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Peter Nijkamp and Jacques Poot

Abstract

This paper explores growth models for regions or countries which are highly interdependent, but which may differ in initial factor endowments and technology. The regions interact through trade, factor mobility and the diffusion of innovations. The implications of traditional and recent growth theories for an explicit two-region situation are identified and the properties of the growth process are established. The role of policy instruments such as the investment ratio and expenditure on R&D are discussed. Both demand and supply side considerations receive attention. It is found that endogenous technical change and scale effects are likely to lead to uneven development. While steady-state growth paths may exist on which the regions grow at different rates, the stability of such steady-state growth depends on a range of behavioural parameters and the mobility of production factors.

1. Introduction

The history of economic growth theory is marked by fluctuating patterns of interest. For example, it was noted by Fisher (1988) in a review of recent developments in macroeconomics that the theory of economic growth received relatively little attention during the last two decades, after the subject had been extensively developed in the literature of the 1950s and 1960s. Yet a revival seems to be emerging now, resulting from (1) theoretical developments regarding dynamic neoclassical general equilibrium models and the implications for growth of new trade theories; (2) much analytical work in the early 1980s on the process of technical change and its effect on productivity (e.g. Nelson and Winter, 1982 and Stoneman, 1983); and (3) empirical observations on long-run economic change such as the productivity growth slowdown in OECD countries followed by renewed growth in recent years, the remarkable growth performance of NICs etc.

Recently, Lucas (1988) showed that the traditional Solow-Swan neoclassical growth model results from intertemporal optimisation in an Arrow-Debreu competitive equilibrium framework, although much earlier Cass (1965) showed that from any starting-point optimal capital accumulation converges to the balanced Solow-Swan growth path. However, Lucas also emphasised that this model is rejected by a casual comparison of long-run growth performance of different economies which do not exhibit converging growth patterns. The Solow-Swan model implies that countries with the same preferences and technology will converge to identical levels of *per capita* income and long-run rates of growth (assuming the same rate of population growth). Thus, differences in the growth paths between countries must be due, in the context of this model, to variations in preferences (e.g. the discount rate and the intertemporal elasticity of substitution, which determine the propensity to save) or differences in technology. Lucas stated rightly that the latter avenue for explaining growth differentials is more promising. Indeed, that technology remains the dominant engine of growth with human capital investment in second place, was also noted by Solow (1988) on the basis of Denison's growth accounting for the USA. Lucas formulated in his paper two models which embody endogenous technical change through human capital accumulation by means of schooling or on-the-job training. These fit the stylized facts of world economic development better than the original Solow-Swan model. Similar approaches were adopted by Romer (1986) and Rouwendal and Nijkamp (1989).

Clearly, an important drawback of most neoclassical growth models with endogenous technical change is that they focus on real capital accumulation and, in a multisectoral framework, real trade, thus abstracting from monetary considerations. This may be a serious omission in models explaining growth differences between countries, although Lucas (1988) points out that we do not know as yet how serious this omission is. However, this feature does make the existing neoclassical models eminently suitable to analyse regional (i.e. intra-national) differences in growth, since monetary conditions (e.g. interest rates and inflationary expectations) may be assumed largely constant across regions and are thus unlikely to generate differential effects.

However, it is noteworthy that the conventional regional growth literature has tended to proceed along Keynesian lines with a heavy emphasis on demand considerations. Thus, in the well known Kaldor-Dixon-Thirlwall model output growth in a region is driven by relative competitiveness and income growth outside the region (Dixon and Thirlwall, 1975). Supply side factors play in such an export-led growth model only a role in terms of the effects of cost inflation and productivity on relative competitiveness, with the latter effect being generated by means of Verdoorn's law. This model can explain differences in equilibrium growth rates between regions in terms of differences in price and income elasticities in the demand for exports and differences in rates of autonomous productivity growth. Such differences in growth rates between regions are constant, but Krugman (1989) noted recently that long-run balance of payments equilibrium in such a regional growth-and-trade framework necessitates a strict relationship between differences in growth rates between regions on the one hand and income elasticities of the demand for exports and imports on the other. However, the Kaldor-Dixon-Thirlwall model is itself not informative about the processes which would ensure that the growth rates which their model generates would be consistent with long-run balance of payments equilibrium.

Theoretical models of the nature discussed above must be confronted with the observation that in recent years economic restructuring, technological change and the shifts in spatial growth patterns have exerted a far reaching impact on resource allocation and welfare. National and regional economic systems have become more interdependent. In addition, public policymakers have become aware of the need to stimulate competitive behaviour and their policies are increasingly oriented towards deregulation, devolution and a reliance on market signals. Among these, regional policies reflect responses to a permanent conflict between the relatively efficient use of scarce resources in core regions and the resulting equity discrepancies with respect to peripheral regions. Production-oriented policies can have strong spatial and sectoral impacts. For instance, a regional innovation policy favouring the microelectronics industry or the telecommunications sector gives areas with a favourable "seedbed" potential for these sectors a priority treatment. Technological innovation is therefore not "manna from heaven", but can be generated by well-focused public policies (in close collaboration with private initiatives). Hence, technology policy tends to become a tailor-made endeavour to favour the creation of specific innovative activities in specific sectors and at specific locations. Once developed, the new technology and ideas may spread to nurture growth elsewhere. As such, technology policy cannot be separated from other fields of public policy such as socio-economic policy and physical planning (cf. Whittington, 1985). A clear analytical framework which integrates economic growth, spatial interdependencies and the creation of new technology as an explicit production process is required to formulate production-oriented regional policies.

In this paper we review some traditional and recent theories of regional growth in which endogenous technological progress and spatial interdependence can be considered explicitly. We outline the implications of such models for a specific situation of two regions which exchange goods, or production factors, or technical knowhow, or - in the most general case - all three simultaneously. We commence in the next section with the Kaldor-Dixon-Thirlwall export-led growth model. It is straightforward to compute equilibrium growth rates for the two regions in this model. The implications for trade, factor mobility and productivity growth when the two regions have different growth rates are discussed.

