On the predictability of knowledge formation: the tortuous link between regional specialisation, trade and development

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Abstract

The paper examines the relation between industrial mix and regional productivity growth. For this purpose, a dynamic model of the open economy with differentiated sectoral knowledge formation and incomplete interregional knowledge diffusion is constructed. The theoretical framework is first used to show the consequences of increasing globalisation on regional growth. It is then applied to German regional data in order to investigate whether there is evidence of generally specified patterns of knowledge formation. It emerges that some causal relationships are robust for the case of German regions but cannot be exploited by economic policy in general.

Keywords : Regional growth, sectoral specialisation, knowledge formation, German regions.

JEL-Classification : O18, R11, C21

1. Introduction

Is it possible that regional economies grow or converge to a steady state independent of their sectoral structure? At first sight, this seems to be counterintuitive. Why should we assume the dynamics of a financial centre to be the same as the dynamics of a rural hinterland? But when we look at recent theoretical and empirical literature, the impression prevails that the industry mix is not of primary importance for the determination of growth. In particular, most contributions in the broad field of convergence literature rely on one-sector models. This means assuming that the different sectors are equal or at least very similar regarding growth mechanics. For instance, in Mankiw/Romer/Weil (1992), Barro/Sala-i-Martin (1992), and Barro/Mankiw/Sala-i-Martin (1995), the aggregate national or regional economies uniformly converge towards their long-term equilibrium as a consequence of decreasing returns to aggregate capital. Dollar/Wolff (1993) additionally consider the possibility of technology convergence and explicitly focus on the disaggregate level. Based on their empirical studies for different OECD countries, they conclude that shifts in the industrial mix played no role in the convergence process. However, it emerges from their study that different countries had their strongest convergence in different industries, which means that productivity growth can be successful in very different kinds of regional specialisation. Using different data and methodology for the same countries, Bernard/Jones (1996) argue that convergence of aggregate productivity may mask substantial differences at the sectoral level. According to their results, services were responsible for convergence while manufacturing showed little evidence in this respect.

Summarising the results of these contributions, the dynamic impact of the sectoral mix of an economy, if existent, seems to be difficult to predict. The effects are thus viewed as uncertain both in importance and direction. This contrasts with the political debate, where the assumption of specific ”key” industries – most often called ”high-tech sectors” – being important for growth is pervasive. It also differs from an important strand of literature in growth theory, where a relationship between the sectoral structure of the economy and development is assumed. In various well-known multi-sector endogenous growth models, the growth process depends on spillovers stemming from specific sectors of an economy. For instance, Romer (1990) and Grossman/Helpman (1991) assume positive knowledge spillovers from research and development (R&D), which is the sector that drives the growth process. In these models, knowledge formation and the growth rate are predictable, depending directly on the sectoral structure, i.e. the size of the R&D-sector.[1] The multi-sector approach allows us to study growth and trade simultaneously, which is important especially for regions. Regional economies have become increasingly integrated in larger economic areas, even more than national economies. When analysing the effects of free interregional trade in this multi-sector framework, one has to derive what happens to the R&D-sector. A larger economic area produces more spillovers, which fosters productivity in R&D (scale effect). But on the other hand, increasing trade alters the regional specialisation, which might have the opposite effect on R&D (resource reallocation effect). Reallocation is the consequence of regional specialisation according to comparative advantage [see Bretschger (1999a) for a survey]. The same principle of comparative advantage governs the direction of trade flows; it ultimately relies on different sectoral production techniques. But is it plausible, then, that something is crucial for regional trade while the same thing is not of importance for regional dynamics? Three points can be considered here. *First*, resource reallocation caused by trade could be small in practice so that it becomes negligible in theory. However, this would be equal to saying that the major part of trade theory addresses a largely irrelevant topic. *Second*, all sector-specific growth factors, i.e. all types of spillovers, could be interregional or even international in scope. In the case of knowledge, this is not really convincing. And even if it were the case, it is still possible that trade lowers the growth rate through resource reallocation between sectors, see Grossman/Helpman (1991, ch.5) and Bretschger (1997). *Third*, knowledge externalities could be nonexistent or not relevant for growth. This is certainly the most controversial issue. But the long tradition of contributions to knowledge formation and diffusion in theory, see e.g. Marshall (1920), Arrow (1962), Griliches (1992), Jaffe et al. (1995), Ben-David/Loewy (1996), Keller (1996) and the numerous applications in new growth theory, tend to lead the reader to another conclusion. As a consequence, it is appropriate to infer that the industry mix should not be viewed as unimportant for the growth process from a priori reasoning. But, and this is a major point, it may still be that one of the main messages of Dollar/Wolff (1993) remains valid: that changing the industry mix might be a difficult if not an inappropriate target of economic policy, at least when interpreted in the sense of the general ”key-sector” assumption.

This paper starts out from the assumption that regional growth depends on endogenous knowledge formation. While a three-sector structure similar to Grossman/Helpman (1991, ch. 5),

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[1] In older growth theory, the so-called ”von Neumann models” also assume linear relations between inputs and outputs as well as sector-specific growth rates. But there, sectoral resource allocation is not the result of decisions of optimising agents as is the case in endogenous growth theory.

