b_{S3} \ln PD_n + \mu_{S_r}.$$

Version III of the system of equations (assuming $\Theta_r = Y_r L_r^{-\alpha} B_r^{-\beta} AS_r^{-1}$) where fixed assets $AS_r = (N_{RD,r} x_{RD,r})^\gamma (N_{M,r} x_{M,r})^\delta (N_{S,r} x_{S,r})^\epsilon$ are used as an indicator of intermediate inputs reads

$$(34a_{III}) \quad d \ln L_n = [C_L - a_L \beta \ln(\beta / \Psi)] - a_L \ln L_n + a_L (1 - \alpha - \beta) \ln B_n + a_L \ln Y_r - a_L \ln AS_r \\ + b_{L1} \hat{E}_{L_n} + b_{L2} \ln(1 - u)_n + b_{L3} \ln PD_n + \mu_{L_r},$$

$$(34b_{III}) \quad d \ln H_{RDn} = [C_{RD} - a_{RD} \beta \ln(\beta / \Psi)] - a_{RD} \ln \rho_n + a_{RD} (1 - \alpha - \beta) \ln B_n \\ + a_{RD} \ln Y_n - a_{RD} \ln AS_r + a_{RD} \phi_{RD1} \ln UR_n + a_{RD} \phi_{RD2} \ln HD_{RDn} \\ + a_{RD} \phi_{RD3} \ln SH_{RDn} + a_{RD} \phi_{RD3} \ln PH_{RDn} \\ + b_{RD1} \hat{E}_{RDn} + b_{RD2} \ln(1 - u)_n + b_{RD3} \ln PD_n + \mu_{RD_r},$$

$$(34c_{III}) \quad d \ln H_{Mn} = [C_M - a_M \beta \ln(\beta / \Psi)] - a_M \ln \rho_n + a_M (1 - \alpha - \beta) \ln B_n \\ + a_M \ln Y_n - a_M \ln AS_r + a_M \phi_{M1} \ln UR_n + a_M \phi_{M2} \ln HD_{Mn} \\ + a_M \phi_{M3} \ln SH_{Mn} + a_M \phi_{M3} \ln PH_{Mn} \\ + b_{M1} \hat{E}_{Mn} + b_{M2} \ln(1 - u)_n + b_{M3} \ln PD_n + \mu_{M_r},$$

$$\begin{aligned}
 d \ln H_{sr} = & [C_s - a_s \beta \ln(\beta / \Psi)] - a_s \ln \rho_r + a_s (1 - \alpha - \beta) \ln B_r \\
 & + a_s \ln Y_r - a_s \ln AS_r + a_s \phi_{s1} \ln UR_r + a_s \phi_{s2} \ln HD_{sr} \\
 & + a_s \phi_{s3} \ln SH_{sr} + a_s \phi_{s3} \ln PH_{sr} \\
 & + b_{s1} \hat{E}_{sr} + b_{s2} \ln(1-u)_r + b_{s3} \ln PD_r + \mu_{sr}.
 \end{aligned}
 \tag{34_{dIII}}$$

Appendix 2 – Descriptive statistics

Table A1 — Descriptive statistics for variables used in the empirical estimations^a

Variable	Mean	Std.Dev.	Sum	Minimum	Maximum
$d \ln L$	-0.09	0.16	-7.05	-0.48	0.26
$d \ln H_{RD}$	0.63	0.31	47.21	-0.28	1.54
$d \ln H_M$	0.22	0.22	16.75	-0.42	0.86
$d \ln H_S$	1.20	0.22	89.73	0.77	1.74
$\ln \rho$	2.11	0.06	158.39	1.93	2.21
$\ln(Y/P)$	10.19	0.16	764.09	9.91	10.59
$\ln Y$	9.64	0.82	722.90	8.37	11.99
$\ln P$	13.27	0.71	994.97	12.13	15.46
$\ln AS$	8.62	0.99	646.79	7.04	11.84
$\ln L$	10.87	0.80	815.05	9.53	12.93
$\ln B$	5.02	0.62	376.16	3.65	6.80
$\ln UR^b$	6.46	0.77	484.65	4.32	8.08
$\ln UR^c$	6.68	0.48	501.06	4.96	7.69
$\ln HD_{RD}$	-1.15	1.21	-86.27	-3.54	1.34
$\ln HD_M$	-0.61	0.96	-45.72	-2.31	1.54
$\ln HD_S$	-1.37	1.04	-102.40	-3.26	1.29
$\ln SH_{RD}$	-0.60	0.25	-44.67	-1.18	-0.02
$\ln SH_M$	-1.06	0.28	-79.57	-1.57	-0.07
$\ln SH_S$	-0.23	0.11	-17.60	-0.63	-0.06
$\ln PH_{RD}$	7.57	0.74	568.06	6.18	9.21
$\ln PH_M$	7.88	0.66	590.95	6.53	9.34
$\ln PH_S$	7.38	0.49	553.37	5.99	8.43
$d \ln E_L$	0.28	0.10	20.80	-0.05	0.47
$d \ln E_{RD}$	0.17	0.10	12.84	-0.13	0.38
$d \ln E_M$	0.17	0.10	13.05	-0.13	0.38
$d \ln E_S$	0.17	0.10	12.45	-0.14	0.37
$\ln(1-u)$	-0.75	0.12	-56.61	-1.04	-0.50
$\ln PD$	5.27	0.61	394.95	4.30	6.92