However, the weakness of the Verdoorn relationship in the Kaldor-Dixon-Thirlwall model is that it does not make explicit how technological change, scale effects and structural change generate increasing returns in the economy. Such supply-side phenomena are of critical importance when we wish to analyse spatial development. Recent literature in the area of technology-push phenomena has made plausible that industrial innovations (either basic or process innovations) may be regarded as major driving forces for structural changes in the space-economy. The so-called depression-trigger hypothesis is here an important analytical idea, which suggests that the down-swing phase of the economy induces the invention and implementation of radically new (often clustered) technologies (see also Mensch, 1979). Besides, the demand side of the market can in this framework be incorporated by means of the so-called demand-pull hypothesis (see Clark *et al.*, 1981 and Mowery and Rosenberg, 1979).

The depression-trigger hypothesis, which is essentially based on a challenge-response type of economic behaviour, states that a stimulus for economic restructuring requires basic innovations in the productive sector. Such innovations do not only need the production of new commodities, but also the provision of new locations or locational advantages for innovative entrepreneurs. This also implies that the implementation of new urban or regional infrastructures is a *sine qua non* for spatial economic dynamics. Altogether, the combination of productive capital, public overhead capital, R & D capital and the emergence of new markets are critical conditions for creating radical technological changes (Schmookler, 1966).

Such complex processes are not easily captured in simple analytical models. Nonetheless, in section 3 we introduce the interplay of the accumulation of physical capital and "knowhow", labour mobility and economic growth by means of an extension of the standard Solow-Swan growth model. Without technical progress, it is easy to identify a balanced growth path even with non-zero net migration, but with both technical progress and labour supply endogenous, the situation is more complex. Such technical change is assumed to be induced by resources devoted to R&D and education through a "technical knowhow" production function. In this situation it is possible for positive net migration to coincide with an increase in the real wage. Of particular interest in this context is also the effect of diffusion of technology as another form of spatial interaction. In the latter case, it will be shown that both balanced and unbalanced growth paths can emerge.

In reality, trade, migration, technical change and capital flows occur simultaneously. Freeman (1988) noted recently that trade theory offers two quite different views of the interrelationship between these flows. On the one hand, the Heckscher-Ohlin theory suggests that trade and factor mobility are substitutes to achieve factor price equalisation and a final equilibrium with a static allocation of factors. However, if trade results from differences in technology between regions or countries, the flows are likely to be complementary. Increases in net migration can then increase trade and generate capital inflows as well. In the penultimate section we comment on the likely implications of allowing some factor mobility and technical change in trade and growth models. An extension to the standard Oniki and Uzawa (1965) two-sector two-region growth model with endogenous technical change will then be considered. Moreover, the increasing returns growth-and-trade models proposed by e.g. Krugman (1981), Romer (1986) and Lucas (1988) are reviewed. Rigorous treatments in this area are often thwarted by the analytical complexities of the resulting differential equation systems and this paper purports by no means to provide an exhaustive account of regional growth with interregional interaction. In the final section we outline possible further developments.

2. Trade and technical change in a demand-determined two-region model

If technical change proceeds at a different pace in two regions, growth in the more innovative region could be hampered by lower demand for its output from the less innovative, and competitive, region. Yet, without built-in "correction" mechanisms the two regions could continue to grow at different rates, implying an ever-increasing trade-imbalance. This can be easily demonstrated by applying the Dixon-Thirlwall (1975) model to two specific areas. This model is linear in growth rates and it is easy to derive the reduced form to compute the equilibrium growth rates. Since exports tend to dominate the part of demand unrelated to domestic income, it is not a bad approximation to assume that exports are a constant proportion of income. If g is the steady-state rate of growth of production or income in one region and g^f in the other, this implies that the growth rates g and g^f are equal to the growth rate of exports, x and x^f respectively. Hence

$$g = x \qquad (2.1)$$

$$g^f = x^f \qquad (2.2)$$

However, the demand for exports in both regions is sensitive to the own price level, and the price and income level in the other region. Assuming constant elasticities, we can write

$$x = -\eta\, p + \delta\, p^f + \varepsilon\, g^f \qquad (2.3)$$

$$x^f = -\eta^f p^f + \delta^f p + \varepsilon^f g \quad (2.4)$$

with the rate of change in the price-level denoted by p and p^f respectively, and η, η^f, δ, δ^f, ε and ε^f the corresponding elasticities. Naturally one region's imports is the others exports, hence

$$m = x^f \quad (2.5)$$

$$m^f = x \quad (2.6)$$

where m and m^f represent import volume growth rates. Price inflation results from fixed mark-up pricing on production costs, which in turn depend on unit wage costs and labour productivity. Thus, in rate of change terms

$$p = w - r \quad (2.7)$$

$$p^f = w^f - r^f \quad (2.8)$$

with w and w^f the exogenous change in unit labour costs and r, r^f the rate of change in labour productivity. Central to this growth model is that labour productivity is partly dependent on growth of output itself, i.e. Verdoorn's Law:

$$r = ra + \lambda g \quad (2.9)$$

$$r^f = ra^f + \lambda^f g^f \quad (2.10)$$

in which ra and ra^f refer to autonomous productivity growth and λ and λ^f are elasticities. An extensive literature exists regarding the empirical evidence for this relationship (reviewed in e.g. Bairam, 1987), which suggests that the observed relationship may be the result of simultaneous responses in output and labour markets to changes in demand, combined with the effects of economies of scale and technical progress. Naturally, a simultaneous equation approach is required for empirical estimation of the parameters in (2.9) and (2.10). There is extensive evidence that λ (and λ^f) are positive. Nonetheless, Skott (1989) noted recently that the link between productivity and competitiveness implied by the Verdoorn relationship and the export demand function is too strong: nominal wages could react to an increase in productivity, which could partly offset the the effect of productivity growth on export growth.

