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Spatial perspectives on new theories of economic growth*

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Abstract. A new wave of interest in long-run economic growth emerged since the late 1980s. This paper uses a simple model to illustrate how technological change can be endogenised in macroeconomic theories of growth and then surveys how – through factor mobility, the diffusion of innovations and trade – spatial interdependence in a system of regions can influence technological change and growth. Endogenous technological change generates in our illustrative model long-run steady-state growth in a closed economy. However, it turns out that the dynamic impact of spatial interdependence depends on the specification of the model. Spatial convergence, a steady state with persisting spatial differences in growth rates and unstable growth are all theoretically possible. Issues relating to the role of aggregate demand and policy also receive attention. There is much scope for further theoretical and empirical work on endogenous growth in a spatial-economic context, while a better integration of micro and macro level approaches is also desirable.

1. Introduction

The spatial-economic landscape exhibits a panorama of changing hills and valleys of welfare levels. Why growth rates differ between nations, or regions, is a fundamental question which has intrigued economists ever since Adam Smith's (1776) "Inquiry into the nature and causes of the wealth of nations". Research on the subject, however, has not been at a steady pace during the past two centuries. Instead, there have been several waves of in-

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terest. Temporal and spatial differences in the standard of living were important issues for classical economists such as Adam Smith, Malthus (1798) and Ricardo (1817). Except for Marx's (1867) alternative interpretation of the driving forces in long-term capitalist accumulation, further major theorising did not occur until the 20th century. During the first half of this century, Schumpeter (1934) laid the foundations for recent insights into the role of technological change and entrepreneurial competition in long-run development, while Harrod (1939) and, independently, Domar (1946) studied the growth of a Keynesian economy. In their model, the long run growth path would be likely to exhibit either growing unemployment or accelerating inflation.

The second half of this century has seen two major waves of interest in the macroeconomics of growth. The first of these commenced with the seminal articles by Solow (1956) and Swan (1956), whose neoclassical growth model provided a more plausible description of the long-term path of the economy than the Harrod-Domar model. Yet the major weakness of the standard neoclassical model, and of the wave of theoretical contributions which built upon it, was that it did not provide an explanation for the actual "engines" of long-run growth in income per worker, although its predictions were consistent with several stylised facts of economic development.

The reason for this deficiency was not that economists were ignorant about the causes of spatial or temporal differences in long-run growth rates but, instead, that causes of productivity improvements such as innovation, economies of scale and learning-by-doing had effects on the economy which violated the assumptions of perfect competition and constant returns to scale. As Krugman (1995) argued, the theoretical tools were not yet available in the 1950s to study such phenomena of increasing returns and imperfect competition within the accepted axiomatic neoclassical framework. Consequently, policy makers requiring advice on how to improve national and regional growth rates needed to look elsewhere and the fields of development economics and regional economics emerged respectively as more pragmatic responses to fill this vacuum. Thus, theoretical and empirical models of regional growth could build upon the idea of growth poles (Perroux 1955) or cumulative causation (Myrdal 1957; Kaldor 1970).

When several North-American macroeconomists returned to the issue of long-run growth in the mid 1980s, now with new tools to formulate equilibrium models with increasing returns and imperfectly competitive sectors, a revival of the field emerged starting with the influential articles by Paul Romer (1986) and Robert Lucas (1988). This literature describes macroeconomic outcomes in terms of microfoundations such as an intertemporal optimisation of consumption by rational and forward-looking households. However, the essence of this idea itself goes back to Ramsey (1928) and was earlier applied to growth modelling by Cass (1965) and Koopmans (1965).

Parallel to the development of the new theoretical explanations, a vast literature on the empirics of growth emerged, commencing with the contribution of Kormendi and Meguire (1985). Here the objective was not only to identify causes of growth, but also to find out whether growth rates across countries or regions converge or diverge over time.

The importance of increasing returns, externalities and imperfect competition for an understanding of the dynamics of economic development by means of the "New Growth Theories" has also led to two related research paradigms. One of these is the "New International Economics", which provides a reformulation of the theories of trade and trade policy (see e.g. Krugman 1988). The other is the "New Economic Geography", which attempts to explain the spatial distribution of economic activity, both in terms of urban systems and in terms of regional development (see e.g. Krugman 1991; Fujita et al. 1995).