^a Cross section of 75 West German regions. See text for definitions of the variables. —

^b Calculated assuming a distance decay parameter of 0.05. — ^c Calculated assuming a distance decay parameter of 0.025.

Table A2 — Correlation coefficients for variables used in the empirical estimations^a

	dL	dH _{RD}	dH _M	dH _S	ρ	(Y/P)	Y	P	AS	L	B	UR	UR	HD _{RD}	HD _M	HD _S	SH _{RD}	SH _M	SH _S	PH _{RD}	PH _M	PH _S	dE _L	dE _{RD}	dE _M	dE _S	(1-u)	PD
dL	1 (0)	0.64 (0.00)	0.59 (0.00)	0.36 (0.00)	-0.24 (0.04)	-0.40 (0.00)	-0.52 (0.00)	-0.51 (0.00)	-0.51 (0.00)	-0.49 (0.00)	-0.36 (0.00)	-0.48 (0.00)	-0.37 (0.00)	-0.63 (0.00)	-0.62 (0.00)	-0.66 (0.00)	-0.00 (0.97)	-0.17 (0.14)	0.33 (0.00)	-0.12 (0.32)	-0.13 (0.25)	0.05 (0.65)	0.72 (0.00)	0.87 (0.00)	0.87 (0.00)	0.88 (0.00)	-0.56 (0.00)	-0.67 (0.00)
dH _{RD}	0.64 (0.00)	1 (0)	0.61 (0.00)	0.33 (0.00)	-0.14 (0.24)	-0.31 (0.01)	-0.39 (0.00)	-0.38 (0.00)	-0.36 (0.00)	-0.30 (0.01)	-0.37 (0.00)	-0.23 (0.05)	-0.13 (0.25)	-0.50 (0.00)	-0.41 (0.00)	-0.50 (0.00)	-0.14 (0.23)	-0.15 (0.20)	0.27 (0.02)	0.06 (0.63)	0.05 (0.65)	-0.01 (0.93)	0.60 (0.00)	0.61 (0.00)	0.62 (0.00)	0.63 (0.00)	-0.33 (0.00)	-0.50 (0.00)
dH _M	0.59 (0.00)	0.61 (0.00)	1 (0)	0.31 (0.01)	-0.12 (0.29)	-0.17 (0.15)	-0.32 (0.00)	-0.33 (0.00)	-0.27 (0.02)	-0.29 (0.01)	-0.31 (0.01)	-0.21 (0.07)	-0.20 (0.09)	-0.32 (0.00)	-0.40 (0.00)	-0.44 (0.00)	0.15 (0.20)	-0.11 (0.35)	0.35 (0.00)	-0.03 (0.81)	-0.05 (0.65)	-0.17 (0.16)	0.60 (0.00)	0.63 (0.00)	0.63 (0.00)	0.64 (0.00)	-0.27 (0.02)	-0.48 (0.00)
dH _S	0.36 (0.00)	0.33 (0.00)	0.31 (0.01)	1 (0)	0.12 (0.29)	-0.08 (0.49)	-0.22 (0.06)	-0.23 (0.04)	-0.16 (0.18)	-0.11 (0.34)	-0.32 (0.01)	-0.01 (0.90)	-0.10 (0.92)	-0.10 (0.37)	-0.11 (0.33)	-0.33 (0.00)	0.04 (0.72)	0.09 (0.47)	0.19 (0.11)	0.08 (0.52)	0.05 (0.66)	-0.17 (0.15)	0.63 (0.00)	0.54 (0.00)	0.54 (0.00)	0.53 (0.23)	-0.14 (0.05)	-0.23 (0.05)