The final equations in the model simply define employment growth rates n and n^f by

$$n = g - r \quad (2.11)$$

$$n^f = g^f - r^f \quad (2.12)$$

The full model is now a linear system in which money wages and autonomous productivity are the only exogenous variables. Substituting (2.1), (2.2) and (2.7) to (2.10) into (2.3) and (2.4), two linear equations in the variables g and g^f emerge, which can be solved to yield:

$$g = \frac{(\delta - \varepsilon\, \eta^f)\, (w^f - ra^f) + [\, (\varepsilon - \delta\, \lambda^f)\, \delta^f - (1 - \eta^f \lambda^f)\, \eta \,]\, (w - ra)}{[\, (1 - \eta\, \lambda)\, (1 - \eta^f \lambda^f) - (\varepsilon - \delta\, \lambda^f)\, (\varepsilon^f - \delta^f \lambda)\,]} \tag{2.13}$$

and

$$g^f = \frac{(\delta^f - \varepsilon^f \eta)\, (w - ra) + [\, (\varepsilon^f - \delta^f \lambda)\, \delta - (1 - \eta\, \lambda)\, \eta^f \,]\, (w^f - ra^f)}{[\, (1 - \eta\, \lambda)\, (1 - \eta^f \lambda^f) - (\varepsilon - \delta\, \lambda^f)\, (\varepsilon^f - \delta^f \lambda)\,]} \tag{2.14}$$

Once these two growth rates have been computed, all other endogenous variables follow readily. The growth rates are not uniquely determined by the model if the corresponding parameters of the two regions are identical and, at the same time, the income elasticity of the demand for exports is equal to one. However, in all other cases, unique equilibrium growth rates g and g^f emerge which are dependent on both "domestic" and "foreign" conditions (unless $\delta = \varepsilon\, \eta^f$ and $\delta^f = \varepsilon^f \eta$ when only domestic conditions matter, but there is no *a priori* justification for such restrictions on the parameters). If equations (2.13) and (2.14) generate two growth rates g and g^f which are unequal, it is obvious that the region with the higher growth rate would eventually experience an ever-increasing trade volume surplus (in view of equations (2.1), (2.2), (2.5) and (2.6)) since we do not take into account a balance-of-payments constraint. However, Krugman (1989) pointed out that a long-run trade balance between two regions which grow at different rates requires a continuous adjustment in the real exchange rate, unless $\varepsilon / \varepsilon^f = g / g^f$. Interestingly, the latter condition appears indeed consistent with international trade data, i.e. countries which grow fast tend to experience a high income elasticity of the demand for their exports, while the income elasticity of their demand for imports is low.

In general, the effects of exogenous shocks on the equilibrium growth rates would depend on the choice of parameters. As a simple illustration, assume that the price elasticities in the two regions are equal, i.e. $\eta=\eta^f=\delta=\delta^f$. It is easy to see that this implies that the effect of a change in w-ra is of the same magnitude, but opposite sign, of the effect of a change in $w^f - ra^f$. If these parameters have empirically plausible values, for example $\eta=\eta^f=\delta=\delta^f=1.5$ and $\varepsilon=\varepsilon^f=1.2$ while $\lambda=\lambda^f=0.5$, simple substitution shows that in this case an increase in the rate of productivity growth in the trading partner's economy of 1 percentage point reduces the own region's equilibrium growth rate by 2.1 percentage points, while a 1 percentage point increase in the rate of growth of local labour productivity increases the growth rate by 2.1 percentage points. These relatively large responses may appear somewhat unrealistic, but they are of course the result of the amplification of the Verdoorn effect through trade in a closed two- region system. Indeed, if the Verdoorn effect is strong enough, a perverse situation is generated in which a detrimental shock in the trading partner's economy (e.g. a rapid growth in nominal wages) is more than compensated by an, on balance, negative effect on the local economy. For example, if $\lambda=\lambda^f=0.9$ while $\varepsilon=\varepsilon^f=1.2$ and $\eta=\eta^f=\delta=\delta^f=1.5$ we find that $\partial g / \partial(w^f - ra^f) = -3.0$ and $\partial g^f / \partial(w^f - ra^f) = +3.0$.

The model discussed above does not take into account explicitly the possibility of migration between the regions, nor the diffusion and adoption of technological advances. These phenomena cannot be readily introduced here. For example, net migration would respond to the difference in employment growth rates, $n - n^f$, as well as to the differential growth in wages, $w - w^f$, but in this case the latter may become endogenous due to demand-supply interactions and hence be affected by net migration itself. Moreover, production capacity limits are assumed unimportant. In essence, the model provides a short-run comparative static approach rather than a truly dynamic one. [1] Yet the model does make explicit that an exogenous shock to trade can have a long-term impact on the equilibrium growth rate, although the discussion clearly demonstrates that the introduction of simple explicit feedback effects (here aggregate demand and relative competitiveness) can strongly modify the behaviour which may be expected in the absence of such effects. [2]

In contrast with the emphasis on the demand side in the model discussed above, in the next section we move to supply considerations by addressing explicitly the effects of migration and technical change on growth. We return to trade in the penultimate section.

3. Endogenous technical change and migration in a one-sector neoclassical growth model

It is well known that technical change, rather than the increase in capital intensity, is the dominant force behind long-run growth of output per head. In the Solow-Swan neoclassical growth model with labour-augmenting technical progress, long-run growth is balanced and the rate of growth in output is simply the sum of an exogenous rate of growth in labour supply, plus an exogenous rate of growth in technical change (e.g. Ramanathan, 1982, pp.84-85). Yet, in practice, technological innovation is not a *deus ex machina* which serves to save a malfunctioning economy without active efforts of all actors involved. Regions are competitive geographical units which will try to obtain an economic advantage by either generating technologically advanced products (or processes) or attracting an optimal share of the pool of available technologies. Thus the question of the spatial selection environment

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[1] It is possible to introduce lags in the behavioural equations. Dixon and Thirlwall show that the introduction of one period lags in the export demand function still generates convergence to the equilibrium growth rate for plausible values of the elasticities. In our case, convergence would depend on the eigenvalues of the resulting linear first-order difference equation system in g and gf.

