Ann Reg Sci (1999) 33:251–268

The Annals of
Regional Science

Knowledge diffusion and the development of regions

Lucas Bretschger

Institute for Empirical Research in Economics, University of Zürich, Blümlisalpstrasse 10, CH-8006 Zürich, Switzerland
(e-mail: lubret@iew.unizh.ch)

Received: October 1996 / Accepted: December 1997

Abstract. The economic prosperity of a region is largely dependent on the accumulation and diffusion of knowledge. In this paper, the scale effects as well as the resource reallocation effects of intra- and interregional knowledge transmission are analysed. Within a model, the optimal levels of knowledge diffusion are calculated. It is also shown that knowledge diffusion becomes more important if regions are more integrated in interregional goods trade. Free trade in goods can harm the development of a region if the interregional knowledge diffusion is not intensive enough.

1. Introduction

Knowledge is an important factor for regional development. An increasing stock of knowledge leads to rising productivities of regional inputs like labour, physical capital and human capital, as well as to higher per-capita incomes. In the long run, the accumulation of knowledge largely determines the growth of total factor productivity, which is often considered to be the best available indicator for regional development and competitiveness. As the spatial pattern of an economy plays a decisive role in regional development, the diffusion of knowledge is just as important as the creation of knowledge. Knowledge diffusion can be described as a special type of communication concerned with the spreading of messages that constitute new ideas (see Rogers 1983). The intensity of knowledge diffusion depends on different factors and mechanisms. According to Marshall (1920), information flows more rapidly within a region than over greater distances. He identifies the flow of information and ideas between firms of a certain region as one of the main reasons for the spatial concentration of economic activities. In regional economics, recent contributions emphasise the impact of communication net-

I wish to thank three anonymous referees for helpful comments.

works. A network consists of interconnected individuals who are linked by patterned flows of information. Networks must have a certain degree of structure and stability to be effective. Moreover, the design of a network is strongly connected to the character of knowledge it is able to transmit (see Batten et al. 1989). On the one hand, telecommunication networks are especially efficient for the transportation of information consisting of uncomplicated messages. On the other hand, high-speed transportation networks are of special importance to facilitate face-to-face contacts. These contacts are often necessary for intensive learning effects, i.e. for the diffusion of knowledge which has a more complex character (see e.g. Kobayashi 1995). Concerning the relation between the two types of knowledge diffusion in regional development, Gaspar and Glaeser (1996) find in an empirical study that telecommunication may be a complement, or at least not a strong substitute for face-to-face interactions. This relation between the two network types also applies to the relation between intraregional knowledge diffusion, which is relatively intensive in face-to-face contacts, and interregional knowledge diffusion, which is relatively intensive in the use of telecommunication.

In terms of economic theory, knowledge is not restricted to the technical aspects of know-how for firms, but also includes knowledge components like institutional and organisational know-how. Concerning the generation of new knowledge, Arrow (1962) and subsequent literature assume knowledge to be built up by positive externalities of certain activities carried out under market conditions. Adding this element to a neo-classical production sector leads to increasing returns to scale for the aggregate regional economy, whereas a single firm still faces constant or decreasing returns to scale. This allows us to study increasing returns to scale in production while preserving the assumption of perfect competition. With regard to interregional goods trade, the existence of positive externalities requires the departure from traditional trade theory. The same holds true if we realistically assume regional economies to trade in differentiated goods (see Krugman 1991 and Johansson 1995). The dynamic consequences of external effects of capital accumulation and the existence of differentiated goods in open economies have been discussed in a strand of literature combining new growth and new trade theory (see Grossman and Helpman 1991). Let us e.g. assume knowledge stocks and factor rewards to be unequal among regions. Then, the case of increasing returns to scale activities being harmed by free goods trade cannot be disregarded. What is suggested by recent theory is indeed a serious problem: that the long-term growth rate of an economy may decrease with increasing goods trade (i.e. may be lower under free trade than in autarky). The reason for this possible outcome is that the inputs used intensively in the increasing returns to scale activities become more expensive under the conditions of free goods markets. In this respect, it has been demonstrated in recent theoretical contributions how resources are reallocated after the opening of free trade, both in cases of perfect international knowledge diffusion (Grossman and Helpman 1991) and in cases of deficient international knowledge diffusion (Bretschger 1997).

In this paper, the different long-term effects of both intra- and interregional knowledge diffusion on regional development are derived in terms of a dynamic macroeconomic model. The approach builds on the first explanation of Marshall (1920) for regional concentration of economic activities. It complements Krugman (1991), who deals with the other two Marshallian explanations, which are the critical size of pooled labour markets and the variety of differentiated goods. The framework used here combines elements of economic geography, location theory, new growth theory, and new trade theory. To focus on the dynamic aspects of the theory, it deals with the impact of knowledge on total factor productivity. In this respect, knowledge diffusion acts as a direct scale effect with respect to regional productivity, income and welfare. But the indirect effects are at least as important. The most obvious of these indirect effects is the impact of knowledge diffusion on the reward for physical capital. In the model used below, the return on the interregionally mobile factor capital is the centre of the analysis. Knowledge and labour inputs are assumed to have a large impact on this return. A higher marginal product of capital attracts capital from other regions and increases incentives for local savings. Any increase in the aggregate physical capital raises regional labour productivity and per-capita income.