ρ	-0.24 (0.04)	-0.14 (0.24)	-0.12 (0.29)	0.12 (0.29)	1 (0)	0.47 (0.00)	0.47 (0.00)	0.44 (0.00)	0.47 (0.00)	0.49 (0.00)	0.30 (0.01)	0.35 (0.00)	0.31 (0.01)	0.56 (0.00)	0.61 (0.00)	0.48 (0.00)	0.11 (0.33)	-0.01 (0.95)	-0.18 (0.13)	0.13 (0.25)	0.18 (0.11)	-0.08 (0.48)	-0.03 (0.78)	-0.11 (0.34)	-0.10 (0.37)	-0.12 (0.29)	0.41 (0.00)	0.53 (0.00)
(Y/P)	-0.40 (0.00)	-0.31 (0.01)	-0.17 (0.15)	-0.08 (0.49)	0.47 (0.00)	1 (0)	0.72 (0.00)	0.60 (0.00)	0.66 (0.00)	0.63 (0.00)	0.49 (0.00)	0.46 (0.00)	0.33 (0.00)	0.80 (0.00)	0.76 (0.00)	0.74 (0.00)	0.26 (0.02)	0.25 (0.03)	-0.53 (0.00)	-0.05 (0.68)	-0.03 (0.83)	-0.22 (0.06)	-0.20 (0.09)	-0.26 (0.02)	-0.26 (0.03)	-0.28 (0.02)	0.77 (0.00)	0.66 (0.00)
Y	-0.52 (0.00)	-0.39 (0.00)	-0.32 (0.00)	-0.22 (0.06)	0.47 (0.00)	0.72 (0)	1 (0.00)	0.99 (0.00)	0.95 (0.00)	0.93 (0.00)	0.89 (0.00)	0.66 (0.00)	0.54 (0.00)	0.78 (0.00)	0.76 (0.00)	0.80 (0.00)	0.09 (0.45)	0.02 (0.86)	-0.54 (0.00)	0.02 (0.84)	0.08 (0.51)	-0.12 (0.29)	-0.33 (0.00)	-0.38 (0.00)	-0.38 (0.00)	-0.40 (0.00)	0.55 (0.00)	0.79 (0.00)
P	-0.51 (0.00)	-0.38 (0.00)	-0.33 (0.00)	-0.23 (0.04)	0.44 (0.00)	0.60 (0.00)	0.99 (0.00)	1 (0)	0.94 (0.00)	0.93 (0.00)	0.91 (0.00)	0.65 (0.00)	0.54 (0.00)	0.72 (0.00)	0.71 (0.00)	0.75 (0.00)	0.04 (0.72)	-0.03 (0.78)	-0.50 (0.00)	0.04 (0.75)	0.09 (0.42)	-0.09 (0.43)	-0.33 (0.00)	-0.38 (0.00)	-0.37 (0.00)	-0.40 (0.00)	0.46 (0.00)	0.75 (0.00)
AS	-0.51 (0.00)	-0.36 (0.00)	-0.27 (0.02)	-0.16 (0.18)	0.47 (0.00)	0.66 (0.00)	0.95 (0.00)	0.94 (0.00)	1 (0)	0.94 (0.00)	0.84 (0.00)	0.67 (0.00)	0.58 (0.00)	0.80 (0.00)	0.77 (0.00)	0.74 (0.00)	0.07 (0.57)	0.05 (0.66)	-0.44 (0.00)	0.12 (0.31)	0.17 (0.14)	-0.06 (0.62)	-0.29 (0.01)	-0.39 (0.00)	-0.39 (0.00)	-0.41 (0.00)	0.53 (0.00)	0.78 (0.00)
L	-0.49 (0.00)	-0.30 (0.01)	-0.29 (0.01)	-0.11 (0.34)	0.49 (0.00)	0.63 (0.00)	0.93 (0.00)	0.93 (0.00)	0.94 (0.00)	1 (0)	0.78 (0.00)	0.62 (0.00)	0.51 (0.00)	0.78 (0.00)	0.79 (0.00)	0.69 (0.00)	0.10 (0.38)	0.04 (0.75)	-0.45 (0.00)	0.12 (0.29)	0.18 (0.13)	-0.15 (0.21)	-0.20 (0.09)	-0.36 (0.00)	-0.35 (0.00)	-0.37 (0.00)	0.61 (0.00)	0.74 (0.00)