Englmann/Walz (1995) and Bretschger (1997) is used, knowledge formation is not exclusively dependent on a specific sector of the economy. All sectors are assumed to contribute to the knowledge build-up in a certain manner. At the same time, the model set-up with a single growth-driving sector (being R&D) where knowledge is a crucial input is maintained. By broadening the spillover-concept and by considering trade relations, the model is able to address the relationship between industry mix and growth in a more realistic manner compared to the key sector approach and the uniform convergence model. It thus aims to address the different empirical findings without neglecting the achievements of advanced theoretical growth models. More specifically, the analysis is appropriate to address the connection between the size of the home market in manufacturing and the efficiency of research (home market effect). Following the arguments raised in public debate, the home market is assumed to be equal to the market of the considered region in the following. This is an interesting issue which is not considered in detail in recent literature. For many firms, the existence of a large home market enables the research teams to have immediate and detailed feedback from customers (which are firms in this case). Intensive knowledge exchange between firms and research definitely increases the productivity in the research labs. By the same token, a small home market may become a serious obstacle for successful R&D. It is due to the lack of a large home market, among other, that the research sectors of small countries are under permanent threat. A too small home market can lead to the relocation of innovative activities to larger countries, which has, for example, happened in the case of the Swiss chemical industry.

Thus the basic idea of the present paper is that knowledge formation and growth are systematically influenced by the sectoral structure of the economy, but that the connection is not a simple one-to-one relation. The dynamic impact of the industry mix results as the outcome of a simultaneous model; the relationship is referred to as the ”tortuous link” above. The paper contains both a theoretical and an empirical part. The theoretical framework is first used to reconsider some recent results on trade and growth. Massive improvements in transportation technologies have lead to large increases in interregional trade relations and to specific patterns of regional specialisation. It will turn out in our model that the impact of trade depends both on the size of the home economy and on the labour division between regional economies. Whether trade is advantageous for a region depends not only on the factor supplies of the trading partners, but also on the size of home market in manufacturing. If the home market is too small, i.e. does not reach a critical size, some of the results of existing literature will be reversed. This paper shows that a lagging region with abundant unskilled labour may first have to concentrate on building up a large enough home market before aiming at pushing the R&D-sector. The model will thus lead to the conclusion that the policy of targeting ”key-sectors” can, under certain conditions, have effects that are exactly the opposite from what would be generally expected in public debate. By taking into account the size of the home market, the results contribute to the current discussion of the so-called “scale effects” in the theory of economic growth. The hypothesis of a sector-specific learning-by doing is then confronted with data on German regions. For the empirical estimation, the content of the theoretical model is expressed in a straightforward manner to make optimal use of the available data. Data on 327 German regions (”Städte und Landkreise”) are available for the time period of 1980–1994; they are, in general, of good quality. Related growth studies on German regions are Herz/Röger (1995), Büttner (1997), Keller (1997) and Bretschger/ Schmidt (1999).

The remainder of the paper is organised as follows. In section 2, the theoretical three-sector model of the regional economy with economy-wide knowledge spillovers is constructed. Section 3 regards the effects of trade on regional growth. Here, the cases of perfect and of incomplete interregional knowledge transmission will be distinguished. Section 4 presents the empirical model and describes the data on German regions used for estimation. In section 5, the empirical results are presented. Section 6 concludes.

2. The Model

We start from the assumption that regional knowledge is built up by positive knowledge spillovers from the activities in all sectors of the economy. We regard three sectors with the production of traditional goods *Z*, high-tech goods *Y*, and additional designs $\dot{n}$. In the following, *Y*- and *Z*-production are, for simplicity, referred to as ”manufacturing”[2] and the design-sector as ”R&D”. Each design contains the know-how for the production of one intermediate good x; intermediates are differentiated goods used for *Y*-production. Long-term growth is driven by a continuous expansion-in-varieties of x-goods, see Romer (1990), Grossman/Helpman (1991) and Bretschger (1997) for additional explanations in a similar framework. With n different intermediates of equal size x, the aggregate input in *Y* production is denoted by $X = n \cdot x$. The variables *X* and *Z* are referred to when speaking of the size of the home market. Using the variable k for total knowledge and adopting a multiplicative specification for knowledge formation yields:

$$k = n^{g} \cdot X^{h} \cdot Z^{y} \qquad (1)$$

[2] Of course, services are also meant to be summarised under *Y* and *Z*, see the empirical part in section 5.

In earlier contributions, the assumptions $g = 1, h = y = 0$ were used, see Romer (1990) and Grossman/Helpman (1991), or it was argued that $g < 1, h = y = 0$, see Jones (1995). In the present model, all sectors of the economy contribute to the growth-relevant learning by doing, i.e. $h, y > 0$. One can postulate the spillovers from R&D being more intensive than those from manufacturing but this is not necessary to solve the model. Following the endogenous growth assumption for convenience, however, we will assume that $g = 1$ below. Knowledge is a productive input in the production of new designs. Skilled labour S and unskilled labour L are the two other inputs. So, the output of designs becomes:

$$\dot{n} = f(S_g, L_g) \cdot k \tag{2}$$

where f is a function with neo-classical properties and the subscript g denotes the share of labour being employed in the dynamic sector. Inserting (1) into (2) and using $g = 1$, the growth rate of designs g becomes:

$$\frac{\dot{n}}{n} \equiv g = f(S_g, L_g) \cdot X^h \cdot Z^y \tag{3}$$

The fixed labour resources of a region can be used either for R&D or for manufacturing. But according to (3), both a large labour input in the research sector and a large manufacturing output contribute to a high growth rate of designs. Thus, looking at the consequences of sectoral factor allocation more closely, the main difference of this model to existing literature becomes clear. In the models mentioned in section 1, less labour input into R&D unambiguously means less knowledge formation and a lower growth rate. Here, one sees from (3) that the strict trade-off between manufacturing and growth is no longer valid under all conditions. If labour is released from R&D to manufacturing, it might be that the resulting effect on the growth rate is positive due to the home market effect. Whether this outcome materialises depends on the parameters used in (3). More specifically, one has to compare the marginal effect of manufacturing and the marginal effect of R&D on knowledge formation. The effect of aggregate labour input into R&D on knowledge formation is linear, whereas the effect of labour input in the manufacturing sectors yields decreasing, constant or increasing returns to knowledge formation. Accordingly, with a given labour input in R&D, a reallocation between the two manufacturing sectors can increase or decrease growth depending on the size of the parameters X, Z, h and y.

To determine the labour input in R&D in (3), the labour market equilibria and the capital market equilibrium have to be determined. For this, we first introduce prices for the three sectors.

Homogeneous goods Z are produced under perfect competition with the inputs of unskilled labour L and skilled labour S, so that unit cost c_Z corresponds to the price p_Z according to:

$$p_Z = c_Z = \sum_k a_{kZ} \cdot w_k \qquad (k = L, S) \tag{4}$$

The a-parameters are unit labour input factors, the ws stand for the wages of the two inputs L and S, which are used for the corresponding subscripts. In addition, the region is assumed to produce n differentiated goods under monopolistic competition with equal quantity x. Variable costs in x-production are the labour costs for skilled and unskilled labour. So, marginal costs c_x in x-production are given by:

$$c_x = \sum_k a_{kx} \cdot w_k \qquad (k = L, S) \tag{5}$$

For demand structure, we adopt the Dixit/Stiglitz (1977) specification of constant elasticity of substitution between differentiated goods. With this approach, the price of an x-good is equal to marginal costs (5) augmented by a constant mark-up $1/b$, according to:

$$p_x = c_x / b \qquad 0 < b < 1 \tag{6}$$

Let c_g denote the labour cost of generating one new design. To obtain the unit production cost in the research lab, c_g is divided by the free input of public knowledge k, so that, under perfect competition in the R&D-sector, the market price of a design p_g becomes:

$$p_g = c_g(w_S, w_L) / k \tag{7}$$

Next, the capital market equilibrium determining the return on R&D can be derived. We use E for expenditures, i.e. $E_x = X \cdot p_x$, $E_Z = Z \cdot p_Z$ and $E = E_x + E_Z$. To facilitate calculation, prices are normalised so that total expenditures are equal to unity at any point in time, i.e. $E_x + E_Z = 1$. Because it is assumed that the assembly of differentiated intermediates to the Y-good does not require additional input factors, expenditures E_x are equal to expenditures for Y-goods. Aggregate profits p are, following (6):

$$p = (1 - b) \cdot E_x \tag{8}$$

R&D thus receives a constant share of the sales of intermediates or of *Y*-goods, respectively. Profits are used to cover the expenses for fixed costs in the production of x-goods which consist of payments for the designs. Each x-firm has to acquire one design as an up-front investment before it can start production. Accordingly, we obtain for the profit per x-firm p_j:

$$p_j = (1 - b) \cdot E_x / n \tag{9}$$

Households maximise a lifetime utility function, which is additively separable in time and contains logarithmic intratemporal subutilities of the Cobb-Douglas type. From this utility function we get constant expenditure shares for *Z*- and *Y*-goods, respectively. According to the well-known Keynes-Ramsey rule and assuming a logarithmic utility function (as well as a depreciation rate and population growth rate of zero), growth of consumption is equal to the difference between the marginal product of capital and the discount rate. Applying this rule to the present type of R&D-model, the growth rate of designs becomes equal to the difference between the return on R&D-investments and the discount rate r, see Grossman/Helpman (1991, ch.3). The corresponding equation (10) below is called capital market equilibrium, because the investors' return on R&D-investments is the same as the return on a bond in equilibrium. The return on R&D is equal to the quotient of profits per x-firm and the price of a design, i.e. p_j / p_g. To calculate this quotient, we combine (9) and (7) and use (1); then, the growth rate of designs becomes:

$$g = \frac{(1-b) \cdot E_x}{c_g} \cdot X^h \cdot Z^y - r \tag{10}$$

In (10), all variables on the r.h.s. are constant in equilibrium, so that the solution of the model describes a balanced growth path. In particular, X is constant as the basic growth mechanism is an expansion-in-varieties in *Y*-production (with each increase in n being exactly compensated by a decrease in x). If L stands for the supply of unskilled labour and S for the input of skilled labour, the equilibrium in labour markets is given by:

$$\begin{bmatrix} a_{LZ}(w_S, w_L) \\ a_{SZ}(w_S, w_L) \end{bmatrix} \cdot Z + \begin{bmatrix} a_{Lx}(w_S, w_L) \\ a_{Sx}(w_S, w_L) \end{bmatrix} \cdot X + \begin{bmatrix} a_{Lg}(w_S, w_L) \\ a_{Sg}(w_S, w_L) \end{bmatrix} \cdot \left(g \cdot X^{-h} \cdot Z^{-y}\right) = \begin{bmatrix} L \\ S \end{bmatrix} \tag{11}$$

The R&D sector is assumed to be the most skilled labour intensive sector, the sector of traditional goods is the relatively most unskilled labour intensive sector and differentiated intermediate goods lie in between in this respect. As n denotes the number of invented designs and also the number of differentiated x-goods, the relation between the growth rate of designs and the growth rate of high-tech consumer goods is constant. Due to the Cobb-Douglas utility function, the relative size of consumer sectors is also constant in equilibrium. The larger the spillovers from manufacturing are, the higher the equilibrium growth rate becomes. Resource reallocation between sectors means fewer spillovers from one sector but more spillovers from another sector; the result for growth depends on the parameters of the model.