Both direct and indirect effects of knowledge diffusion foster long-term regional development. Moreover, the lack of interregional knowledge diffusion can be harmful in a dynamic environment that is characterised by regional goods markets that are becoming more and more integrated. If interregional trade volumes increase, relative factor prices of immobile factors change, which has an influence on the return of mobile factors as well. I will argue below that for regions which are relatively well-supplied with skilled labour, increasing goods trade may harm the return on capital. In this case, less capital from other regions is attracted and savings decline, which harms long-term regional development. In this case, interregional knowledge diffusion can be a remedy to cure fading dynamic forces. Regarding a certain region, knowledge diffusion within the centre of a region and between the centre and the "hinterland" will not be distinguished in the model. It is assumed that a region consists of concentrated economic activities with a uniformly dense network of communication. But regions as a whole differ in the way they produce and communicate knowledge within the region and in the way they have access to knowledge that stems from other regions. This reflects the differences in regional infrastructure and corresponds to the empirical observation that different regions specialise in different economic activities, even if they are highly developed (see Dollar and Wolff 1993). Following the discussion above, the productive use of knowledge from the home region is assumed to differ from the use of knowledge that is transmitted from other regions. For both intra- and interregional knowledge diffusion, the exchange of information is not tied to direct financial compensation, such as the exchange on goods markets. This lack of compensation, combined with the influence of knowledge on regional productivity, demonstrates the normative dimension of knowledge diffusion for regional development, which is another focus of this contribution.

The remainder of the paper is organised as follows. Section 2 contains a formal exposition of the influence of the different types of knowledge and of labour on regional return on capital in a one-sector model. In Sect. 3, optimal levels of intra- and interregional knowledge diffusion are calculated. Section 4 presents the influence of knowledge and labour on the return of capital in a full-fledged three-sector model of the open regional economy. In Sect. 5, the results of comparative dynamics are derived. Section 6 concludes.

2. Return on capital and regional development

Economic geography and the economics of location focus on increasing returns to scale because this assumption is crucial to explain the regional concentration of certain industries. In the following model, it is knowledge and knowledge spillovers that create these increasing returns. To analyse the development of a region, three types of inputs are distinguished below: physical capital, knowledge, and labour. Physical capital is a crucial factor for regional development as it is highly mobile between regions. Investors are constantly seeking the location with the highest return on capital. This return is also an important parameter for the amount of regional savings. Thus it is one of the objectives for regional economic policy to achieve an attractive return on capital investments. In equilibrium, the return is equal to marginal product of physical capital which is heavily influenced by intra- and interregional knowledge diffusion. In addition to physical capital and knowledge, I introduce skilled and unskilled labour, which also have an influence on the marginal product of physical capital. Labour is assumed to stay within the regional borders. Therefore I do not focus on labour migration, local public goods, or regional education systems; these topics are beyond the scope of this contribution. To sum up, in the model used below the marginal product of physical capital differs between regions because of different regional endowments of skilled and unskilled labour, different intraregional knowledge diffusion, and differences in the access to knowledge from other regions.

Total productive knowledge in the home region κ is determined by knowledge κ_h, which stems from the home region, and by knowledge κ_o, which stems from other regions *and* is ready for productive use in the home region. Adopting a Cobb-Douglas specification yields:

$$\kappa = (\kappa_h)^{\gamma} \cdot (\kappa_o)^{\eta} \quad (0 < \gamma < 1, 0 < \eta < 1)\,. \tag{1}$$

According to (1), both types of knowledge are incomplete substitutes as suggested by the discussion in the first section. The more intensive interregional knowledge diffusion is, the higher is κ_o. With interregional knowledge diffusion being weaker, κ_o gets closer to zero. In the following, I analyse

lyse the consequences of variations in κ_o on the development of the home region. For this purpose, the marginal return to capital has to be determined. It makes a difference whether one argues in terms of a one-sector model or in terms of a multi-sector model. In this and the next section I consider a one-sector model and write aggregate regional production Y as:

$$Y = D \cdot K^{a} \cdot (\kappa_h)^{\gamma} \cdot (\kappa_o)^{\eta} \cdot F(S, L)\,. \tag{2}$$

In (2), D is a constant and F is a functional which captures the influence of skilled labour S and unskilled labour L on aggregate output. One of the characteristics of new growth theory is the introduction of positive externalities in the form of knowledge spillovers. In many of these models, it is assumed that capital investments entail learning effects which raise the stock of public knowledge. In economic geography, these spillovers are often assumed to be existent within a location or region. In this model, the positive spillovers from capital formation in the home region represent intraregional knowledge diffusion. The assumption of proportional spillovers from capital formation in the home region to home knowledge stock gives:

$$K = \kappa_h\,. \tag{3}$$

Given (2) and (3), the (private) marginal product of capital μ is determined by:

$$\mu = a \cdot D \cdot K^{-(1-a-\gamma)} \cdot (\kappa_o)^{\eta} \cdot F(S, L)\,. \tag{4}$$

In steady-state, the growth rate of regional income is equal to the growth rate of consumption. Regarding the saving decisions of the households, this growth rate g is given by the well-known Keynes-Ramsey rule. Assuming the elasticity of intertemporal substitution to be equal to 1 and the population to be constant yields:

$$g = \mu - \delta - \rho\,. \tag{5}$$

In this expression ρ denotes the discount rate of households and δ the depreciation rate of capital. To determine the impact of interregional knowledge diffusion, two cases have to be distinguished: decreasing and constant returns to capital. If $a+\gamma<1$, we have decreasing returns to capital. The impact of a discrete increase in κ_o induces adjustment growth in the home region as represented in Fig. 1. From (2) it can be seen that κ_o has a direct impact on regional income. But this impact is only on the *level* of income and not on the growth rate. From Fig. 1 it becomes evident that the influence of κ_0 is intensified by the induced increase in the stock of physical capital and by additional positive spillovers to home knowledge. The solid line shows the effect of a discrete increase in κ_o, the dotted line indicates a further increase in κ_o . A large enough constant increase in κ_o, however, allows the region to reach a constant growth rate even with $a+\gamma<1$.