B	-0.36 (0.00)	-0.37 (0.00)	-0.31 (0.01)	-0.32 (0.01)	0.30 (0.01)	0.49 (0.00)	0.89 (0.00)	0.91 (0.00)	0.84 (0.00)	0.78 (0)	1 (0.00)	0.50 (0.00)	0.40 (0.00)	0.53 (0.00)	0.51 (0.00)	0.61 (0.01)	0.02 (0.91)	-0.43 (0.86)	-0.04 (0.00)	0.01 (0.70)	-0.01 (0.92)	-0.34 (0.95)	-0.31 (0.00)	-0.31 (0.01)	-0.32 (0.01)	0.29 (0.01)	0.58 (0.00)	
UR ^b	-0.48 (0.00)	-0.23 (0.05)	-0.21 (0.07)	-0.01 (0.90)	0.35 (0.00)	0.46 (0.00)	0.66 (0.00)	0.65 (0.00)	0.67 (0.00)	0.62 (0.00)	0.50 (0.00)	1 (0)	0.89 (0.00)	0.64 (0.00)	0.65 (0.00)	0.66 (0.00)	0.00 (0.99)	-0.00 (0.98)	-0.45 (0.00)	0.41 (0.00)	0.47 (0.00)	0.15 (0.21)	-0.27 (0.02)	-0.33 (0.00)	-0.33 (0.00)	-0.35 (0.00)	0.43 (0.00)	0.67 (0.00)
UR ^c	-0.37 (0.00)	-0.13 (0.25)	-0.20 (0.09)	-0.01 (0.92)	0.31 (0.01)	0.33 (0.00)	0.54 (0.00)	0.54 (0.00)	0.58 (0.00)	0.51 (0.00)	0.40 (0.00)	0.89 (0.00)	1 (0)	0.50 (0.00)	0.54 (0.00)	0.54 (0.00)	-0.18 (0.12)	-0.10 (0.41)	-0.33 (0.00)	0.57 (0.00)	0.63 (0.00)	0.45 (0.05)	-0.22 (0.02)	-0.26 (0.02)	-0.26 (0.02)	-0.28 (0.02)	0.26 (0.02)	0.58 (0.00)
HD _{RD}	-0.63 (0.00)	-0.50 (0.00)	-0.32 (0.00)	-0.10 (0.37)	0.56 (0.00)	0.80 (0.00)	0.78 (0.00)	0.72 (0.00)	0.80 (0.00)	0.78 (0.00)	0.53 (0.00)	0.64 (0.00)	0.50 (0)	1 (0.00)	0.95 (0.00)	0.87 (0.00)	0.25 (0.03)	0.19 (0.11)	-0.50 (0.00)	0.10 (0.38)	0.16 (0.17)	-0.10 (0.41)	-0.37 (0.00)	-0.50 (0.00)	-0.49 (0.00)	-0.51 (0.00)	0.76 (0.00)	0.89 (0.00)
HD _M	-0.62 (0.00)	-0.41 (0.00)	-0.40 (0.00)	-0.11 (0.33)	0.61 (0.00)	0.76 (0.00)	0.76 (0.00)	0.71 (0.00)	0.77 (0.00)	0.79 (0.00)	0.51 (0.00)	0.65 (0.00)	0.54 (0.00)	0.95 (0.00)	1 (0)	0.89 (0.00)	0.13 (0.28)	0.16 (0.17)	-0.49 (0.00)	0.15 (0.19)	0.22 (0.06)	-0.07 (0.55)	-0.37 (0.00)	-0.51 (0.00)	-0.50 (0.00)	-0.53 (0.00)	0.78 (0.00)	0.93 (0.00)