3. Trade, regional specialisation and growth

To solve the model, the price-cost-relations (4) and (6) and the definition of the expenditures are used to eliminate goods quantities *X* and *Z* from (10) and (11). Then, the capital market equilibrium (10) and the labour markets in (11) form a system for three unknown variables, which are the two wage rates and the growth rate of designs. With the help of this system, the consequences of trade on growth can be calculated. To do so, one has to totally differentiate the three equations (see appendix for additional explanations). Expenditures E, E_x, E_Z are predetermined by the assumptions of the model. To evaluate the consequences of the transition from autarky to free goods trade (trade in *Z*- and *Y*-goods), complete and incomplete interregional knowledge diffusion are to be distinguished.

3.1 Complete knowledge diffusion

For the case of complete knowledge diffusion, the effects of trade on growth can be shown as usual by calculating the effects of increasing labour supplies in a single economy, see Grossman/Helpman (1991, p. 250 ff.). The transition of an economy from autarky to free trade with a region which is *abundant in the supply of unskilled labour* is then simply calculated as an increase in the supply of unskilled labour. The corresponding procedure applies for skilled labour. In the present model, the effect of a percentage increase of unskilled labour *L* on the growth rate is:

$$\hat{g} = \frac{1+h+y}{\Delta}\left[\sum_{i'} l_{Si'}\left\{q_{Li'}\left(s - \frac{1}{1+h+y}\right) + \frac{q_{Lg}}{1+h+y}\right\} + \left(l_{Sg} q_{Lg} s_g\right) + \sum_{i'} q_{Si'}\left(q_{Li'} - q_{Lg}\right)\right] \cdot \hat{L} \qquad (12)$$

$i' = X, Z$

$q_{Sx} = h \cdot l_{Sg} \cdot X^{-h} \cdot Z^{-y} > 0$, $q_{SZ} = y \cdot l_{Sg} \cdot X^{-h} \cdot Z^{-y} > 0$

$\Delta > 0$

In (12), the $l\,s$ denote the factor shares and the qs are the cost shares for the inputs L and S, e.g. $l_{LZ} = a_{LZ} \cdot Z/L$ and $q_{SZ} = a_{SZ} \cdot w_S / p$. $s_{i'}$ is the elasticity of substitution between S and L in sector *i'* and hats denote growth rates. Given the factor-intensity rankings, the determinant Δ is positive.[3] The variables h, y and $q_{Si'}$ represent the home market effect. With an increasing home market (i.e. rising X and/or Z), the impact of $q_{Si'}$ becomes relatively smaller. Given a large home market, the effect of manufacturing on knowledge formation is small as is the last term in brackets on the r.h.s. Knowledge spillovers from manufacturing are expressed by h and y . The larger these learning effects are, the higher the probability of the expression in brackets on the right hand side of (12) being positive becomes. In (12), the terms under the summation sign on the right hand side are positive if the elasticities of substitution between skilled and unskilled labour are larger than $1/(1+h+y)$. It should be noted that this critical value is smaller than the corresponding value in previous R&D models, because the trade-off regarding the use of the inputs in different sectors is smaller, as soon as economy-wide learning effects are assumed. That the critical value changes exactly from unity to the cute expression given in (12) is not easily predictable; it is only established after doing the appropriate calculations. The second term is positive by definition. Following the intensity ranking, the last term is also positive as $q_{Li'} - q_{Lg} > 0$. Accordingly, free trade has a positive effect on growth if the elasticities of substitution exceed $1/(1+h+y)$, irrespective of the size of the home market. If the elasticities happen to be smaller than $1/(1+h+y)$, a positive growth effect is still possible, however. This can be seen by rearranging (12) to:

$$\hat{g} = \frac{1+h+y}{\Delta}\left[\sum_{i'} l_{Si} q_{Li} s_{i} + \sum_{i'} (q_{Sg} - q_{Si'}) \cdot (q_{Si'} - l_{Si'})\right] \cdot \hat{L} \qquad (12')$$

i=X, Z, g; i'=X, Z

In (12'), the terms $l_{Si} q_{Li} s_i$ and $q_{Sg} - q_{Si'}$ are positive by definition and by assumption of the factor intensity ranking, respectively. So if we have $q_{Si'} - l_{Si'} > 0$, the relationship between L and g in (12') becomes positive, independent of the elasticities. Put differently, in this case the effect of free trade is positive for growth under all assumptions on the flexibility in production. This is the consequence of the home market effect. If an economy has a modest manufacturing sector, it is advantageous for growth if some resources are reallocated from research to manufacturing, as the marginal effect on knowledge formation is comparatively big in manufacturing. With the introduction of this mechanism, we present one of the possible explanations for the Dollar/Wolff (1993) finding that different economies can grow with a similar rate but with a different industry mix. The result in (12) and (12')

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[3] The exact result is available from the author upon request.

is driven by the cost change in R&D which is induced by input supply changes (impact of ”free trade”). To find out whether these costs increase or decrease when changing L, one has to compare a substitution and an output effect. The substitution effect exhibiting the ability to substitute unskilled for skilled labour is represented by s and turns out to be in analogy to Grossman/Helpman (1991, ch.5). The difference to existing models in this tradition is that the output effect is smaller than in previous models due to economy-wide learning-by-doing. As manufacturing contributes to knowledge formation as well, the critical value for the elasticity of substitution is smaller than unity which is derived to be the critical value in Grossman/Helpman (1991).