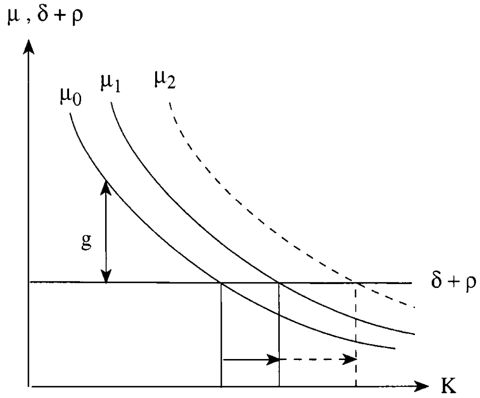

Fig. 1. Interregional knowledge diffusion with decreasing returns to capital

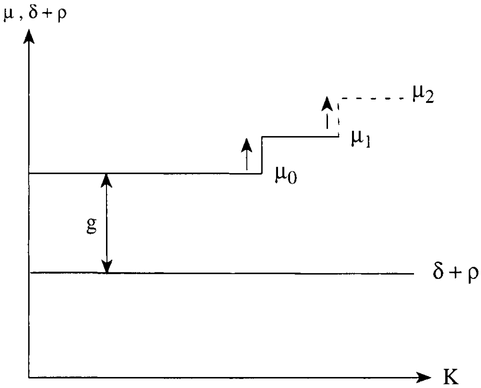

Fig. 2. Interregional knowledge diffusion with constant returns to capital

In analogy to new growth theory, the intensity of intraregional knowledge spillovers can be such that constant returns to aggregate capital (consisting of physical capital and home knowledge) and a linear relationship between aggregate capital and income are obtained. Thus the marginal product of capital investments in the home region is constant. In the production function (2) and using (3) this is the case if we assume $\alpha+\gamma=1$. Then the marginal product of capital becomes:

$$\mu = \alpha \cdot D \cdot (\kappa_o)^{\eta} \cdot F(S, L)\,. \tag{6}$$

It is evident from (6) that κ_o acts now as a scale factor with respect to marginal product of capital and by (5) to the long-term growth rate. The effect of a discrete increase in κ_o is, under the new assumptions, represented in Fig. 2 with solid lines. Again, the dotted line indicates a further increase in κ_o .

3. Optimal knowledge diffusion

Because knowledge spillovers are externalities which are not compensated in a market economy, knowledge diffusion is not on an optimal level. For the derivation of optimal knowledge diffusion, we have to distinguish between intra- and interregional knowledge diffusion. In the following, the optimal policy measures are calculated for both types of externalities. Regarding intraregional knowledge diffusion, the social return on home capital formation is:

$$\mu = (\alpha + \gamma) \cdot D \cdot K^{-(1-\alpha-\gamma)} \cdot (\kappa_o)^{\eta} \cdot F(S, L) \qquad (7)$$

which is bigger than the private return given in (4) as $\gamma>0$. It is an optimal policy to subsidise capital investments so that private investors receive the social marginal return of capital.[1] In the case of intraregional knowledge diffusion, savings and investments are too low, which can be corrected by levying a tax on income; the tax revenue is assumed to be fully invested in physical capital. Denoting the tax rate on income with τ_h, the private marginal return on capital becomes now $(1–\tau_h)$ times the expressions given in (4), as the share τ_h has to be paid in tax. The optimal tax rate for intraregional knowledge diffusion τ_h^* is:

$$\tau_h^* = \gamma\,. \qquad (8)$$

Assuming constant returns to home capital, i.e. $\alpha+\gamma=1$, the optimal tax rate for intraregional knowledge diffusion τ_h* is given by:

$$\tau_h^* = (1 - \alpha)\,. \qquad (8')$$

According to (8) and (8′), the optimal tax rate is equal to the production elasticity of home knowledge in the production function (2). If $\alpha+\gamma<1$ and κ_0 is constant, the income level is higher in steady-state after the tax has been introduced; if $\alpha+\gamma=1$ and κ_o is constant, the equilibrium growth rate becomes higher after the tax has been introduced. The tax rate given in (8′) leads to the optimal long-term growth rate for the home region. If $\alpha+\gamma=1$ and κ_o is constantly increasing over time, an increasing growth rate is obtained in theory; but this case seems to be the exception in reality.[2] Total tax revenue is dependent on the amount of knowledge that stems from other regions. This is because the higher κ_o, the higher is the return on capital and the larger are the spillovers so that the amount of capital investments that should be financed by taxes must also be higher.