[2] This is a general conclusion for models of interdependent regions. See also, for example, the models which have been developed by Frenkel and Razin (1987) to describe the effects of fiscal policies and monetary conditions on equilibrium output in a "two-region world".

(Kamann, 1988) which induces technogenesis is at stake here (see also Davelaar and Nijkamp, 1989).

It is noteworthy that the technological performance of a region is mainly dependent on two factors: (1) its sectoral structure in terms of industrial composition, firm size, industry-technology life cycle, R&D investments, industrial networks, etc.; (2) its incubation potential in terms of agglomeration economies, information networks, accessibility, labour market, cultural amenities, production environment, and the like (cf. Batten, 1982; Oakey,1984). It is evident that the sectoral structure and the incubation potential are not entirely independent factors, as innovative entrepreneurs are operating in an open economic and spatial system.

In Malecki and Nijkamp (1988) it has been argued that the blend of entrepreneurial spirit, technologically-sensitive sectoral structures and creative environments is of critical importance for a successful technological transformation process. Since new technology is an important weapon in a competitive market, firms will consider a favourable geographical location as an important dimension of their entrepreneurial strategy. Consequently, the locational aspects of technogenesis have become an important aspect of current technology research, by analyzing the driving forces that stimulate technogenesis (economic mechanisms, urban and regional "seedbed" conditions etc.). Besides, even when technological innovations have materialized, this does not mean that all firms or regions are able to "reap the fruits" of a new technogenesis. Apparently, there are many bottle-necks to be overcome. This leads for instance to the question which transfer mechanisms (e.g. networks) are favourable for ensuring a smooth diffusion and adoption of new technologies.

It is obvious that at the macro level such diverse aspects of technical change must be simplified to generate an amenable growth model. Here we will assume that the outcome of this complex process of technical change may be measured by changes in productivity of units of labour. Thus, if N measures the effective labour input, N = L T, where L is the quantity of workers and T represents a quantitative index of the stock of technological knowledge and practices which lead to productivity enhancement. Central to the current view about the process of technological innovation is that a change in this stock T requires a production process with real resource inputs, a multi-product output, its own technology, market structure, spatial differentiation and, indeed, its own changing technology (e.g. Dosi, 1988). Here we will assume that a change in the stock T is generated by a quasi production function

$$\frac{dT}{dt} = H\left(\frac{R}{L}, T\right) \qquad (3.1)$$

where R/L is expenditure per worker on activities such as education, training, R&D etc.[3] Thus, the change in T is positively related to the intensity of the effort devoted to the enhancement of the effective labour input, as well as the size of the stock. This function is assumed to have constant returns to scale with the usual properties (H_1, H_2, $H_{12} > 0$, H_{11}, $H_{22} < 0$). The resources

[3] This equation is a generalisation of a model of endogenous technical change proposed by Conlisk (1967), who assumed that dT/dt would be a linear function of Y/L and T.

allocated to this process of technical change are assumed to be proportional to income Y:

$$R = m\,Y \tag{3.2}$$

where m is a behavioural parameter, which can depend on structural and spatial factors. Output is produced according to a well-behaved neoclassical production function, i.e.

$$Y = N\,f(k) \tag{3.3}$$

with $k = \frac{K}{LT} = \frac{K}{N}$. Combining (3.1) to (3.3), we may write

$$\frac{dT}{dt}\frac{1}{T} = H(\frac{R}{LT}, 1) = h(m\,f(k)) \tag{3.4}$$

Ignoring depreciation, net investment is assumed proportional to Y, hence

$$I = \frac{dK}{dt} = s\,Y \tag{3.5}$$

It is obvious that (3.2) and (3.5) imply that the long-run consumption function is one of simple proportionality between consumption and income: since C = Y - R - I, C = (1-m-s) Y. If we assume that the labour input L grows at an exogenous rate, n, it is easy to see that equations (3.1) to (3.5) represent a complete growth model. Since

$$\frac{dk}{dt}\frac{1}{k} = \frac{dK}{dt}\frac{1}{K} - \frac{dL}{dt}\frac{1}{L} - \frac{dT}{dt}\frac{1}{T} \tag{3.6}$$

the path of the effective capital intensity k is given by

$$\frac{dk}{dt}\frac{1}{k} = \frac{s\,f(k)}{k} - n - h(m\,f(k)) \tag{3.7}$$

The long-run equilibrium level of the effective capital intensity is given by k^* for which dk/dt / k = 0. On this growth path $s\,f(k^*) / k^*$ represents the familiar "warranted growth rate", while $n + h(m\,f(k^*))$ is a generalisation of the "natural growth rate". Under the specified conditions, the steady-state growth rate $g = n + h(m\,f(k^*))$ exists and is stable. Inspection of Figure 1 will make this clear.

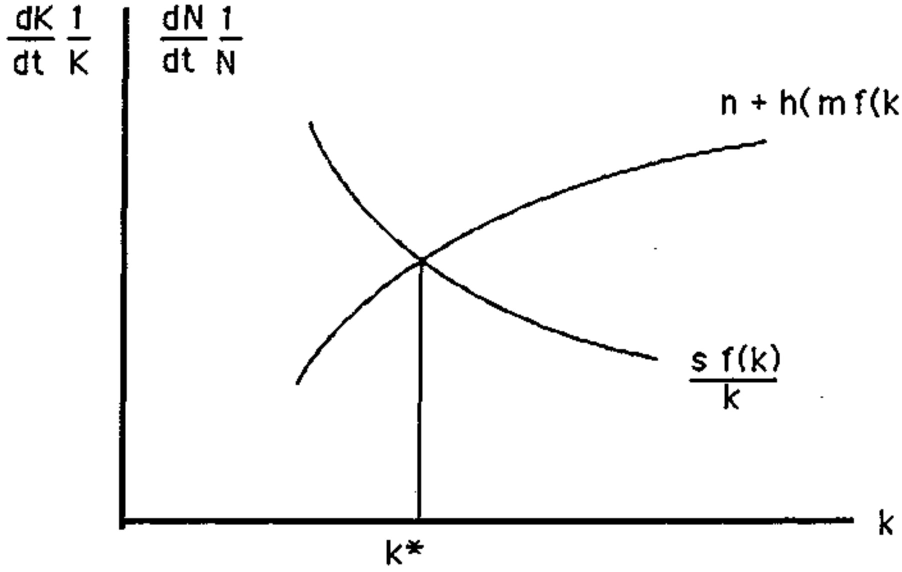

Figure 1

The warranted growth rate is a declining function of k because of the diminishing average product of capital, with increasing capital intensity, but the natural growth rate is here an increasing function of k (because both h and f have this property). What does this model predict about the opportunities to move the economy to a higher growth path? By means of Figure 1 it can be easily established that