The corresponding result for skilled labour, representing the effect of free trade with a region which is *abundant in skilled labour*, is:

$$\hat{g} = \frac{1+h+y}{\Delta}\left[\sum_{i} l_{Li} q_{Si} s_{i} + \sum_{i'} \left(l_{Li'} - q_{Li'}\right)\left(q_{Sg} - q_{Si'}\right)\right] \cdot \hat{S} \tag{13}$$

$i = X, Z, g;\ i' = X, Z$

$q_{Lx} = h \cdot l_{Lg} \cdot X^{-h} \cdot Z^{-y} > 0,\ q_{LZ} = y \cdot l_{Lg} \cdot X^{-h} \cdot Z^{-y} > 0$

$\Delta > 0$

In (13), the terms $l_{S} q_{Li} s_{i}$ and $q_{Sg} - q_{Si'}$ are positive by definition and by assumption of the factor intensity ranking. Now, the term $l_{Li'} - q_{Li'}$ is decisive for the result. If it is positive, the standard result that free trade with a skilled labour abundant region is always advantageous for growth can be maintained. If the home market is too small, however, the qs become large and the result may be reversed. While a resource reallocation towards manufacturing would be positive for dynamics, it will not materialise with a small home market. A negative impact of free trade with an S-rich region can thus not be excluded in that case. This might be one of the possible explanations why poorer regions trading with skilled labour abundant regions do not grow so strongly as might be expected from the standard R&D-models. It is instructive to notice from (13) that a large elasticity of substitution between the two labour inputs can cure the situation. The critical value for s can be derived by rearranging (13) according to the procedure in expression (12).

3.2 No interregional knowledge diffusion

A similar procedure to 3.1 can be applied to analyse the dynamic effects of interregional goods trade under incomplete interregional knowledge diffusion. However, the calculation by means of increasing labour supplies is not possible anymore because it now matters which region produces what kind of knowledge. The move from autarky to free trade can be introduced in the model by changes in E_X

and E_Z, see Bretschger (1999b).[4] In a region that is abundant in the supply of skilled labour *S*, free trade increases *S*-intensive *X*-production and relative prices in the *X*-sector. At the same time, *L*-intensive *Z*-production and relative prices in the *Z*-sector decrease. As a consequence of free trade with an unskilled labour abundant region, E_X increases and E_Z decreases; for free trade with a skilled labour rich region, the opposite signs apply. In the following, the move to free trade is represented by an increase in the "free trade parameter" z , which depends on symmetrical sectoral expenditure changes, see appendix for the definition. For free trade with *an L-abundant region*, we have $z > 0$, for free trade with an *S-abundant region*, it is $z < 0$. As an opposite benchmark to above, let us analyse the case of no interregional knowledge diffusion. Then, the impact of trade on growth is calculated as:

$$\hat{g} = \frac{1+h+y}{\Delta}\Big[-\sum_i s_i\left(l_{Li}q_{Si} - l_{Si}q_{Li}\right) - \sum_{i'}\left(l_{Li'} - q_{Li'}\right)\left(q_{Sg} - q_{Si'}\right) - \sum_{i'}\left(l_{Si'} - q_{Si'}\right)\left(q_{Li'} - q_{Lg}\right)\Big]\cdot z \qquad (14)$$

$i = Z, x, g\,;\; i' = Z, x$

$\Delta > 0$

Consider first the case without home market effect, i.e. $q_{Li'} = q_{Si'} = 0$. Then, according to the assumptions on the sectoral factor intensities, the second and the third term on the right hand side of (14) are negative, as $q_{Sg} - q_{Si'} > 0$ and $q_{Li} - q_{Lg} > 0$. Assuming the elasticities of substitution in the first term of (14) to be zero, the entire relation between z becomes negative. This means that if technology is characterised by a Leontief fixed-coefficient production function, the dynamic impact of free trade with an *L*-rich region is unambiguously negative; for trade with an *S*-rich region, the opposite result applies. Allowing for substitution between skilled and unskilled labour in the three sectors, a positive sign of the first term is possible but not guaranteed, as the term $l_{Li}q_{Si} - l_{Si}q_{Li}$ can be positive or negative. Adding the home market effect, the impact of free trade on growth becomes even more complicated. As in the case of complete knowledge diffusion, the home market effect changes the output effect and is capable of changing the whole relation. The only way to find more precise results on this connection is further specifying the size of the different parameters by empirical research.

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[4] In this case, world expenditures can be normalised to unity so that the countries' shares are not fixed when assuming Cobb Douglas preferences.