Next, the optimal tax for interregional knowledge diffusion is determined. So far I have assumed that knowledge from other regions which is *ready for use* in the home region, κ_o, is obtained without cost. As a consequence, the higher κ_o the better for the home region although an increasing κ_o has a decreasing marginal return on income of the home region. In this section, interregional knowledge diffusion is assumed to be costly so that it becomes possible to calculate an optimal level of knowledge transmission from other regions. The costs of interregional knowledge transmission consist of all expenses that occur when establishing interregional communication channels for scientific, technical, and organisational knowledge exchange. Once these costs are known, there is an optimal combination of home and foreign knowledge according to (1) and (2). When investing in communication channels, fewer resources can be used for the accumulation of physical capital, which harms income and home knowledge. Now suppose it is possible to increase κ_o (which is only the part of the immense knowledge from other regions that is readily available at home) ψ units by investing one unit of Y in interregional communication networks. The share of Y that is invested in this way is denoted by Y_o, with $Y_o = \tau_o \cdot Y$. τ_o can again be thought of as the tax rate that the regional authority levies on income for this purpose. This gives:

$$\kappa_o = \psi \cdot Y_o = \psi \cdot \tau_o \cdot Y\,. \tag{9}$$

The marginal return on capital is now $(1-\tau_o)$ times the expressions given in (4), if we assume $\alpha+\gamma<1$, or $(1-\tau_o)$ times the expressions in (6), assuming $\alpha+\gamma=1$, as the share τ_o of income has to be paid for public investment. By inserting the production function (2) into (9) and using (3), one obtains an expression for κ_o which can be inserted in (4) for the case of $\alpha+\gamma<1$ or in (6), assuming $\alpha+\gamma=1$. By taking the derivative and setting the resulting expression equal 0 yields the optimal tax rate τ_o^* for interregional knowledge diffusion which is identical for both cases of $\alpha+\gamma<1$ and $\alpha+\gamma=1$; it is given by:

$$\tau_o^* = \eta\,. \tag{10}$$

According to (10), this rate does not depend on the productivity parameter ψ. Thus ψ turns out to be a shift parameter with respect to productivity of capital and growth but has no influence on the optimal τ_o. It is interesting to see whether the general importance of an intensive knowledge exchange between firms as suggested in this section is reflected in the judgement of firm managers. Firms are the “customers” of a location, so that their opinion reflects the importance of the different location factors. In a broad survey for the region Canton of Zurich, firms were asked which factors they regard as most important and which as less important for the choice of location for their firm.[3] Here, only the results concerning knowledge diffusion are reported. It turned out that there is a big difference between telecommunication networks and face-to-face contacts. In the cited survey, the regional supply of telecommunication is ranked as second most important factor out of a list of 38 location factors. The supply of highly skilled labour is ranked in first place. It can be argued that skills play an important role in receiving information from other firms and in transforming it into productive use. In contrast, according to the survey, the face-to-face aspects of knowledge diffusion are less valued by firms. The corresponding location factors in the questionnaire were called "geographical proximity to firms in the same industrial branch" and "geographical proximity to research institutes, education centres and technoparks".

The first results seem to be in line with theory. The outcome concerning face-to-face contacts requires two further comments. First, it is not entirely clear how accurately the factors mentioned in the questionnaire correspond to what is meant by knowledge diffusion in the theoretical context of this paper. Knowledge is a highly abstract term and is very heterogeneous for different firms; also, interpersonal knowledge diffusion is not necessarily tied to geographical proximity. Second, and more important, knowledge diffusion is a positive externality, so that everybody wants to obtain knowledge but nobody wants to pay for it. It is understandable that, in reality, firms in the same industrial branch form clusters in certain locations in order to gain a high knowledge "profit" from other firms, but do not emphasise this motivation in public. If the results of the survey on face-to-face contacts are interpreted in this way, the importance of knowledge and knowledge diffusion are and remain important issues. It thus seems justified to argue that theory can in this case supplement personal beliefs and official survey statements of firm managers to provide a more complete picture of the real situation.

The introduction of taxes on income as presented in (8) and (10) raise growth and welfare in the one-sector model which has been used so far. The same holds true in models with more sectors, provided that the principal impact of knowledge and knowledge diffusion on productivity remain unchanged. However, the need to pursue policies as presented in this section will turn out to be different in a multi-sector model. If regional goods markets become more integrated, the influence of immobile factors on the return of capital might become negative. The next questions to be addressed concern the conditions that produce this unfavourable result and the possible ways to support the return on capital by changes in knowledge diffusion. To deal with these issues, the return on capital in a three sector model is calculated in the following section.

4. Return on capital with three sectors

Assuming $\alpha+\gamma=1$ in the production function (2), which yields a linear relationship between home capital and income, the marginal product of capital μ is equal to the average product or average return of capital. In the definition of financial markets, μ is the reciprocal of the price-earnings ratio. In principle, earnings have to be valued with a general price index and the capital good with the price of capital. In the one-sector model used so far, these prices are identical as the capital good is produced with the same production technique as the final consumer goods. In a more realistic setting, however, the difference between these prices is one of the key elements to determine average return of capital. Different prices require a multi-sector model, with at least one sector where earnings accrue and one sector where capital goods are produced. Also, to model intersectoral trade we need at least two sectors of tradable goods. Only with a multi-sector model for the open economy does it become possible to capture the separate impact of skilled and unskilled labour on capital productivity. Also, in a multi-sector model the question of intraregional knowledge diffusion is decisive if interregional knowledge diffusion is not strong enough. As a consequence of globalisation in goods markets, it is possible that in a region fewer resources are devoted to capital investments that produce positive spillovers. In this case, the stock of knowledge in the home region increases less rapidly. How can this happen? It is a fact that investment activities that increase the home knowledge stock are generally intensive in the use of skilled labour.[4] Now consider regions that are well supplied with skilled labour relative to other regions. For these regions, increasing interregional integration in goods markets means that skilled labour becomes more and more scarce in the integrated economic area. According to standard trade theory, we expect wages of skilled labour to rise relative to other factor prices. Then, capital investment may be less attractive compared to the production of consumption goods.