Table A2 continued

	dL	dH_{RD}	dH_M	dH_S	ρ	(Y/P)	Y	P	AS	L	B	UR	UR	HD_{RD}	HD_M	HD_S	SH_{RD}	SH_M	SH_S	PH_{RD}	PH_M	PH_S	dE_L	dE_{RD}	dE_M	dE_S	(1-u)	PD	
HD_S	-0.66 (0.00)	-0.50 (0.00)	-0.44 (0.00)	-0.33 (0.00)	0.48 (0.00)	0.74 (0.00)	0.80 (0.00)	0.75 (0.00)	0.74 (0.00)	0.69 (0.00)	0.61 (0.00)	0.66 (0.00)	0.54 (0.00)	0.87 (0.00)	0.89 (0.00)	1 (0)	0.06 (0.62)	0.04 (0.71)	-0.58 (0.00)	0.06 (0.59)	0.13 (0.27)	-0.02 (0.89)	-0.55 (0.00)	-0.57 (0.00)	-0.56 (0.00)	-0.59 (0.00)	0.69 (0.00)	0.95 (0.00)	
SH_{RD}	-0.00 (0.97)	-0.14 (0.23)	0.15 (0.20)	0.04 (0.72)	0.11 (0.33)	0.26 (0.02)	0.09 (0.45)	0.04 (0.72)	0.07 (0.57)	0.10 (0.38)	0.01 (0.91)	0.00 (0.99)	-0.18 (0.12)	0.25 (0.03)	0.13 (0.28)	0.06 (0.62)	1 (0)	0.53 (0.00)	-0.13 (0.26)	-0.16 (0.16)	-0.18 (0.13)	-0.24 (0.04)	0.07 (0.56)	0.04 (0.75)	0.04 (0.75)	0.04 (0.73)	0.04 (0.73)	0.26 (0.03)	0.02 (0.84)
SH_M	-0.17 (0.14)	-0.15 (0.20)	-0.11 (0.35)	0.09 (0.47)	-0.01 (0.95)	0.25 (0.03)	0.02 (0.86)	-0.03 (0.78)	0.05 (0.66)	0.04 (0.75)	0.02 (0.86)	-0.00 (0.98)	-0.10 (0.41)	0.19 (0.11)	0.16 (0.17)	0.04 (0.71)	0.53 (0.00)	1 (0)	-0.04 (0.75)	-0.13 (0.26)	-0.13 (0.27)	-0.14 (0.25)	-0.04 (0.75)	-0.13 (0.28)	-0.12 (0.29)	-0.13 (0.28)	0.21 (0.08)	0.01 (0.91)	
SH_S	0.33 (0.00)	0.27 (0.02)	0.35 (0.00)	0.19 (0.11)	-0.18 (0.13)	-0.53 (0.00)	-0.54 (0.00)	-0.50 (0.00)	-0.44 (0.00)	-0.45 (0.00)	-0.43 (0.00)	-0.45 (0.00)	-0.33 (0.00)	-0.50 (0.00)	-0.49 (0.00)	-0.58 (0.00)	-0.13 (0.26)	-0.04 (0.75)	1 (0)	0.14 (0.22)	0.11 (0.36)	0.13 (0.29)	0.30 (0.01)	0.28 (0.02)	0.27 (0.02)	0.29 (0.01)	-0.49 (0.00)	-0.50 (0.00)	
PH_{RD}	-0.12 (0.32)	0.06 (0.63)	-0.03 (0.81)	0.08 (0.52)	0.13 (0.25)	-0.05 (0.68)	0.02 (0.84)	0.04 (0.75)	0.12 (0.31)	-0.04 (0.29)	0.41 (0.70)	0.57 (0.00)	0.10 (0.38)	0.15 (0.19)	0.06 (0.59)	-0.16 (0.16)	-0.13 (0.26)	0.14 (0.22)	1 (0)	0.97 (0.00)	0.57 (0.00)	-0.00 (0.98)	-0.11 (0.34)	-0.11 (0.34)	-0.11 (0.36)	-0.11 (0.36)	0.01 (0.92)	0.18 (0.13)	
PH_M	-0.13 (0.25)	0.05 (0.65)	-0.05 (0.65)	0.05 (0.66)	0.18 (0.11)	-0.03 (0.83)	0.08 (0.51)	0.09 (0.42)	0.17 (0.14)	0.18 (0.13)	0.01 (0.92)	0.47 (0.00)	0.63 (0.00)	0.16 (0.17)	0.22 (0.06)	0.13 (0.27)	-0.18 (0.13)	-0.13 (0.27)	0.11 (0.36)	0.97 (0.00)	1 (0)	0.60 (0.00)	-0.01 (0.92)	-0.12 (0.30)	-0.12 (0.31)	-0.12 (0.31)	0.04 (0.70)	0.25 (0.03)	