The wave of "New Growth Theories" and its empirical counterpart has now reached a stage of maturity whose substantive contribution has already been assessed in special issues of major journals and general surveys (e.g. Ehrlich 1990; Stern 1991; Jones and Stokey 1992; Verspagen 1992; Romer 1994; Mankiw 1995; Jones and Manuelli 1997). There is also some dissent, e.g. Scott (1989) provides an alternative approach which rejects the use of the neoclassical production function. The empirical work on growth has benefited from new comparative data bases for a wide range of countries in the world (e.g. Summers and Heston 1991; International Monetary Fund, various years; World Bank, various years). However, some of the conclusions regarding the determinants of growth drawn from such data appear as yet rather fragile (Levine and Renelt 1992; Mankiw 1995). Theory and empirics are brought together skillfully in the textbook by Barro and Sala-i-Martin (1995) which provides an advanced, but accessible, treatment of all the major issues in theoretical models of economic growth and the related empirical investigations.

Thus, the present paper does not purport to provide yet another broad survey. Instead, we will focus only on the spatial aspects of the neoclassical and the new growth models. A distinction is made between differences in growth rates due to spatial variations in parameters which influence growth in closed economies and causes of differences in growth rates between open economies. The predictions of the models are also compared with the main conclusions of the well-established literature on regional economic development. Finally, implications for regional policies are identified briefly.

Many of the neoclassical and new growth models describe accumulation in closed economies. Explanations for spatial differences in growth rates between such economies must necessarily derive from differences in parameters, initial conditions or other exogenous variables. Closed economy explanations of differences in growth rates are discussed in Sect. 2.

At the regional level, there is spatial interaction in terms of trade, capital flows, migration, diffusion of technological innovation and information exchanges. Thus, the closed economy models can provide at best a very limited understanding of regional growth. Section 3 considers the implications of introducing factor mobility, trade, economic integration and innovation diffusion into models of growth. It will become clear that the extension of the new growth models to the case of open economies is not yet fully satisfactory, and much work remains to be done in this area (Barro and Sala-i-Martin 1995, p. 128).

Section 4 focuses on the transitional dynamics in closed or open economies. An understanding of the transitional dynamics will enable predictions to be made about convergence or divergence. An assessment of the sometimes contradictory empirical evidence on this matter is provided.

Section 5 compares the new theories of growth with the conventional theories of regional development. While some of these have built upon neoclassical theories (as surveyed in e.g. McCombie 1988a), the post-Keynesian perspective which puts more emphasis on the role of demand in the economy and Kaldor's formulation of technical change (Kaldor 1957), had tended to be more popular (McCombie 1988b). The contribution, and potential, of evolutionary economics for an understanding of the regional growth process is also briefly addressed in this context. The final section provides some general conclusions and suggestions for further research in the field of spatial modelling of economic growth.

2. Why growth rates differ between closed economies

The process of economic growth, by which we mean the growth in real income per person in an economy, can be described in a simple way by the neoclassical model formulated by Robert Solow (1956) and independently by Trevor Swan (1956). Their work remains important because many of the new growth models can generate steady-state long-run growth paths which resemble those of the Solow-Swan model, with the only difference being that the new models now provide endogenous explanations for aspects of the Solow-Swan model which were assumed to be constant and given, such as the production function, the rate of technological change, the propensity to save and the population growth rate. Moreover, some of the stylised facts of development of economies are consistent with the predictions of the Solow-Swan model, provided capital accumulation in the model is interpreted as including human capital accumulation through education and training (e.g. Mankiw 1995; Bal and Nijkamp 1997).

Thus, it is useful to commence with reviewing briefly the key features of the Solow-Swan model. Consider a closed economy with competitive markets and a constant returns technology. At date t, labour supply is $L(t)$. The exogenously given rate of growth of $L(t)$ is n. Real production $Y(t)$ is assumed to result from combining inputs according to

$$Y(t) = F(K(t)\,,\ L(t)e^{xt}) \tag{1}$$

where $K(t)$ is the stock of capital at time t and e^{xt} represents the effect of exogenous labour-augmenting technical progress. The model neglects labour-leisure choices and assumes full employment. Population and labour force are therefore equivalent concepts and both grow at rate n. Equation (1) can be rewritten as

$$\hat{y} = f(\hat{k}) \tag{2}$$

where the symbol ^ denotes a quantity per effective unit of labour $L(t)e^{xt}$. We shall assume that $f(.)$ has the usual "well-behaved" properties, formalised in the Inada (1963) conditions. If the rate of depreciation of capital is a fraction δ of the stock, net investment is given by