In the following, I consider a three-sector economy in the home region. The first sector is assumed to produce traditional goods with constant returns to scale. The second sector is assumed to consist of differentiated goods where earnings for capital goods accrue; in the third sector capital goods are produced. Skilled labour S and unskilled labour L are used in all sectors. The capital goods-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 goods lie in between in this respect. In the first sector, homogeneous goods Z are produced under perfect competition so that unit cost c_Z correspond to the price p_Z according to:

$$p_Z = c_Z = \sum_i a_{iZ} \cdot w_i \quad (i = L, S)\,. \tag{11}$$

The a-parameters are unit labour input factors, the ws stand for the wages of the two inputs unskilled labour L and skilled labour S, which are used for the corresponding subscripts. In the second sector, the region is assumed to produce n differentiated goods denoted by x_j ($j = 1,...,n$) under monopolistic competition. In a symmetrical equilibrium, the quantity x is equal for all n, which we will assume. Variable cost in x-production are the labour cost for skilled and unskilled labour. So, marginal costs c_x in x-production are given by:

$$c_x = \sum_i a_{ix} \cdot w_i \quad (i = L, S)\,. \tag{12}$$

For demand structure we adopt the Dixit and Stiglitz (1977) specification of constant elasticity of substitution between differentiated goods.[5] With this approach, the price of an x-good is equal to marginal costs (11) augmented by a constant mark-up $1/\beta$, according to:

$$p_x = c_x/\beta \quad 0 < \beta < 1\,. \tag{13}$$

Using X for the total sectoral output, i.e. $X = n \cdot x$, and E for the expenditures, i.e. $E_x = X \cdot p_x$, aggregate profits π are using (13):

$$\pi = (1 - \beta) \cdot E_x\,. \tag{14}$$

These profits are used to cover the expenses for fixed cost in the production of x-goods. Fixed costs are paid to the third sector where capital goods are produced. Capital thus receives a constant share of the sales of the X-sector. It is assumed that each x-firm has to acquire one unit of capital as an up-front investment before it can start production, which yields $n = K$.[6] The profit per x-good is the return per unit of capital. In this multi-sector model, we get for the profit per x-firm π_j:

$$\pi_j = (1 - \beta) \cdot E_x/K\,. \tag{15}$$

For the production of new capital goods, skilled and unskilled labour are used as inputs. As for final goods in the one-sector model, knowledge κ is assumed to be a proportional free input into the production of capital goods in this three-sector model. Thus the production function of the capital goods sector is (in continuous formulation) $\dot{K} = G\,(S, L) \cdot \kappa$ where G is a functional for the effect of the labour inputs on capital output. Because knowledge from other regions is assumed to be an exogenous variable in this multi-sector model, we assume the input of home knowledge to yield a constant return of output of capital goods, i.e. $\gamma = 1$. Total knowledge is now:

$$\kappa = \kappa_h \cdot (\kappa_o)^\eta\,. \tag{1'}$$

For proportional spillovers we get $\kappa_h = K$ according to (3). Then, the "output" in the capital goods sector can be written as: $\dot{K}/K = g = G\,(S, L) \cdot (\kappa_o)^\eta$. In the following, the variable g is used for the sectoral output in the same way as the outputs X and Z of the other two sectors. The price of a capital good p_K is equal to unit *labour* cost c_K divided by total knowledge in the home region according to (1′) and (3), so that:

$$p_K = \frac{c_K}{K \cdot (\kappa_o)^\eta} = \frac{\sum_i a_{iK} \cdot w_i}{K \cdot (\kappa_o)^\eta} \quad (i = L, S)\,. \tag{16}$$

Assuming – to facilitate calculations – that total consumer expenditures are equal to one at any point in time, i.e. $E = 1$, the average return on capital μ is obtained by the quotient of the per firm profit given in (15) and the cost of producing one unit of capital given in (16) (see also Grossman and

Helpman 1991, p. 61 ff.). The average return on capital investments is now calculated by using (13) and (12) which gives:

$$\mu = \frac{(1-\beta)}{\beta} \cdot \frac{\sum_i a_{ix} \cdot w_i}{\sum_i a_{iK} \cdot w_i} \cdot X \cdot (\kappa_o)^{\eta} \quad (i = L, S)\,. \tag{17}$$

It can be seen from (17) that the higher the advantage of product differentiation in the X-sector (lower β), the larger the return on capital. In addition to the constant $(1–\beta)/\beta$, there are three distinct effects on the return on capital in this three-sector model. First, the relative labour cost in the X- and K-sector, second, the quantity of produced x-goods and, third, the level of knowledge from other regions.