3.3 The Home Market Effect

As can be seen from (12) and (13), the dynamic impact of trade depends in this model on the size of home manufacturing, on the intensity of knowledge diffusion and on the relative labour supplies of the trading partners. In particular, under both scenarios for interregional knowledge diffusion, regional growth and the effects of trade depend on the size of the home market. Only if the home market is very large, i.e. is larger than a critical size, the home market effect becomes small and the results for the effects of free trade are similar to those in previous R&D-models. For a region with a small manufacturing sector, however, free trade with a region which is abundant with skilled labour can lower the growth rate. In this case, labour is reallocated to R&D where it has a smaller effect on knowledge formation. Free trade with a region which is abundant in the supply of unskilled labour can in this case be more advantageous, because resources are more likely to remain in manufacturing after integration of the markets. The opposite results have to be expected for regions with a large manufacturing sector, which is the standard case in recent growth literature. What remains as a difference under all conditions regarding the home market is that the critical value for the elasticity of substitution between the two labour inputs becomes smaller as soon as we assume knowledge spillovers from manufacturing.

4. Data and empirical estimation

After showing the dynamic consequences of free trade with an enlarged concept of learning by doing in a theoretical model, a cross-section study for German regions shall help to clarify whether the effects derived from theory are relevant in practice. The main purpose of the empirical part is to take a first step in inquiring after the (non-linear) effects of the sectoral mix on regional growth, which are decisive for the calculation of the theoretical results. Ceteris paribus, the marginal effect of each manufacturing sector on knowledge formation and growth is given by the values of h and y respectively, whereas the marginal effect of R&D is constant (see equation 3). But of course, the *ceteris paribus* condition cannot be fulfilled: the labour supplies are constant so that more resources in one sector implicate less resources in another sector. This means that an increase of a specific sector yields additional learning effects (by the same sector) but lowers knowledge formation by decreasing learning effects from other sectors.

Assuming e.g. $0<h, y<1$ in the theoretical model, it becomes clear that an increase of a very small X-sector at the expense of a large Z-sector has positive marginal effects on knowledge formation. If the X-sector is large and the Z-sector is small, however, the positive impact on knowledge formation is small and the loss of learning becomes large so that, in the end, a negative effect results. But it is also possible that knowledge formation from one or several manufacturing sectors (and of services) exhibit increasing returns to scale, i.e. that $h, y>1$. Then, the more concentrated resources in one manufacturing sector are, the larger the additional learning effects compared to the learning "losses" in other sectors become. Both types of hypothesis yield a non-linear relationship between sector size and growth; the functional form of this link shall be directly estimated in the empirical equation. In the estimations below, not all sectors of the regional economies are included in the regressions because of perfect multicollinearity. Thus, evaluating the consequences of varying sector sizes on growth means that some sectors not included in the regression have to change as well.

We consider three different sectors, two manufacturing sectors (MANU I and MANU II) and an aggregate service sector (SERV), for which data are available. The public sector as well as the farming sector are not included in the regressions so that the three sectoral employment shares do not sum to one. To test for the non-linear relationship between sector size and growth, a quadratic form is used. More specifically, the different sector sizes are included in the regressions both as linear and as squared variables.[5] Beside the industry mix, further parameters important for knowledge diffusion are considered in the regression. Regarding interregional knowledge diffusion, the difference of the knowledge stock of each region to the knowledge stock of the leading region at the beginning of the period is included; it is captured by the difference in the initial income levels, see Bretschger/Schmidt (1999) for further explanations. To control for intraregional knowledge diffusion, the density of economic activities and the skill level of the labour force are introduced in the regression. Moreover, as the data on the industry mix are measured by sectoral employment shares, the size of the total regional labour force is added as an explanatory variable. By including this scale effect, the direct link to the theoretical model is maintained. Finally, dummies for the three "Bundesländer" with a particular sector mix within the three general categories are introduced: for Hesse (banking and finance), North Rhine-Westphalia (steel, coal) and Bavaria (advanced technologies).

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[5] The quadratic form corresponds exactly to the case of a one-input economy with a single manufacturing sector and proportional knowledge spillovers from manufacturing. With two input factors and two manufacturing sectors as regarded in the previous section, the form of the equation corresponding to the theoretical model would in fact

For estimation, data for 327 West-German regions, called ”Landkreise” and ”Städte”, are used. The data were provided by the ”Statistisches Landesamt Baden-Württemberg” (SLB-W), Stuttgart, the ”Bundesforschungsanstalt für Landeskunde und Raumordnung” (BLR), Bonn, and the ”Statistisches Bundesamt” (SB), Wiesbaden, Germany. The variables are determined as follows:

Growth rate	Income growth (or productivity growth, respectively) is the difference of the logarithms of per capita incomes 1994 and 1980 divided by the number of years, adjusted for inflation (unweighted average of g: 1.75 %, st.dev.: 0.7 %). Per capita values are ”Brutto-Wertschöpfung pro Einwohner zu Marktpreisen”. Source: SLB-W.
MANU I	The size of the first manufacturing sector is measured as the employment share of total manufacturing (”produzierendes Gewerbe”) minus the share of the finishing industry (”verarbeitendes Gewerbe”). It mainly consists of zhe mining, energy, water supply and construction industry. Source: BLR.
MANU II	The size of the second manufacturing sector is measured as the employment share of the finishing industry (”verarbeitendes Gewerbe”). It contains all activities in manufacturing not included in MANU I. Source: BLR.
SERV	The size of the service sector is measured as the employment share of aggregate services. All employment shares are taken as an average of the years 1982 and 1996. Source: BLR.
Y(0)	The knowledge gap of a region to the leading region at the beginning of the time period X is approximated by the income at the beginning of the observation period (1980) Y_0 with ”Brutto-Wertschöpfung pro Einwohner zu Marktpreisen”. Source: SLB-W.
LFOR	Total labour force is equal to the number of all workers in a region (”Beschäftigte insgesamt”). Source: BLR.
DEN	The density of economic activities is measured by the number of employees per square kilometer in 1992 (unweighted average 297, st.dev. 427). Source: SB.

exhibit a more complicated non-linearity not considered in this contribution.