$$\dot{K} = Y - C - \delta K \tag{3}$$

where $\cdot$ denotes a derivative with respect to time and C is the level of consumption. Under these assumptions, we can derive the following equation of motion for the amount of capital per effective unit of labour $\hat{k}$:

$$\dot{\hat{k}} = f(\hat{k}) - \hat{c} - (n + x + \delta)\hat{k} \, . \tag{4}$$

In the Solow-Swan model, the tradeoff between current and future consumption is not explicitly considered. Households simply consume a constant fraction of income, which implies that there is a constant savings rate

$$s = \frac{f(\hat{k}) - \hat{c}}{f(\hat{k})} \, . \tag{5}$$

Substituting (5) into (4) gives the fundamental growth equation:

$$\dot{\hat{k}} = sf(\hat{k}) - (n + x + \delta)\hat{k} \, . \tag{6}$$

It is straightforward to show that given the assumptions made, any initial resources $K(0)$ and $L(0)$ and the dynamics described by (6), the economy will converge to a balanced, or steady-state, path asymptotically. In the steady state, the quantities $\hat{y}$, $\hat{k}$ and $\hat{c}$ do not change and the steady-state value of $\hat{k}$, $\hat{k}^*$ is found by setting the left-hand side of (6) equal to zero. Income, capital and consumption per capita each grow in the steady state at the rate of technological progress, x. The absolute quantities Y, K and C grow at the rate $x + n$.

This simple model suggests that if countries or regions have access to the same technology (the same production function and the same rate of technical change x), income per head must in the long run grow in each one at the same rate. During the transition to the steady state, the less capital endowed economy will have a lower income per head and grow faster. In the steady state, income per head will be higher in the economies with lower population growth and lower depreciation of capital.

The model as outlined above is only consistent with some of the stylised facts about the growth of nations and regions. Mankiw (1995, p. 277) summarises the predictions of the model as follows:

1. In the long run, the economy approaches a steady state that is independent of initial conditions.
2. The steady-state level of income depends on the rate of saving and population growth.
3. The steady-state rate of growth of income per head depends only on the rate of technological progress.
4. In the steady state, the capital-to-income ratio is constant.
5. In the steady state, the marginal product of capital is constant and the marginal product of labour grows at the rate of technological change.

Predictions 2, 4 and 5 among these are broadly supported by the empirical evidence. However, predictions 1 and 3 are more contentious and have led to a large empirical literature, which we review in Sect. 4.

The oldest way to endogenise one of the aspects of the Solow-Swan model is to make savings behaviour endogenous. Following Barro and Sala-i-Martin (1995), we refer to this model as the Ramsey model since the original idea of optimal savings behaviour was developed by Ramsey (1928). Cass (1965) showed that from any starting-point optimal capital accumulation converges to the balanced Solow-Swan growth path. The advantage of the Ramsey approach is that it permits a description of the economy in terms of the rational optimising behaviour of individual households and firms, which is now the cornerstone of modern macroeconomics. It can be shown that the Solow-Swan model predictions are consistent with those of a model with intertemporal optimisation in an Arrow-Debreu competitive equilibrium framework (e.g. Romer 1989).

In the Ramsey model, households seek to maximise lifetime utility[1] given by

$$W = \int_{t=0}^{\infty} u(c)e^{nt}e^{-\rho t}dt \tag{7}$$

where $c = C/L$ and ρ is the constant rate of time preference. Note that household utility rather than individual utility is in the welfare criterion since the utility of each person's consumption is multiplied by household membership which grows at rate n. Assuming that the utility function has the form

$$u(c) = \frac{c^{1-\theta} - 1}{1-\theta} , \tag{8}$$

[1] Note that the usual "infinite horizon" assumption has been introduced for simplicity. Alternatively, economic growth models can use the overlapping generations approach, first formulated by Maurice Allais (1947) and subsequently in the seminal paper by Paul Samuelson (1958).

marginal utility $u'(c)$ has the constant elasticity $-\theta$ with respect to c.[2] To find the consumption path $c(t)$ which maximises (7) subject to (6) is a standard dynamic optimisation problem, which can be solved by Pontryagin's maximum principle of optimal control (Pontryagin et al. 1962). It can be shown that on the optimal time path for consumption

$$\tilde{c} = [f'(\hat{k}) - \delta - \rho]/\theta \tag{9}$$

where ˜ refers to a rate of growth, i.e. $\dot{c}/c = .\tilde{c}$ (see e.g. Barro and Sala-i-Martin 1995, chapter 2). The long-run rate of return to capital is $f'(\hat{k}^*)$ where $\hat{k}^*$is the steady-state effective capital intensity found by setting the rate of growth in per capita consumption in (9) equal to x. Hence,