(i) If the savings ratio increases, the growth rate g, k* and the rate of growth of output per worker h(m f(k*)) increase;[4]

(ii) If the rate of growth of labour supply n increases, the growth rate g increases, but k* and the rate of growth of output per worker decline;

(iii) If the proportion of income devoted to the production of technical change m increases, the growth rate g increases, k* decreases, but here the rate of growth of output per worker increases.

With respect to point (iii) above, Lucas (1988) noted that there may be a conflict between the decisions of individual agents regarding the resources to be allocated for technical change on the basis of the trade-off between current consumption and technology accumulation, for a *given* aggregate level of T, and the determination of the optimal level of T itself. Thus, an externality is generated, which has the interesting implication that the competitive equilibrium growth path (on which agents take the aggregate T as given) and the optimal growth path (on which the present value of consumption is maximised by varying aggregate T) will diverge. This is in contrast with the standard Solow-Swan model where the optimal and competitive equilibrium growth paths are identical. The solution to the optimal control problem yields the result that the growth rate of human capital is greater on the optimal growth path than on the competitive growth path and the former could be computed, in principle, by the policymaker. The immediate implication is that there is an explicit role for a technology policy to increase the rate of change

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4 Lucas' (1988) model of growth with human capital accumulation generates the same result.

in T above the growth in technological knowhow generated by competitive equilibrium.

In summary, the model described above generates the plausible conclusion that an increase in the proportion of resources devoted to the process of technological change increases the rate of growth in output per head, *ceteris paribus*. It can also be derived easily that if production factors are paid their marginal products, the real rate of return on capital is constant, but the real wage increases at the same rate as *per capita* output, i.e. h(m f(k*)).

However, in a spatial context, the growth in the real wage could induce an increase in labour supply which, in turn, could affect the equilibrium capital intensity k*. This suggests that labour supply should be considered endogenous. Separating the effect of "natural" growth and migration, the change in labour supply is given by

$$\frac{dL}{dt} = n\,L + M \qquad (3.8)$$

in which net migration M is assumed given by

$$\frac{M}{L\ L^f} = q\,(\,w - w^f\,) \qquad (3.9)$$

in which q measures the speed of response of the, imperfectly mobile, production factor labour to a real wage differential. This is a somewhat simplified version of a common model in the migration literature (see e.g. Greenwood and Sweetland, 1972; Inoki and Suruga, 1981).

If labour is paid its marginal product, then

$$w = T\,(f(k) - k\,f'(k)) \qquad (3.10)$$

Combining (3.8) - (3.10) with the earlier model, the fundamental growth equation now becomes

$$\frac{dk}{dt}\frac{1}{k} = \frac{s\,f(k)}{k} - n - q\,[\,T\,\{f(k) - k\,f'(k)\} - w^f\,]\,L^f - h(m\,f(k)) \qquad (3.11)$$

Equation (3.11) shows that unless net migration is zero (i.e. the real wage grows at the same rate in the local and "foreign" economy), a steady-state growth path on which the capital intensity k is constant would not exist. Assume, for example, two regions on a balanced growth path with zero net migration. This implies that $w = w^f$ and that both grow at the rate h(m f(k*)). A brief increase in m at a certain point in time would temporarily increase the rate of growth in the real wage w relative to w^f, so that positive net migration follows. The influx of labour increases output growth in the local economy, but the effective capital intensity declines further. This has a downward effect on technical change and the growth in the real wage, so that net migration is reduced, growth declines and the economy moves back to the original growth path. But if net migration is zero, we simply have the situation of Figure 1.

However, if no resources are devoted to technical change, i.e. m=0 and T is therefore constant, a stable steady-state growth path can be found by setting (3.11) equal to zero and assuming that w^f is constant. In the steady-state, labour supply grows at the rate $n + q\ (T\ (f(k^*) - k^*\ f'(k^*)) - w^f)\ L^f$, so that positive net migration persists. Nonetheless, this steady-state would require the additional assumption that net migration is insignificant relative to the size of the foreign labour force (L^f and w^f must be approximately constant).

As in the previous section, it is more appropriate to explicitly take into account the repercussions of the growth path of one region on another. In the present context, there are two such interactions: migration and the diffusion of technical change. The latter aspect is also of importance, because differences in the rate of economic growth between regions in advanced economic systems are not only explained from the sector structure, investment patterns and migration, but also from the diffusion pattern of new technologies.

Diffusion analysis has in recent years become an important field of research in industrial economics. This analysis does not only focus on the distribution and adoption of new technologies (see Brown, 1981; Soete and Turner, 1984), but also on business services and networks related to technological transformations (Cappellin, 1989) .

In most diffusion studies the S-shaped curve forms a central component (see Davies, 1979; Metcalfe, 1981; and Morrill *et al.*, 1988). Both the adoption time and the adoption rate can be pictured in this curve. The precise shape of the S-curve can then be explained from firm size, market structure, profitability of innovations etc. (see Kamien and Schwartz, 1982). An important negative role can be played in this context by barriers to information transfer in a multi-region system (see Giaoutzi and Nijkamp, 1988). It is evident that the adoption of innovations via a spatial transfer mechanism brings also the demand side of innovations back into the picture. In this context various social-spatial communication linkages/patterns are often distinguished, such as hierarchical and contagious diffusion patterns. All of them have a clear impact on the direction and intensity of diffusion.