5. Comparative dynamics in the three sector approach

Let us derive the impact of interregional knowledge diffusion on regional growth in two steps. First, a graphical and verbal explanation is presented to demonstrate the basic effects at work and to show the difference from the one-sector model most clearly. Second, an analytical derivation of the impact of goods trade on regional growth will be presented, which demonstrates possible negative dynamic effects provided interregional knowledge diffusion is not strong enough. Following equation (17), I begin the verbal explanations with the relative labour cost effect and then comment on the influence of x-goods and intraregional knowledge diffusion on capital productivity. I consider the effect of rising interregional integration on goods markets which is observed today. According to trade theory, the effect of increasing goods market integration can be captured by the comparison of autarky and free trade, which is sufficient to describe the relevant features. Assume the home region to be richer in skilled labour than its trading partner regions. Then, referring to standard trade theory, the reward for unskilled labour is decreased and the reward for skilled labour is increased in this region as a consequence of free trade.[7] If this expectation is correct (which can be shown by means of the model, see below), the relative cost effect on marginal and average return of capital is unambiguously negative for a region that is relatively well-supplied with skilled labour. The opposite results apply to a region that is relatively well-supplied with unskilled labour.

Consider Fig. 3 and assume again the home region to be relatively well-supplied with skilled labour. The μ-curve represents the equilibrium levels of capital productivity according to (17). The relative labour cost effect of integrating goods markets is shown by the shift of the equilibrium point of the economy to the left of the original μ-curve, which means lower regional capital productivity and lower growth. A corresponding discrete change in wages, i.e. in relative costs, lowers μ which is indicated by the solid arrow. To counter this effect, an increase in the production of x-goods can lead the region back to the original capital productivity and the original

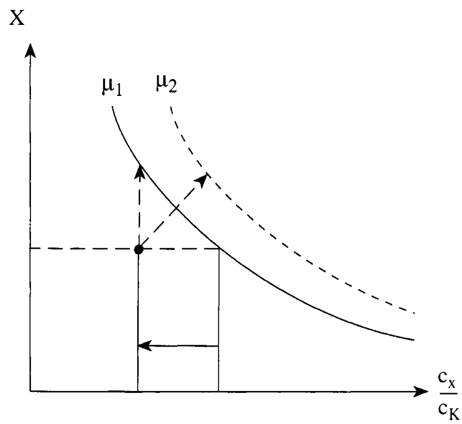

Fig. 3. Increasing goods trade in a region with abundant skilled labour

growth rate. Increasing production in the X-sector has to be accomplished by raising interregional export activities. This effect is shown in Fig. 3 by the dotted arrow pointing in the vertical direction. But a substantial increase in κ_o will do as well. Also, a combination of an increase in X and κ_o would be welcome for the home region. As the chances to increase interregional exports are often limited, interregional knowledge diffusion turns out to be a powerful tool to preserve the region's long-term prosperity if it becomes more integrated in interregional goods markets. With a large effort concerning an increase in κ_o, the home region is even able to overcompensate for the negative effect of goods market over time, which is indicated by the dotted arrow pointing north-east in Fig. 3. It must be emphasised that the results here are only concerned with regional dynamics so that the argument for static gains from interregional trade (sectoral specialisation, increasing goods variety) remains valid in the dynamic setting.

In the following, the formal derivation of comparative dynamics is carried out in order to weigh the relative labour cost effect against the impact of increasing X-production. To demonstrate this effect most clearly, we neglect interregional knowledge diffusion, i.e. it is assumed here that $\eta=0$. Denoting again unit labour input factors with a-parameters and using the variable g for the "output" of the investment sector, the equations for the equilibria on the labour markets for L and S in the home region become:

$$\begin{bmatrix} a_{LZ} \\ a_{SZ} \end{bmatrix} \cdot Z + \begin{bmatrix} a_{Lx} \\ a_{Sx} \end{bmatrix} \cdot X + \begin{bmatrix} a_{LK} \\ a_{SK} \end{bmatrix} \cdot g = \begin{bmatrix} L \\ S \end{bmatrix}. \tag{18}$$

Using the price-cost relations (11), (12) and (13), and denoting consumer expenditures by the variable E, Z and X in (18) can be substituted by E_x, E_z, p_x and p_z. For comparative dynamics, one has to observe that prices p_x and p_z depend directly on wages, which will be determined endogenously, and that moving from autarky to free trade can be introduced by a change in E_x and E_z. This is – according to standard trade theory of comparative advantage – done in the following way. In a region that is abundant in the supply of skilled labour S, the move from autarky to free trade increases S-intensive X-production and prices in the X-sector whereas L-intensive Z-production and prices in the Z-sector decrease, i.e. in the model, E_x increases and E_z decreases as a consequence of free trade. In the following, the move to free trade is represented by an increase in the "free trade parameter" ζ, which depends on symmetrical sectoral expenditure changes (see appendix for the definition). Also, it can be referred to the fact that, with $E=1$, the quotient of π_j given by equation (15) and of p_K of equation (16) is equal to the average return of capital μ used in equation (5). Here, we set for convenience the depreciation rate equal to zero, i.e. $\delta=0$.