$$f'(\hat{k}^*) = \delta + \rho + \theta x \; . \tag{10}$$

Some explicit formulae for the level and growth rate of income and the optimal propensity to save can be easily derived with the use of a Cobb-Douglas production function. If α denotes the share of profits in income, this production function is given by

$$f(\hat{k}) = A\hat{k}^{\alpha} \; . \tag{11}$$

It is then straightforward to derive an equation for the time path of real income per capita once the steady-state has been reached:

$$y(t) = A^{\frac{1}{1-\alpha}} \left[\frac{\alpha}{\delta + \rho + \theta x} \right]^{\frac{\alpha}{1-\alpha}} e^{xt} \; . \tag{12}$$

The optimal propensity to save in the steady-state is again constant, as in the Solow-Swan model, and is equal to

$$s^* = \frac{(n + x + \delta)\hat{k}^*}{f(\hat{k}^*)} = \frac{\alpha(n + x + \delta)}{(\delta + \rho + \theta x)} \; . \tag{13}$$

It can be seen from (13) that a low rate of time preference ρ and a high intertemporal elasticity of substitution (i.e. small θ) increase s^*. This demonstrates the well-known prediction of the neoclassical model that a thrifty society will in the long run be wealthier than an impatient one, but does not grow faster. Note also that population growth no longer affects real income per head in Eq. (12). A faster growing population will simply find it optimal to save more (see Eq. (13)).

[2] The reciprocal of θ is called the intertemporal elasticity of substitution σ. A special case occurs when the intertemporal elasticity of substitution is one. In this case $\theta = \sigma = 1$ and $u(c) = ln\ c$. Consequently, a 1% postponement of consumption from now until later raises marginal utility in the current period by 1%.

Both the Solow-Swan and the Ramsey model provide only two reasons for differences in growth rates between regions or countries. The first is that the rate of technological change x differs between economies. Reasons for such differences are not explained. Secondly, economies may not yet be on the steady-state growth path. In this case, poor economies with a low quantity of capital per head would grow faster than rich economies. This is referred to as the *absolute convergence* property of the model.

Barro and Sala-i-Martin (1995) suggest parameter values which will make the Ramsey model generate both a plausible long-run growth rate, but also a slow convergence to this growth rate which is consistent with empirical observations (see also Sect. 4). The slow convergence can only be explained with an interpretation of capital as a broad concept which also includes human capital accumulation. With this interpretation, the share of capital in income (combined with returns to education) is perhaps 0.75. Thus, $\alpha = 0.75$. Other plausible parameter values for developed economies are: the natural growth rate $n = 0.01$, the rate of technical change $x = 0.02$; the rate of depreciation $\delta = 0.05$, the rate of time preference $\rho = 0.02$ and the elasticity of marginal utility $\theta = 3$. Substituting these values in (12) suggests an optimal propensity to save of 45% (including investments in education and training).

The purpose of many of the models of growth which have been developed during the last decade is to provide an endogenous explanation for the natural growth rate n, or the rate of technical change x, or both.[3] We will focus here primarily on the latter issue, but we refer to Barro and Becker (1989) for a model which explains the natural growth rate n in a closed economy with exogenous technical change. In such an economy, the population growth rate and the rate of technical change are inversely related. Their model is an extension of the Ramsey model, namely through the introduction of a dynastic utility function: parents care about the utility attained by their children when reaching adulthood and by subsequent generations.

Becker et al. (1990) describe a closed-economy model in which technical change and population growth are both endogenous (with productivity growth driven by education). In this case, multiple equilibria emerge with the possibility of an economy becoming trapped in a “low income growth with high fertility” steady state. This is an example of a growth model in which the steady state is sensitive to initial conditions, which is a general feature of increasing returns and other “positive-feedback loop” models (see also Arthur 1994). Thus, historical endowments and “luck” may be critical determinants of differentials in growth which we may observe between countries or regions in such models.

A “poverty trap” can also be generated by the original Solow-Swan model by simply assuming that the average product of capital $f(k)/k$ is initially declining, then increasing and finally again declining with increasing

[3] Another possibility is to make the internal rate of time preference, i.e. the discount rate, endogenous. See Drugeon (1996) for the impact of growing impatience on long-run growth.

values of k (see Barro and Sala-i-Martin 1995, pp. 49–52). The possibility of a poverty trap is a popular idea in the development literature, see for example the "Big Push" model of Lewis (1954).