Diffusion models can then be used to mirror the techno-economic landscape of a spatial system. However, such models often have the shortcoming of assuming constancy of certain parameters, which in practice may vary over time. This is a major flaw in diffusion analysis, as in this case the Schumpeterian swarming effects of new basic technologies and the feedback effects from adopted innovations on spatial structures cannot be adequately taken into account (see Alderman, 1989).

In the model outlined in this section, the type of technical change considered is assumed to have the form of new "knowhow" augmenting the labour input. Equation (3.4) can be modified to explicitly consider the transmission of the accumulation of "knowhow" from one region to another (see also Nijkamp *et al.* , 1988):

$$\frac{dT}{dt}\frac{1}{T} = h(m\ f(k)) + d\ \ h(m^f\ f(k^f)) \qquad (3.12)$$

where d is a diffusion parameter, which for simplicity is assumed constant. Combining both this type of link between the two regions, as well as the migration link given in (3.9), a complex first-order non-linear differential equation system emerges in the variables k, k^f, T, T^f, L and L^f.

In the absence of labour mobility (q=0), however, a steady-state growth path for both regions exists on which the growth rates of the two regions need not be identical. The equilibrium effective capital intensities k^* and k^{f*} can be found as the solution to the simultaneous equations:

$$\frac{s\, f(k)}{k} = n + h(m\, f(k)) + d\, h(m^f f(k^f)) \qquad (3.13a)$$

$$\frac{s^f f(k^f)}{k^f} = n^f + h(m^f f(k^f)) + d\, h(m\, f(k)) \qquad (3.13b)$$

Under the assumptions made about the functions f and h, a solution (k^*, k^{f*}) may or may not exist, dependent on the values of the parameters. If the behavioural parameters are the same, $k^*=k^{f*}$ and the two curves are mirror images around the 45° line. One situation is depicted in Figure 2. The curve dk/dt = 0 in Figure 2 represents the locus of points (k,k^f) at which the first region experiences

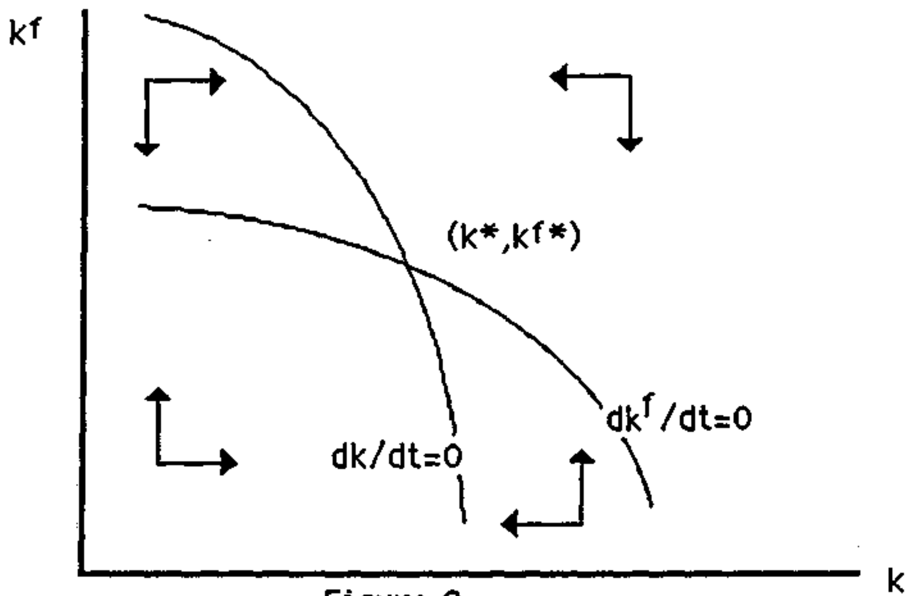

Figure 2

steady-state growth (given by equation 3.13a), while the curve $dk^f/dt = 0$ similarly defines steady-state points for the second region. These curves are both downward sloping and concave. The stability of the solution (k^*, k^{f*}) depends on the relative slopes of the two curves. Figure 2 shows a situation of global stability.

The slope at a point of the curve dk/dt = 0 is given by

$$\frac{dk^f}{dk} = \frac{-\, s\, (f - k f')\, /\, k^2 - h'\, m\, f'}{d\, h'\, m^f\, f'} \qquad (3.14)$$

and, similarly, for the curve dkf/dt = 0

$$\frac{dk^f}{dk} = \frac{d\ h'\ m\ f'}{-\ s^f\ (\ f - k^f\ f'\ )\ /\ (k^f)^2\ -\ h'\ m^f\ f'} \tag{3.15}$$

Since (f - k f') > 0 and (f - k^f f') > 0, both derivatives are negative. Hence, when d is small (the diffusion of technical change is slow), or when s and s^f are large, a situation such as in Figure 2 emerges and the system is likely to be stable. An unstable situation is depicted in Figure 3. Here, for example, starting from situation (k_0, k^f_0) the effective capital intensity in both regions commences to grow at a diminishing rate, until dk/dt=0, but dk^f/dt is then still positive and generates a declining capital intensity in the first region, while k^f continues to grow.