PH_S	0.05 (0.65)	-0.01 (0.93)	-0.17 (0.16)	-0.17 (0.15)	-0.08 (0.48)	-0.22 (0.06)	-0.12 (0.29)	-0.09 (0.43)	-0.06 (0.62)	-0.15 (0.21)	-0.01 (0.95)	0.15 (0.21)	0.45 (0.00)	-0.10 (0.41)	-0.07 (0.55)	-0.02 (0.89)	-0.24 (0.04)	-0.14 (0.25)	0.13 (0.29)	0.57 (0.00)	0.60 (0.00)	1 (0)	-0.19 (0.11)	-0.11 (0.33)	-0.12 (0.32)	-0.11 (0.36)	-0.26 (0.02)	0.07 (0.58)	
dE_L	0.72 (0.00)	0.60 (0.00)	0.60 (0.00)	0.63 (0.00)	-0.03 (0.78)	-0.20 (0.09)	-0.33 (0.00)	-0.33 (0.00)	-0.29 (0.01)	-0.20 (0.09)	-0.34 (0.00)	-0.27 (0.02)	-0.22 (0.05)	-0.37 (0.00)	-0.37 (0.00)	-0.55 (0.00)	0.07 (0.56)	-0.04 (0.75)	0.30 (0.01)	-0.00 (0.98)	-0.01 (0.92)	-0.19 (0.11)	1 (0)	0.92 (0.00)	0.92 (0.00)	0.93 (0.00)	-0.32 (0.00)	-0.53 (0.00)	
dE_{RD}	0.87 (0.00)	0.61 (0.00)	0.63 (0.00)	0.54 (0.34)	-0.11 (0.02)	-0.26 (0.00)	-0.38 (0.00)	-0.38 (0.00)	-0.39 (0.00)	-0.36 (0.01)	-0.31 (0.00)	-0.33 (0.00)	-0.26 (0.02)	-0.50 (0.00)	-0.51 (0.00)	-0.57 (0.00)	0.04 (0.75)	-0.13 (0.28)	0.28 (0.02)	-0.11 (0.34)	-0.12 (0.30)	-0.11 (0.33)	0.92 (0.00)	1 (0)	1.00 (0.00)	1.00 (0.00)	-0.49 (0.00)	-0.60 (0.00)	
dE_M	0.87 (0.00)	0.62 (0.00)	0.63 (0.00)	0.54 (0.00)	-0.10 (0.37)	-0.26 (0.03)	-0.38 (0.00)	-0.37 (0.00)	-0.39 (0.00)	-0.35 (0.01)	-0.31 (0.00)	-0.33 (0.02)	-0.26 (0.00)	-0.49 (0.00)	-0.50 (0.00)	-0.56 (0.00)	0.04 (0.75)	-0.12 (0.29)	0.27 (0.02)	-0.11 (0.34)	-0.12 (0.31)	-0.12 (0.32)	0.92 (0.00)	1 (0)	1.00 (0.00)	-0.49 (0.00)	-0.59 (0.00)	-0.49 (0.00)	-0.59 (0.00)
dE_S	0.88 (0.00)	0.63 (0.00)	0.64 (0.00)	0.53 (0.00)	-0.12 (0.29)	-0.28 (0.02)	-0.40 (0.00)	-0.40 (0.00)	-0.41 (0.00)	-0.37 (0.00)	-0.32 (0.01)	-0.35 (0.00)	-0.28 (0.02)	-0.51 (0.00)	-0.53 (0.00)	-0.59 (0.00)	0.04 (0.73)	-0.13 (0.28)	0.29 (0.01)	-0.11 (0.36)	-0.12 (0.31)	-0.11 (0.36)	0.93 (0.00)	1.00 (0.00)	1.00 (0.00)	-0.50 (0.00)	-0.62 (0.00)	-0.62 (0.00)	
(1-u)	-0.56 (0.00)	-0.33 (0.02)	-0.27 (0.23)	-0.14 (0.00)	0.41 (0.00)	0.77 (0.00)	0.55 (0.00)	0.46 (0.00)	0.53 (0.00)	0.61 (0.00)	0.29 (0.01)	0.43 (0.00)	0.26 (0.02)	0.76 (0.00)	0.78 (0.00)	0.69 (0.00)	0.26 (0.03)	0.21 (0.08)	-0.49 (0.92)	0.01 (0.70)	0.04 (0.00)	-0.26 (0.02)	-0.32 (0.00)	-0.49 (0.00)	-0.50 (0.00)	1 (0)	0.64 (0.00)		
PD	-0.67 (0.00)	-0.50 (0.00)	-0.48 (0.00)	-0.23 (0.05)	0.53 (0.00)	0.66 (0.00)	0.79 (0.00)	0.75 (0.00)	0.78 (0.00)	0.74 (0.00)	0.58 (0.00)	0.67 (0.00)	0.58 (0.00)	0.89 (0.00)	0.93 (0.00)	0.95 (0.00)	0.02 (0.84)	0.01 (0.91)	-0.50 (0.00)	0.18 (0.13)	0.25 (0.03)	0.07 (0.58)	-0.53 (0.00)	-0.60 (0.00)	-0.59 (0.00)	-0.62 (0.00)	0.64 (0.00)	1 (0)	