The process of labour-augmenting technological change, which proceeds at a constant rate x in the Solow-Swan model, is the simplest formalization of many phenomena which may lead to long-run productivity improvements. In macroeconomic models with only one good, technological change represents a growth of knowledge. There are four ways of accumulating knowledge: research, schooling, learning-by-doing and training. Alternatively, if a model permits more than one good, technological change may be due to an increase in the variety of intermediate inputs or consumer goods. Furthermore, the quality of goods may improve for a given variety. Finally, increasing returns may result from economies of scale.

Endogenous growth models have been formulated for each of these situations. For example, Lucas (1988) describes one model in which education generates external benefits and another model in which productivity improves through learning by doing. The idea that experience spills over to other producers goes back to Arrow (1962) and is also the engine of growth in Romer's (1986) model.

Other papers explicitly describe the activities of the R&D sector which generates new knowhow, see e.g. Romer (1990) and Aghion and Howitt (1992). Osano (1992) points out that basic research may have a stronger impact on the growth rate than applied research. He proceeds therefore to formulate a growth model with two research sectors. Schmitz (1989) points to the importance of entrepreneurial imitation, while Stokey (1988) studies the effects of the introduction of new goods on long-run growth. In this context, Jovanovic (1995) notes that the emphasis on generating new knowledge is overemphasised in the new growth models. A significant proportion of resources in an economy is devoted to adopting existing recent technologies rather than inventing new ones and firms frequently adopt "dominated" technologies. Thus, new growth models which explicitly consider the adoption decision are warranted. A recent issue in this context is also the optimal timing of adoption of a new technology (Choi 1994). Early adoption may create a competitive edge, but may be costly. Late adoption may be less risky, but may also generate less benefits (see also Koski and Nijkamp 1996).

A key issue is that technological inputs create spillovers due to the fact that they are non-rival goods. New inventions are produced at a high cost for the first unit but subsequent units (e.g. photocopies) can be produced at virtually zero cost. This generates nonconvexities in production, even if such goods are partially excludable (i.e. appropriable) through patents and if adoption is costly. The technological spillover phenomenon is better captured by human capital accumulation or the introduction of new goods rather than by physical capital accumulation.

In many of the models with endogenous technological change, the characteristics of the dynamic competitive equilibrium can be traced by setting up an optimal control problem similar to the Ramsey model. Where a steady-state exists, the presence of an externality, e.g. through R&D, creates a divergence between the private and social rates of return and the competitive equilibrium may not be Pareto-optimal.

To highlight some common features of many endogenous growth models we will now formulate a simple model of endogenous technological change in which the existence and properties of the steady-state are readily established without having to explicitly solve the underlying dynamic optimisation problem.[4] This will also simplify the discussion of growth in the open economy in the next section.

As noted earlier, technological change is most conveniently interpreted as a labour-augmenting process. Thus, if N measures the effective labour input, $N = LT$, where L is the quantity of workers and T is an index of the average quality of labour input, which depends on the stock of knowledge and practices. In the Solow-Swan model, T grows at the exogenous rate x. Here we relax this assumption. Central to the current view about the process of technological innovation is that a change in 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). Hence we shall assume that a change in T is generated by the following process of knowledge creation:

$$\dot{T} = H\left(\frac{R}{L}\,,\ T\right) \tag{14}$$

where R/L is expenditure per worker on activities such as education, training, R&D etc.[5] Thus, the change in T is positively related to the intensity of the effort devoted to the enhancement of labour quality as well as the current level of labour quality. This function is assumed to be homogeneous of degree one, twice differentiable and concave. Both the public sector and private sector in the economy carry out knowledge-creating activities, funded through taxes and retained profits respectively. For simplicity, we lump these activities here together and assume that a fraction τ of national income is allocated to this process of technical change. Hence,

$$R = \tau Y\,. \tag{15}$$

As in the case of the accumulation of physical capital, a trade-off arises in that a large value of τ reduces current consumption, but yields a higher level of output in the future. Using (14) and (15) we can derive that

$$\tilde{T} = H\left(\frac{R}{LT}\,,\ 1\right) = H(\tau\hat{y}\,,\ 1) \equiv h(\tau f(\hat{k})) \tag{16}$$

[4] Solow (1994, p. 49) has in fact argued that the intertemporally-optimising representative agent formulation in itself has had little to add to the insights of the New Growth literature.
[5] 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.