UNI	The skill level of the labour force is captured by the proportion of employees with higher education (degree from a university or ”höhere Fachschule”) of the total labour force as an average of the years 1982 and 1996 (unweighted average: 3.0% in 1982 and 5.4% in 1996, st.dev.: 1.81% in 1982 and 2.83% in 1996). Source: BLR.
DNRW	Bundesland dummy for North Rhine-Westphalia.
DBA	Bundesland dummy for Bavaria.
DHS	Bundesland dummy for Hesse.

5. Empirical Results for 327 German Regions

The considered time period ranges from 1980 to 1994. The estimation method is ordinary least squares; t-values are given in parenthesis. The results are given in the table below. The three versions which were tested differ in the sense that the ”catch-up”-variable Y(0) was introduced in logs in the second and the third column and density DEN was also included in logs in the third column to reflect the possible non-linearities in convergence and agglomeration effects. The results are very similar for the three specifications. Regarding the influence of the industry mix on growth, the results are significant and reflect a non-linear relationship. The size of the first manufacturing sector (MANU I) has a positive influence on growth up to a certain critical value. If the sector exceeds a certain size, a further increase in the sector size reduces the region’s growth rate.

Growth rate	(1)	(2) log Y(0)	(3) log Y(0), log DEN
MANU I	0.1493*** (3.117)	0.1544*** (3.255)	0.1599*** (3.372)
(MANU I) square	-0.5129*** (-3.008)	-0.5308*** (-3.147)	-0.5430*** (-3.225)
MANU II	-0.0117 (-0.841)	-0.0099 (-0.716)	-0.0134 (-0.978)
(MANU II) square	0.0465** (2.301)	0.0436** (2.171)	0.0479** (2.394)
SERV	-0.1275*** (-3.149)	-0.1197*** (-2.993)	-0.1266*** (-3.166)
(SERV) square	0.2457*** (3.909)	0.2334*** (3.768)	0.2448*** (3.936)
Y(0)	-4.60e-07*** (-7.741)	-0.0234*** (-8.047)	-0.0249*** (-8.176)
LFOR	2.07e-09 (0.317)	7.08e-10 (0.109)	4.14e-09 (0.712)
DEN	2.59e-06* (1.967)	2.53e-06* (1.938)	0.0010** (2.371)
UNI	0.0545** (2.179)	0.0615* (2.459)	0.0575** (2.317)
DNRW	-0.0019* (-1.829)	-0.0017 (-1.650)	-0.0021* (-1.969)
DBA	0.0027*** (3.020)	0.0023** (2.520)	0.0024*** (2.626)
DHS	0.0085*** (5.848)	0.0084*** (5.810)	0.0085*** (5.868)
F(13,313)	16.12	16.65	16.89
Prob > F	0.0000	0.0000	0.0000
R-squared	0.4011	0.4088	0.4122
Adj R-squared	0.3762	0.3842	3878
Root MSE	0.00616	0.00612	0.0061

***significant at the 99%-level ** significant at the 95%-level * significant at the 90%-level (two-tailed-test)

The other two sectors show the reversed signs. As long as they are small, an increase in the sector size has no impact (MANU II) or reduces the growth rate (SERV), whereas with larger sizes, a positive relation between sector size and growth results. In terms of the used model, this says that the first manufacturing sector exhibits decreasing returns to knowledge formation. However, the other two sectors show the reversed pattern, i.e. increasing returns with regard to the knowledge build-up. This certainly is surprising at first sight and requires further corroboration. The explanation here is that learning effects in the second manufacturing and in the service sector are small when the sectors are small so that they become negligible for growth. With the sectors exceeding a certain size, however, the scale effects in knowledge creation become strong and sustain knowledge formation and growth in the regional economy decisively.

The other variables are generally satisfactory both in signs and in significance. The catch-up variable Y(0) is highly significant and the skill level (UNI) also has the expected positive and significant impact on growth. The absolute size of the regions (LFOR) has the expected positive sign but is not significantly different from zero. The agglomeration effect captured in the density variable (DEN) has the correct sign and performs slightly better when introduced in the logarithmic form. As could be expected, the dummies show the special backgrounds of the three Bundesländer inasmuch as the steel and the coal industry (NRW) have a negative influence, whereas banking (HS) and advanced technologies (BA) have indeed a positive influence on development.

6. Conclusions

The present paper shows the dynamic consequences of economy-wide learning and of spillovers stemming from all sectors of a region. With regard to knowledge formation, the theoretical model predicts an optimal industry mix which is automatically reached neither by free market forces nor by free interregional trade in goods. By increasing the volume of interregional trade, the economy can move closer to the optimal mix or it can move away from it. Therefore, getting closer to the optimal mix means raising the regional growth rate and vice versa. The contribution of this paper to existing literature is that the growth effect of trade is largely influenced by the home market effect. Given that the home market of a region is small, increasing trade with a region which is abundant in the supply of skilled labour can harm the growth rate, whereas increasing trade with a region which is abundant in unskilled labour can foster the growth rate irrespective of the elasticity of substitution in production. Thus some standard results of recent theory change dramatically when one introduces the assumption of economy-wide learning-by-doing. By the same reasoning, one can argue that a lagging region with a small home market may have a bigger profit from increasing its manufacturing sector, while a leading region with a large home market has a larger growth rate when intensifying R&D.