With these additional elements, equations (18) and (5) form a system of three equations for the three endogenous variables g, w_S and w_L (see appendix for details).[8] In equilibrium, the growth rate g as well as prices and wages in the Z- and X-sectors are constant, whereas prices of capital goods decrease with the same rate as the capital quantities and knowledge increase. By differentiation of this system, one obtains the impact of ζ on the percentage change of the regional growth rate and the two wage rates. The result for the percentage change of the growth rate $\hat{g}$ is:

$$\hat{g} = \frac{1}{\Delta}$$
$$\left[-\sum_i \sigma_i(\lambda_{Li}\theta_{Si} - \lambda_{Si}\theta_{Li}) - \sum_{i'} \lambda_{Li'}(\theta_{SK} - \theta_{Si'}) - \sum_{i'} \lambda_{Si'}(\theta_{Li'} - \theta_{LK})\right] \cdot \zeta \tag{19}$$
$$i = Z,\, x,\, K; \quad i' = Z,\, x$$
$$\Delta > 0$$

The λs are the factor shares in the different sectors and the θs are the cost shares (as in standard trade theory) with the corresponding subscripts for the labour input in each of the activities. σ_i is the elasticity of substitution between skilled and unskilled labour in sector i. The determinant Δ is unambiguously positive. According to the assumptions on the sectoral factor intensities, the second and the third term on the right hand side of (20) are negative, as $\theta_{SK}-\theta_{Si'}>0$ and $\theta_{Li'}-\theta_{LK}>0$ for $i'=Z, X$. Assuming the elasticities of substitution in the first term of (20) to be zero, the entire relation between ζ and the change in g becomes negative. This means that if technology is characterised by a Leontief fixed-coefficient production function, the impact of free trade on regional development is unambiguously negative. In this case, only an increase in interregional knowledge diffusion can prevent the region from a lower development path when moving to free trade. Allowing for substitution between skilled and unskilled labour in the three sectors, a positive sign of the first term is possible but by no means guaranteed. Depending on the sectoral mix of the region, the term $\lambda_{Li}\theta_{Si}-\lambda_{Si}\theta_{Li}$ with $i=Z, x, K$ might be negative but might also be positive, so that the negative influence of goods trade remains.

This means that, for a region with abundant skilled labour, interregional knowledge diffusion is of special importance to reach dynamic gains from trade whereas insufficient interregional knowledge might result in regional development being harmed by an opening of the regional economy. The same system can be used to calculate the effect of free trade on wages, which yields the results of the Stolper-Samuelson theorem (see Endnote 7); in the region considered, wages of unskilled labour decrease whereas wages of skilled labour increase as a consequence of free trade. Remember that, in this calculation, the static gains from interregional trade are not diminished by the dynamic effects.

6. Concluding remarks

The present paper shows that the different kinds of intra- and interregional knowledge transmission have serious macrodynamic consequences. Moreover, as knowledge diffusion is effective in the form of a positive externality, spatial diffusion of knowledge is not on an optimal level in reality. It also emerges that globalisation in goods markets is not necessarily positive for long-term development of regions under the externalities of knowledge production. For regions that are well-endowed with skilled labour, the reallocation of resources caused by increasing goods trade can be negative for capital productivity and growth, if interregional knowledge diffusion is not effective. Therefore these regions should not only extend their trade relations to obtain the various gains described in traditional trade theory, but also improve interregional knowledge transmission to avoid unfavourable resource reallocation effects. The opposite result applies to regions that are well-endowed with unskilled labour.

The dynamic perspective of this paper sheds a somewhat different light on the causal relation between the non-EU membership of the region Canton of Zurich (already cited in Sect. 3) and the recent dynamic underperformance of this economy compared to other European regions. It is suggested that the problem for development might not be the lack of trading opportunities, which are still at a very high level, but the incomplete integration in European knowledge networks. One can e.g. plausibly argue that the cross-border restrictions on the markets for skilled labour harm learning-intensive face-to-face contacts to a certain extent. Also, the limited regional availability of European high-speed trains and the difficult access to European research cooperation diminish interregional knowledge diffusion. Moreover, regional telecommunication networks are very expensive compared to the rest of Europe, which might be a further reason for knowledge diffusion being at a suboptimal level.

Because knowledge diffusion has proven to be an important part of regional economic relations, future research should be directed towards a better microeconomic foundation of the efficiency in the absorption of knowledge from other regions. In addition, more empirical results are desirable in this field. Microeconometric research, e.g. on patent citations and on the use of different networks, could yield more insights on how the theoretical models of knowledge transmission should be appropriately specified. To pursue this goal, one should make full use of the existing case studies. Further inquiries are also desirable on the relation between intra- and interregional knowledge diffusion in the regional production function. Regional concentration will heavily depend on the extent the two factors are substitutes or complements. The larger the complementarity is, the stronger the persistence of regional concentration of economic activities gets, despite of rapid progress in information technologies.

An accurate specification of interregional knowledge diffusion will also be valuable in order to answer the question whether regions converge or diverge with regard to long-term income levels. The more important intraregional knowledge diffusion in relation to interregional knowledge diffusion is, the larger are the divergence forces compared to the convergence forces.

Appendix

Inserting prices and expenditures in labour markets (18) yields:

$$\begin{bmatrix} a_{LZ} \\ a_{SZ} \end{bmatrix} \cdot \left(\frac{E_Z}{p_Z} \right) + \begin{bmatrix} a_{Lx} \\ a_{Sx} \end{bmatrix} \cdot \left(\frac{E_x}{p_x} \right) + \begin{bmatrix} a_{LK} \\ a_{SK} \end{bmatrix} \cdot g = \begin{bmatrix} L \\ S \end{bmatrix}.$$