Households now maximise lifetime utility according to Eq. (7) as before, but consumption per capita c at any time cannot exceed $f(k) - \dot{k} - \tau f(k) - \delta k$. There are now two decision variables, the propensity to save and the propensity to allocate resources to technical change, and if a steady-state growth path exists these propensities will both be constant on the steady-state path. Consequently, income per head will still grow at a constant rate in the steady state, as in the standard neoclassical model, but (16) shows that this rate is now a function of both τ (the proportion of resources devoted to education, innovation etc.), and $\hat{k}$ (the effective capital intensity). If we assume that the labour input L again grows at an exogenous rate, n, we can derive a "fundamental growth" equation similar to Eq. (6) for the Solow-Swan model. For given s and τ, the path of the effective capital intensity $\hat{k}$ is given by

$$\dot{\hat{k}} = sf(\hat{k}) - [n + h(\tau f(\hat{k})) + \delta]\hat{k} \ . \tag{17}$$

The long-run equilibrium level of the effective capital intensity is given by $\hat{k}^*$ for which $\dot{\hat{k}} = 0$. Under the specified conditions, such an equilibrium exists and is stable (see Nijkamp and Poot 1993a).

The merit of this simple model of endogenous technical change is that, in contrast with the Solow-Swan or Ramsey model, it identifies various sources of differences in growth rates between countries and regions. Firstly, the model shows that thriftiness is good for an economy: if, e.g., a removal of tax distortions raises the propensity to save, the per capita growth rate becomes permanently higher.[6] Similarly, if capital is depreciated faster or the labour force grows faster, the rate of growth of output per capita decreases. Finally, if the proportion of income devoted to the production of technical change increases, the rate of growth of output per capita increases. These results can be readily derived from considering the effect on the per capita growth rate $h(\tau f(\hat{k}^*))$ when changing a parameter in (17) and setting $\dot{\hat{k}} = 0$.

If government can influence the parameters of the growth model (savings behaviour, R&D, population growth), the endogenous growth model also points to ways in which government could permanently raise the long-run growth rate. It is also possible to formulate endogenous growth models in which the activities of government become explicit in the form of provision of infrastructure, pure public goods, the protection of property rights and taxation policies. For example, Barro (1990) considers a model in which the total of government purchases becomes an additional production factor (external effect) in the production function of private firms.

[6] One issue, which we do not address in this paper, is the effect of savings behaviour in models of heterogeneous capital. The introduction of heterogeneous capital may lead to paradoxical results, see e.g. Garegnani (1970) and Hatta (1976). The issue was raised in the context of the "Cambridge-Cambridge" debate regarding the meaning of the concept of capital and the notion of an aggregate production function (see e.g. Jones 1975 for an introduction into this debate).

The above model generates constant long-run growth, but endogenous growth models may also generate ever-increasing growth rates due to increasing returns. An example can be found in Romer (1986), who justifies such a model by the observation that in the very long run (over several centuries) worldwide labour-productivity growth has been accelerating (see also Kremer 1993), although it is equally true that during the last forty years productivity growth exhibited a downward trend among developed countries (Romer, 1989). Nijkamp and Poot (1993b) formulate a model of increasing returns in which such ever-increasing growth is eventually checked by technological, social and economic capacity constraints.

Another plausible break on ever-increasing growth is a deterioration of the natural environment. On the one hand we may find that damage to the environment or an increasing scarcity of natural resources restricts the economy's ability to generate innovations which drive the growth in income per head (Barbier 1996). On the other hand, it is likely that a society becomes more interested in environmental preservation at higher incomes. A growing preference for a clean environment may then become incompatible with growth when the production technology exhibits increasing returns to scale (Yoshida 1995). However, if pollution abatement technologies themselves benefit from endogenous technological change, more resources devoted to such activities may lower output growth in the short run, but increase it in the long run (Bovenberg and Smulders 1996). This phenomenon is also referred to as the environmental Kutznets curve.

3. Long-run growth tendencies in open economies

Our analysis has been so far confined to the case of the closed economy. The growing importance of trade, capital flows, a diffusion of product and process innovations, and migration at the interregional and international levels, suggests that spatial interactions need to be explicitly considered, both in terms of their direct effects on growth and their effects on technological change. In this section we address these issues by considering, in this order: factor mobility, diffusion and trade.

3.1 Factor mobility

If interregional differences in preferences, factor endowments or technology generate interregional differences in returns to production factors, a reallocation of production factors may be expected. The impact of this reallocation depends on the assumed characteristics of the model of the interacting economies. In standard neoclassical analyses in which spatial factor price differentials are due to differences in factor endowments, factor movements have an equilibrating effect. However, with differences in preferences or technology, factor movements may lead to divergence in which all mobile resources are eventually attracted to one region (see e.g. Nana and Poot 1996).