The empirical results show several regularities in the relationship between industry mix and regional growth in Germany. According to the results, knowledge spillovers from ”traditional” manufacturing (MANU I) are effective up to a certain critical value. If this manufacturing sector becomes larger than the critical size, the growth impact becomes negative. In the second case, resources are more efficient for dynamics when being allocated to the other sectors of the economy. The home market effect thus seems to be existent for this sector of the economy and the effects calculated in the theoretical part might well be an important issue. Of course, this outcome and the results concerning the rest of manufacturing (MANU II) and of services (SERV) need to be investigated more closely in further studies. The present regressions show that more empirical research, e.g. adopting non-linear estimation methods, seems to be promising. Non-linear methods would allow one to remain closer to the theoretical model in the empirical part. Furthermore, theory could profit from the empirical finding that two large sectors of the economy (MANU II, SERV) exhibit increasing returns to scale in regional knowledge formation.

With the growth rate of an economy depending on the industry mix, one could be tempted to argue in favour of policies targeted at promoting specific sectors. However, it turns out that not all regions should have the same priorities regarding the industry mix. In some cases, the theory suggests that promoting the sectors generally known as ”key sectors” could be precisely the wrong thing to do. The relationship between mix and growth is not direct but complex as each resource reallocation between sectors causes several non-linear effects on knowledge formation. To be successful in sectoral policy, a regional authority would first have to know about the optimal knowledge (i.e. industry) mix; then, it should be informed about the difference between its own and the optimal industry mix. Moreover, the information should be available on a disaggregate level, i.e. at least on the level of sub-industries. It is obvious that the high aggregation level of this study does not lead to concrete guidelines for regional economic policy. Even more importantly, it might be that a region’s own policies are continuously undermined by the effects of free goods trade, which permanently alter regional specialisation. In the presence of the huge trade flows between regions, it might well be that the impact of education – which increases the share of skilled labour – is a more effective way to influence regional growth than the active change of the industry mix, which might not be sustainable under free trade. To conclude, one also has to observe that increasing returns to knowledge formation in certain sectors could lead policy-makers to favour highly specialised regional economies; such economies might well grow faster than more diversified regions, but the risks of this development will also be higher, especially in the long term.

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Appendix

We differentiate the system of the three equations consisting of the labour markets in (11), where goods quantities are replaced by expenditures and prices out of (4), (5) and (6), and the capital market (10). Using again hats for percentage changes yields for both cases of interregional knowledge diffusion:

$$\begin{bmatrix} c_{11} & c_{12} & l_{Lg} \\ c_{21} & c_{22} & l_{Sg} \\ c_{31} & c_{32} & \frac{g}{g+r} \end{bmatrix} \cdot \begin{bmatrix} \hat{w}_L \\ \hat{w}_S \\ \hat{g} \end{bmatrix} = \begin{bmatrix} m_1 \\ m_2 \\ m_3 \end{bmatrix}$$

with i = X, Z, g ; i' = X, Z and

$$c_{11} = -\sum_i l_{Li} q_{Si} s_i - \sum_{i'} (l_{Li'} - q_{Li'}) q_{Si'}$$

$$c_{12} = \sum_i l_{Li} q_{Si} s_i - \sum_{i'} (l_{Li'} - q_{Li'}) q_{Si'}$$

$$c_{21} = \sum_i l_{Si} q_{Li} s_i - \sum_{i'} (l_{Si'} - q_{Si'}) q_{Li'}$$

$$c_{22} = -\sum_i l_{Si} q_{Li} s_i - \sum_{i'} (l_{Si'} - q_{Si'}) q_{Si'}$$

$$c_{31} = q_{Lg} + q_{Lg} = q_{Lg} + h q_{Lx} + y q_{LZ}$$

$$c_{32} = q_{Sg} + q_{Sg} = q_{Sg} + h q_{Sx} + y q_{SZ}$$

$$q_{Lx} = h \cdot l_{Lg} \cdot X^{-h} \cdot Z^{-y} > 0\text{, } q_{LZ} = y \cdot l_{Lg} \cdot X^{-h} \cdot Z^{-y} > 0$$

$$q_{Sx} = h \cdot l_{Sg} \cdot X^{-h} \cdot Z^{-y} > 0\text{, } q_{SZ} = y \cdot l_{Sg} \cdot X^{-h} \cdot Z^{-y} > 0$$

For the case of complete interregional knowledge diffusion (section 3.1) we have:

$$m_1 = \hat{L}; m_2 = \hat{S}; m_3 = 0$$

For the case of no interregional knowledge diffusion (section 3.2) we have:

$$m_1 = z_1 = -l_{LZ} \cdot \hat{E}_Z - l_{Lx} \cdot \hat{E}_x$$

$$m_2 = z_2 = -l_{SZ} \cdot \hat{E}_Z - l_{Sx} \cdot \hat{E}_x$$

$$m_3 = \hat{E}_x$$

To calculate the effect of free trade in 3.2, we use the symmetrical case $z_1 = -z_2 = z$, which is referred to in the main text.