^a Pearson correlation coefficients across 75 West German regions. See text for definitions of the variables. All variables are in logs, resp. are log-differences (d). —

^b Calculated assuming a the distance decay parameter of 0.05. — ^c Calculated assuming a the distance decay parameter of 0.025.

Appendix 3 – Summary of regression results for Versions II and III

Table A3 — Regression results for technical R&D employment, equations (34b_{I-III})^a

Equation	(34b _I)		(34b _{II})		(34b _{III})	
Method	ML		ML		ML	
Explanatory variables	parm	prob ^b	parm	prob ^b	parm	prob ^b
C	-6.05	0.09 *	-0.71	0.59	-0.45	0.71
lnρ	0.11	0.81	0.17	0.72	0.17	0.74
TFP:						
lnY/P	0.42	0.16	—		—	
lnY	—		—		0.10	0.45
lnP	—		-0.09	0.61	—	
lnAS	—		0.15	0.10 *	0.23	0.01 **
R&D productivity:						
lnL	0.36	0.00 **	0.27	0.03 **	—	
lnB	-0.38	0.00 **	-0.35	0.00 **	-0.37	0.00 **
lnUR	0.08	0.07 *	0.07	0.12	0.04	0.39
lnHD	-0.22	0.00 **	-0.23	0.00 **	-0.23	0.00 **
lnSH	-0.07	0.49	-0.05	0.61	-0.05	0.60
lnPH	-0.02	0.61	-0.03	0.48	0.01	0.82
additional determinants of migration:						
dlnE ^c	1.41	0.00**	1.65	0.00 **	1.65	0.00 **
ln(1-u)	0.23	0.57	0.70	0.04 **	0.95	0.00 **
lnPD	-0.03	0.75	-0.1	0.93	-0.03	0.81
spatial lag	-0.77	0.00 **	-0.80	0.00 **	-0.59	0.02 **
No. of Dummies	1		1		1	
R ² _{adj.} (pseudo- R ²)	(0.64)		(0.64)		(0.62)	
lnL	20.82		21.30		18.96	
SSR	2.42		2.38		2.58	
F	.		.		.	
Homoscedasticity ^d	o		o		o	
Parameter stability ^d	o		A≠P ^e		P≠R ^e	
No autocorrelation ^d	o		o		o	

^a Cross-section ML regressions including spatially lagged endogenous variables for 75 West German regions 1976–1994; dependent variable: $d\ln H_{RD}$. Definitions of the variables are given in the text. — ^b Error probability of rejecting $H_0: \text{parameter}=0$; two-tailed test. *: Different from zero with a probability of at least 90 per cent; **: Different from zero with a probability of at least 95 per cent. — ^c Growth rate of regional employment excluding workers covered by the dependent variable. — ^d o: H_0 of homoscedasticity, parameter stability, or no spatial autocorrelation is not rejected by all tests at the 95% level. For details of the tests, see text. — ^e A≠P (P≠R): Parameters differ significantly between agglomerations and peripheral (poor and rich) regions.

Source: Own estimations.

Table A4 — Regression results for management employment, equations (34c_{I-III})^a