This contrast is also evident in the attempts to date to formulate the neoclassical growth model in an open economy setting. For example, it is often considered plausible to assume perfect capital mobility and immobile labour. Barro and Sala-i-Martin (1995, chapter 3) find that in these circumstances a multi-country Ramsey model generates several paradoxical conclusions. Firstly, the speed of convergence to the steady state is infinite. Secondly, consumption in all but the most patient country tends to zero and assets in these countries become negative. Finally, the most patient country eventually owns all resources and consumes all output.

In practice, capital is far from being perfectly mobile and, specifically, capital does not seem to flow from rich to poor countries to the extent that neoclassical models would predict. Similarly, human capital may migrate from places where it is scarce to places where it is abundant (a process sometimes referred to as the “braindrain”), rather than vice versa (Lucas 1988). These observations may be explained by asymmetric information, imperfect credit markets or labour markets, or adjustment costs for investment (Barro and Sala-i-Martin 1995; Gordon and Bovenberg 1996). Alternatively, the incentives for capital mobility may be exaggerated, because spatial real risk-adjusted rate of return differentials may in fact be small due to significant differences between countries in human capital accumulation, the external benefits of human capital, capital market imperfections and political uncertainties (Lucas 1990; Mankiw 1995).

However, as long as a production factor moves in the “right” direction (i.e. to where its price is higher) it has in the neoclassical growth models the tendency to speed up convergence to the steady-state. As an example, we illustrate the role of factor mobility in the endogenous growth models by explicitly considering labour migration.

Separating the effect of “natural” growth and migration, the change in labour supply is given

$$\dot{L} = nL + M \tag{18}$$

in which net migration M may be assumed to be given positively related to the effective capital intensity $\hat{k}$ since the real wage is $f(\hat{k}) - \hat{k}f'(\hat{k})$, which increases with higher values of $\hat{k}$ (see also Barro and Sala-i-Martin 1995, p. 288). Hence

$$M = m(\hat{k})L \tag{19}$$

in which $m(\hat{k})$ is the migration rate, which is an increasing function of $\hat{k}$. Migrants can also bring capital with them, so that the change in the domestic capital stock is now given by:

$$\dot{K} = sF(K, \hat{L}) - \delta K + \phi M \tag{20}$$

where ϕ is the value of capital per migrant (which could be human capital when K is interpreted in a broad sense). When we combine (18)–(20) with our earlier model of endogenous technical change, the following dynamic equation for the effective capital intensity emerges:

$$\dot{\hat{k}} = sf(\hat{k}) - [h(\tau f(\hat{k})) + \delta + n + m(\hat{k})]\hat{k} + m(\hat{k})\hat{\phi} \, . \tag{21}$$

As in the previous models, Eq. (21) can be used to identify which factors influence the long-run growth rate. It is clear that in addition to policies with influence R&D, immigration policies can now also affect the long-run growth rate. For example, if immigration controls are relaxed, the $m(\hat{k})$ function may shift upward. This would lead to a lower steady-state effective capital intensity $\hat{k}^*$ and it would also lower the long-run growth rate in per capita income.

The conclusion that immigration lowers the growth rate requires the assumption that there is no change in the amount of capital which immigrants bring with them. If a new immigration policy targets specifically highly skilled workers, this raises $\hat{\phi}$ and leads to an increase in $\hat{k}^*$, so that in this case the long-run growth rate will increase.

In addition, migrants may directly influence productivity growth in various ways. If migrants provide new ideas and encourage investment which embodies new technologies, there are dynamic gains from inward migration not captured in (21). The empirical literature suggests that there are indeed dynamic gains from migration, at least in the traditional immigrant receiving countries of North America and Australasia (see also Gorter et al. forthcoming). This literature suggests that net immigration in these developed countries has raised per capita incomes. The regional literature also suggests that migrants on balance move in the "right" direction, but that this reallocation does not reduce interregional disparities (e.g. Van Dijk et al. 1989). These observations would be consistent with a "cumulative causation" process rather than neoclassical convergence. However, recent work by Persson (1994) and Cashin and Loayza (1995) finds empirical evidence for migration aiding convergence among Swedish regions and between South Pacific countries respectively.