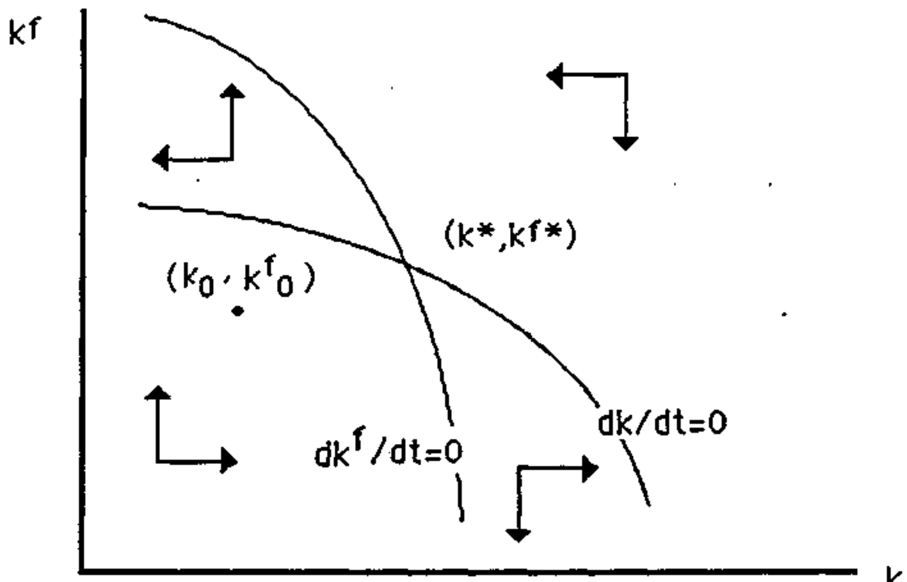

Figure 3

A comparison with the previous section can be drawn. There we found that in the demand-driven model with a trade link, regions could grow at different rates. These differences can persist and, under certain conditions, even be consistent with trade equilibrium. Here, the introduction of a diffusion link in a supply-driven model does also affect the existence and stability of the steady-state growth rates in both regions. If these growth rates differ, because the equilibrium capital intensities differ, there will be a persistent, and constant, difference in the rate of return on capital and an increasing real wage gap unless migration and capital movements (in opposite directions) are significant enough to reduce the factor price gaps.

In conclusion, factor mobility in this model has the usual equilibrating effect of bringing capital intensities closer, but large values of diffusion parameter d can have a de-stabilising influence in terms of generating diverging growth. For the two regions to grow at equal rates, the relative factor endowments, the technology stocks T and T^f and the parameters would have to be equal. Even if, for example, the two regions would be identical in all respects, except for the exogenous natural growth rate n, a steady-state growth path with factor mobility would not exist, because a difference in the rate of technical change in the two regions would persist. Nonetheless, even when the two regions are identical in terms of the parameters of this model, we can still identify a benefit from the diffusion of technical change: the growth rate of output *per capita* (and the real wage) in both regions in the steady-state is $(1+d)\ g(m\ f(k^*))$ (recall the role of d as the diffusion parameter) rather than $g(m\ f(k^*))$, which is the corresponding growth rate under autarky.

4. Trade, growth and endogenous technical change

Traditional trade-and-growth models, such as Oniki and Uzawa (1965) suggest that two trading regions or nations in which the rate of growth in labour supply is identical would, under standard conditions, move towards a long-run balanced growth path. The two regions grow on this path at identical rates and the pattern of specialisation is determined by the equilibrium factor intensities, i.e. the regions would produce relatively more of the good which uses the abundant production factor more intensively. The extension of this two-good two-factor model to incorporate endogenous technical change along the lines discussed in the previous section is straightforward.

In the trade model, there are two goods: a consumption good and an investment good. The consumption good is chosen as *numéraire* whilst the price of the investment good (i.e. the terms of trade) is p. Under standard neoclassical conditions, domestic product *per capita* is fully determined by the capital intensity k and p, i.e. $y=y(k,p)$ in each region. The demand for the investment good is given by

$$p\, I = s\, Y \qquad (4.1)$$

and since again $dk/dt\ /\ k = dK/dt\ /\ dK - dL/dt\ /\ L - dT/dt\ /\ T$, we get here

$$\frac{dk}{dt}\frac{1}{k} = \frac{s\ y(k,p)}{k\ \ p} - n - h(m\ y(k,p)) - d\ h(m^f\ y^f(k^f,p)) \qquad (4.2)$$

and

$$\frac{dk^f}{dt}\frac{1}{k^f} = \frac{s^f\ y^f(k^f,p)}{k^f\ \ p} - n^f - h(m^f\ y^f(k^f,p)) - d\ h(m\ y(k,p)) \qquad (4.3)$$

At any point in time, for given labour forces L, L^f and technology stocks T and T^f, the terms of trade are uniquely determined, in Heckscher-Ohlin fashion, by the existing capital intensities (k,k^f), through assuming trade equilibrium. This implies that p, the price of the investment good in terms of the consumption good, is given by

$$p = P\ (k,k^f\ |\ L,L^f,T,T^f) \qquad (4.4)$$

The equations (4.1) to (4.4) completely specify from any given factor endowments and initial technology stocks T_0 and T^f_0, the growth of both regions and the pattern of specialisation. However, it is easy to see that equilibrium capital intensities k^* and k^{f*} will exist if and only if both regions grow at the same rate, otherwise p continues to change. This requires that

$$n - h(m\, y(k^*,p^*)) - d\, h(m^f\, y^f(k^{f*},p^*)) \quad = \quad n^f - h(m^f\, y^f(k^{f*},p^*)) - d\, h(m\, y(k^*,p^*)) \qquad (4.5)$$

This is the generalisation of the usual assumption that the natural growth rate in both regions must be identical. While differences in the growth rates of labour supply n and n^f may indeed be small between regions, the introduction of endogenous technical change is clearly a disequilibrating factor in a trade model, since it is unlikely that from any given starting position the growth rates of effective labour supply in the two regions would converge. It is useful to point out that the above model assumes that the labour augmenting technical change affects both the consumption and the investment goods sectors equally. It would be more realistic to assume that labour productivity improvements could vary between products, or that a trade advantage is generated by product innovations such as is described in the product cycle theory (Vernon, 1966; Krugman, 1979).

It would therefore be of greater interest to move attention away from the balanced growth path and focus on changes over time in the growth rates, when

(i) each region generates technical change at different rates;
(ii) there is diffusion of knowledge of new processes and products;
(iii) production factors may respond to differences in factor prices by relocating, but factor mobility is imperfect, so that the speed of response (e.g. the parameter q in (3.9)) plays a role in the growth process.