Equation	(34c _I)		(34c _{II})		(34c _{III})	
Method	OLS		OLS		OLS	
Explanatory variables	parm	prob ^b	parm	prob ^b	parm	prob ^b
C	-3.00	0.25	-0.82	0.52	-1.34	0.20
lnp	0.43	0.29	0.35	0.35	0.40	0.28
TFP:						
lnY/P	0.13	0.53	—		—	
lnY	—		—		-0.03	0.71
lnP	—		-0.01	0.92	—	
lnAS	—		0.15	0.01 **	0.13	0.02 **
R&D productivity:						
lnL	0.06	0.30	-0.05	0.52	—	
lnB	-0.10	0.11	-0.13	0.07 *	-0.14	0.05 *
lnUR	0.04	0.20	0.03	0.47	0.03	0.33
lnHD	-0.17	0.08 *	-0.19	0.05 **	-0.21	0.01 **
lnSH	-0.01	0.89	-0.04	0.58	0.03	0.69
lnPH	-0.01	0.78	-0.01	0.73	-0.02	0.69
additional determinants of migration:						
dlnE ^c	1.27	0.00 **	1.29	0.00 **	1.31	0.00 **
ln(1- μ)	0.23	0.50	0.54	0.04 **	0.54	0.04 **
lnPD	0.08	0.51	0.07	0.57	0.11	0.30
spatial lag	—		—		—	
No. of Dummies	3		4		4	
R ² _{adj} (pseudo- R ²)	0.61		0.67		0.67	
lnL						
SSR	1.15		0.93		0.94	
F	9.79	0.00 **	11.14	0.00 **	11.97	0.00 **
Homoscedasticity ^d	o		o		o	
Parameter stability ^d	o		o		o	
No autocorrelation ^d	o		o		o	

^a Cross-section OLS regressions for 75 West German regions 1976–1994; dependent variable: $d\ln H_M$. Definitions of the variables are given in the text. — ^b Error probability of rejecting H_0 : parameter=0; two-tailed test. *: Different from zero with a probability of at least 90 per cent; **: Different from zero with a probability of at least 95 per cent. — ^c Growth rate of regional employment excluding workers covered by the dependent variable. — ^d o: H_0 of homoscedasticity, parameter stability, or no spatial autocorrelation is not rejected by all tests at the 95% level. For details of the tests, see text.

Source: Own estimations.

Table A5 — Regression results for producer services employment, equations (34d_{I-III})^a

Equation	(34d _I) ^b		(34d _{II})		(34d _{III})	
Method	ML		ML		OLS	
Explanatory variables	parm	prob ^c	parm	prob ^c	parm	prob ^c
C	-4.92	0.01 **	-2.90	0.01 **	-2.28	0.02 **
lnp	0.31	0.31	0.35	0.26	0.36	0.32
TFP:						
lnY/P	0.27	0.11	—	—	—	—
lnY	—	—	—	—	0.07	0.50
lnP	—	—	0.16	0.24	—	—
lnAS	—	—	-4E-3	0.93	-0.08	0.19
R&D productivity:						
lnL	-0.14	0.02 **	-0.24	0.03 **	—	—
lnB	0.07	0.21	0.03	0.67	-0.02	0.80
lnUR	0.18	0.00 **	0.17	0.00 **	0.17	0.00 **
lnHD	-0.41	0.00 **	-0.44	0.00 **	-0.34	0.00 **
lnSH	-0.04	0.78	-0.01	0.96	-0.03	0.87
lnPH	-0.14	0.00 **	-0.13	0.00 **	-0.13	0.01 **
additional determinants of migration:						
dlnE ^d	0.95	0.00 **	1.18	0.00 **	1.13	0.00 **
ln(1- <i>u</i>)	0.40	0.15	0.87	0.01 **	0.41	0.07 *
lnPD	0.56	0.00 **	0.60	0.00 **	0.45	0.00 **
spatial lag	0.24	0.03 **	0.16	0.05 *	—	—
No. of Dummies	2		2		2	
R ² _{adj.} (pseudo- R ²)	(0.73)		(0.72)		0.64	
ln L	57.40		56.62			
SSR	0.94		0.96		1.08	
F					11.86	0.00 **
Homoscedasticity ^e	0		0		0	
Parameter stability ^e	(N≠S) ^f		(N≠S) ^f		(N≠S) ^f	
No autocorrelation ^e	0		0		(Moran's I) ^g	

^a Cross-section OLS regressions for 75 West German regions 1976–1994; dependent variable: $d\ln H_s$. Definitions of the variables are given in the text. — ^b ML estimation with spatially lagged dependent variable. — ^c Error probability of rejecting $H_0: \text{parameter}=0$; two-tailed test. *: Different from zero with a probability of at least 90 per cent; **: Different from zero with a probability of at least 95 per cent. — ^d Growth rate of regional employment excluding workers covered by the dependent variable. — ^e 0: H_0 of homoscedasticity, parameter stability, or no spatial autocorrelation is not rejected by all tests at the 95% level. For details of the tests, see text. — ^f N≠S: Parameters differ significantly between northern and southern German regions. — ^g H_0 of no spatial autocorrelation is rejected at the 95% level by various Moran's I-test statistics for different spatial weights matrices.

Source: Own estimations.

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