Assuming $E=1$ and $\delta=0$, using (5), (15) and (16) gives the capital market equilibrium (i.e. the adjusted Keynes Ramsey rule):

$$g = \frac{(1-\beta) \cdot E_x}{c_K} - \rho\,.$$

Differentiating the system consisting of these three equations, using hats for percentage changes, and assuming a constant labour force yields:

$$\begin{bmatrix} c_{11} & c_{12} & \lambda_{LK} \\ c_{21} & c_{22} & \lambda_{SK} \\ \theta_{LK} & \theta_{SK} & \frac{g}{g+\rho} \end{bmatrix} \cdot \begin{bmatrix} \hat{w}_L \\ \hat{w}_S \\ \hat{g} \end{bmatrix} = \begin{bmatrix} \zeta_1 \\ \zeta_2 \\ \zeta_3 \end{bmatrix}$$

with $i=Z, x, K$; $i'=Z, x$ and:

$$c_{11} = -\sum_i \lambda_{Li}\theta_{Si}\sigma_i - \sum_{i'} \lambda_{Li'}\theta_{Si'}$$

$$c_{12} = \sum_i \lambda_{Li}\theta_{Si}\sigma_i - \sum_{i'} \lambda_{Li'}\theta_{Si'}$$

$$c_{21} = \sum_i \lambda_{Si}\theta_{Li}\sigma_i - \sum_{i'} \lambda_{Si'}\theta_{Li'}$$

$$c_{22} = -\sum_i \lambda_{Si}\theta_{Li}\sigma_i - \sum_{i'} \lambda_{Si'}\theta_{Si'}$$

$$\zeta_1 = -\lambda_{LZ} \cdot \hat{E}_Z - \lambda_{Lx} \cdot \hat{E}_x > 0 \quad (\text{for } \hat{E}_x > 0 \text{ and } \hat{E}_Z < 0)$$
$$\zeta_2 = -\lambda_{SZ} \cdot \hat{E}_Z - \lambda_{Sx} \cdot \hat{E}_x < 0 \quad (\text{for } \hat{E}_x > 0 \text{ and } \hat{E}_Z < 0)$$
$$\zeta_3 = \hat{E}_x > 0\,.$$

To calculate the effect of free trade, we use the symmetrical case $\zeta_1 = -\zeta_2 = \zeta$ which is referred to in the main text.

Endnotes

[1] If the financing of this subsidy causes distortions, these have to be weighed as a welfare loss against the dynamic gains by the subsidies. In this model, however, we disregard the labour/leisure choice such that a tax on income or consumption is non-distorting.
[2] If the depreciation rate in (5) is not constant but increases with rising knowledge inflows from other regions, the growth rate might be constant which is more realistic.
[3] The results are in Bretschger et al. (1995).
[4] This is especially obvious for R&D investments.
[5] Growth models using differentiated goods rely on the well-known symmetric CES-specification of monopolistic competition as introduced by Dixit and Stiglitz (1977) into economic theory. A more detailed motivation for the assumptions used here is provided in the expansion-in-varieties model used in Grossman and Helpman (1991) p. 43 ff.
[6] Romer (1990) assumes that capital is the know-how i.e. the knowledge capital that a firm producing differentiated goods needs to acquire before it can start production. In a broader sense, one could also argue with other types of capital that are needed before production can start.
[7] The argument is based on the Stolper-Samuelson theorem which is valid for the 2×2 Heckscher-Ohlin-Samuelson model and continues to hold when adding an additional sector (see e.g. Ethier 1984, p. 144).
[8] In the three sector model, the growth rate *g* is defined as the rate of increase in differentiated goods as well as the increase in capital goods and knowledge.

References

Arrow KJ (1962) The Economic Implications of Learning by Doing. *Review of Economic Studies* 29:155–173

Batten DF, Karlsson C, Andersson AE (1989) Knowledge, Nodes and Networks: An Analytical Perspective. In: Andersson AE, Batten DF, Karlsson C (eds) Knowledge and Industrial Organization. Springer, Berlin Heidelberg New York, pp 31–46

Bretschger L (1997) International Trade, Knowledge Diffusion, and Growth. *The International Trade Journal* 9(3):327–348

Bretschger L et al. (1995) Wirtschaftsstandort Zürich, Wettbewerbsfähigkeit heute und morgen. ZKB (Hrsg), Zürich

Dixit AK, Stiglitz J E (1977) Monopolistic Competition and Optimum Product Diversity. *American Economic Review*, 67(3):297–308

Dollar D, Wolff E (1993) Competitiveness, Convergence, and International Specialization. MIT Press, Cambridge, Mass

Ethier WJ (1984) Higher Dimensional Issues in Trade Theory. In: Jones RW, Kenen PB (eds) *Handbook of International Economies*, Vol. 1. North-Holland, Amsterdam, pp 133–184

Gaspar J, Glaeser EL (1996) Information Technology and the Future of Cities. *NBER Working Paper* No. 5562

Grossman GM, Helpman E (1991) Innovation and Growth in the Global Economy. MIT Press, Cambridge, Mass

Johansson B (1995) The Dynamics of Economic Networks. In: Batten D, Casty J, Thord, R (eds) Networks in Action – Communication, Economics and Human Knowledge. Springer, Berlin Heidelberg New York, pp 287–308

Kobayashi K (1995) Knowledge Network and Market Structure: An Analytical Perspective. In: Batten D, Casty J, Thord R (eds) Networks in Action – Communication, Economics and Human Knowledge. Springer, Berlin Heidelberg New York, pp 127–158

Krugman P (1991) Geography and Trade. MIT Press, Cambridge Mass

Marshall A (1920) Principles of Economics. Macmillan, London

Rogers EM (1983) Diffusion of Innovations, 3rd edn. The Free Press, New York

Romer P (1990) Endogenous Technical Change. *Journal of Political Economy* 98:71–102