In this very general situation it is unlikely that strong theoretical results can be obtained. However, for parameter values consistent with stylized facts of economic development, it would be possible to simulate the growth paths for given initial resource endowments K, L and T. An alternative would be to introduce fairly restrictive assumptions, as is often - by analytical necessity - the case in the trade literature.

With technical change positively related to output, a feedback mechanism is generated in which production exhibits increasing returns to scale. It has been shown that "uneven development" is a necessary outcome of such a situation: an initial discrepancy in capital-labour ratios between regions will accumulate over time (e.g. Krugman, 1981). The model of Krugman (1981) is of interest in our context, because it leads to a similar phase diagram as given in Figure 3. Krugman assumes that two products, an agricultural good and a manufactured good, can be produced by means of Ricardian production techniques, with increasing external economies of scale. Such external economies are of course often empirically indistinguishable from technical change. In either case, the technical coefficients representing the input requirements per unit of output decline as the capital stock increases. In this situation the region with the larger initial capital stock has the higher profit rate and, if all profits are saved, generates the fastest capital accumulation. The result is an ever-increasing divergence between the regions, which only ends when a boundary of some kind has been reached. Krugman assumed this to be a limit to labour supply, while in Nijkamp *et al.* (1988) there was an emphasis on the eventual emergence of external diseconomies.

Similarly, Markusen and Svensson (1985) suggest that uneven development is generated by trade patterns resulting from spatial differences in technology rather than differences in resource endowments. In their model of product-augmenting technical change, production changes generated by trade will bid up the price of the factor used intensively in an export industry (which is the industry in which a region has technical superiority). Thus, factor mobility leads to a direction of factor flows which reinforces the pattern of comparative advantage and trade caused by differences in technology. This approach suggests that factor mobility and trade are complements in that factor movements reinforce the pattern of goods trade.

This conclusion is in contrast with the static Heckscher-Ohlin model in which factor movements and commodity trade are substitutes: regions would have a comparative advantage in the production of commodities which use abundant factors intensively. If this were true, factor movements would lead, in a sense, to less commodity trade. Factor price equalisation would result in this traditional framework from either specialisation associated with goods trade or from factor mobility, when there are trade barriers.

However, the suggestion that factor mobility and commodity trade may instead reinforce each other through technical change can also be found in Lucas (1988). As noted in the introduction, Lucas (1988) suggested that differences in human capital accumulation are responsible for differences in growth rates between regions or countries. Different goods have different potentials for human capital growth through on-the-job training or through learning-by-doing. Consequently, the comparative advantage which determines which goods get produced also determines the rate of growth in human capital (and therefore technical change). Technically, this model formulated by Lucas has characteristics similar to those of the Krugman (1981) one mentioned earlier. Here, the increase in the efficiency of the Ricardian production technology is due to human capital accumulation through learning by doing, rather than economies of scale through physical capital accumulation. Nonetheless, if two goods are produced which are "good" substitutes (i.e. they have a substitution elasticity greater than one), there will be a tendency for complete specialisation under autarky, with the direction of specialisation determined by the initial conditions. The immediate implication is that there is a role for policy to ensure that initial conditions on the growth path are generated which take the possibility of a technological comparative advantage into account. To ensure that more resources are devoted to the good with a high learning-by-doing propensity, an industrial policy of "picking winners" would appear helpful. The introduction of trade in this framework also generates complete specialisation. Over time, the terms of trade change continuously to reinforce the pattern of comparative advantage. Provided the goods are good substitutes, regions which produce the good which enjoys a faster technical change will continue to have a higher growth rate, resulting in a persisting change in the terms of trade (at a constant rate in Lucas' model). Thus, this dynamic trade model suggests again a persistent pattern of uneven development.

There is of course a fairly long tradition of emphasising uneven development in the regional growth literature, such as expounded, for example, in Myrdal's (1957) cumulative causation theory.[5] The current challenge in this type of modelling is to be able to endogenise changes in the position of individual regions in this growth continuum. Possibilities for such growth switches would include - on the demand side - the introduction of different income elasticities for different classes of goods; and on the supply side the continuing introduction of new goods, with learning potentials declining with the amount produced. Such factors could continuously shake up the existing pattern of specialisation and explain why, for example, the rapid growth in NICs has been associated with a growth of exports in products initially not produced in these countries.

5. Conclusion

The conceptual framework discussed above served to identify and explore new departures for the analysis of economic dynamics in an open system, with specifically a focus on spatial interdependencies in the form of trade, factor mobility and innovation diffusion. The design of a coherent and theoretically interwoven framework appears to be far from easy. Both the export-led growth model and the neoclassical models considered in this paper had the ability to generate persisting differences in long-run growth rates in the presence of some spatial interdependency, provided there were barriers to other types of flows. However, in the presence of endogenous technical change generating increasing returns there is a tendency for a highly interdependent system to be unstable, with a likelihood of increasingly "uneven development". While the neoclassical approaches outlined in the previous section offer interesting and appropriate foundation stones for a thorough analysis of the evolutionary patterns of a multi-regional system, it is obvious that much work in this area remains to be done.

For example, the locational aspects of R&D creation, diffusion and adoption deserves much closer attention, as is also witnessed in various recent OECD reports on technology policy. To some extent, this issue is comparable to the infrastructure debate as presented, among others, in Biehl *et al.* (1986) and Nijkamp (1986). In their approach a quasi production function has been used to assess the implications of a favourable infrastructure in particular regions with respect to differential competitiveness. In our context, a regional dynamisation of a production function, accompanied by a technological diffusion function with variable parameters, dependent on information barriers on the one hand and competitive behaviour (such as a depression trigger response) on the other, would provide a promising analytical framework. Equilibrating forces such as the changing trade patterns and factor flows can then be incorporated to identify the long-run growth tendencies of the regions in the system.

[5] Features of cumulative causation such as imperfect competition, increasing returns to scale and product differentation have emerged as central themes of the "new international economics" of which the models of Markusen-Svensson, Lucas and Krugman are examples (see also Krugman (1988).

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