A final point to note with respect to growth models with endogenous migration is that the migration function in Eq. (19) is a macro function, which does not explicitly consider the micro-level behaviour of individual households. For example, migration will be a function of the gain from migration in terms of wages or amenities, but this gain may depend on interregional differences in the rate of technical change rather than just the amount of capital per worker. Moreover, if the productivity growth rate between regions or countries differs, mobile labour may have the same effect as mobile capital which we discussed earlier, namely the final equilibrium may be a corner solution in which all population is concentrated in one region. To avoid such an extreme, it is plausible to introduce some capacity constraint either in terms of technological bottlenecks or congestion of a natural resource (see also Nijkamp and Poot 1993b). Braun (1993) formulates several growth models with endogenous migration.

3.2 Diffusion

Diffusion analysis has become an important field of research in industrial economics. At the micro level, it 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; Bertuglia et al. 1997). In most diffusion studies the S-shaped (or logistic) curve forms a central component (Davies 1979; 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. (Kamien and Schwartz 1982).

An important negative role can be played in this context by barriers to information transfer in a multi-region system (Giaoutzi and Nijkamp 1988). Without the right local conditions, the adoption of diffused technological innovations may also not be effective. For example when adoption requires a skilled work force, a low level of human capital accumulation will slow down technological change. Kubo and Kim (1996) find evidence of a strong complementarity between imported technology and human capital in a study of growth in Japan and Korea.

Several authors have proposed long-run growth models which incorporate the diffusion of technological change, for example Krugman (1979), Grossman and Helpman (1991) and Barro and Sala-i-Martin (1995, chapter 8).

For simplicity, we do not consider logistic diffusion here. The simplest way to investigate the effect of diffusion in our dynamical system is to replace the equation for productivity growth (16) by

$$\tilde{T} = h(\tau f(\hat{k})) + dh(\tau^f f(\hat{k}^f)) \qquad (22)$$

where d is a diffusion parameter and the superscript f refers to a second country or region. This parameter is likely to vary over time and space. In the general case, the dynamics of a multi-regional system with endogenous technological change and innovation diffusion can be quite complex, but the properties of the system can be studied by means of simulation results (see Nijkamp et al. 1991).

When d is taken to be a constant parameter, it is straightforward to show that diffusion is compatible with a steady state in which both regions could grow at different rates. This result is obtained by substituting the endogenous rate of technical change (22) into (17) or (21) and by writing down a similar equation for the second country. The equilibrium effective capital intensities $\hat{k}^*$ and $\hat{k}^{f*}$ can then be found as the steady-state solution to the resulting two simultaneous differential equations (see Nijkamp and Poot 1993a).

As $\hat{k}^*$ and $\hat{k}^{f*}$ need not be identical, there can be in this model of technological change and diffusion a difference in steady-state growth rates between regions. Regions will then diverge in terms of a growing absolute difference in real income per head. If the steady-state 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.

If the diffusion parameter is very large, "overshooting" may take place and the system would then be characterized by saddle-path stability (see Nijkamp and Poot 1993a). Thus, ever increasing growth rates or growth rates reducing to zero are then a possibility.[7]

In conclusion, factor mobility and a plausible rate of diffusion have in this model the usual equilibrating effect of bringing capital intensities closer. In the circumstances in which a steady state exists, it is easy to identify the benefits of diffusion: compared with the situation of autarky, the equilibrium effective capital intensity is lower, the rate of return to capital is higher and income per capita grows at a faster rate.

The model discussed above treats both countries identically, i.e. diffusion takes place in both directions. As the adoption of imported technology usually also requires resources, firms must compare at the margin the cost of adopting imported technology with the cost of their own R&D activities. Barro and Sala-i-Martin (1995, p. 276) show that it is likely that a leader-follower situation will emerge in which one country eventually allocates its entire product and process development budget to imitation of foreign ideas while the R&D sector in the other generates all new ideas. Switches of roles may take place in the long run (see also Choi 1994).

Similar results regarding the choice between imported technology and R&D activity along the optimal growth path were obtained by Nijkamp and Poot (1993b). During the "take off" phase of the growth path – when real incomes are still low – productivity growth is driven by importing new technology. At the second stage, a domestic R&D sector may develop, which leads to increasing returns in the economy. However, the R&D sector eventually matures when growth becomes limited by natural resource constraints or other bottlenecks. The issue of an absorptive capacity for technological change in a growth model is also addressed by Keller (1996).

3.3 Trade

The Solow-Swan model, Ramsey model and the endogenous growth models referred to so far focus only on the supply side of the economy, i.e. the production factors and the level of technology. Within the standard neoclassical framework, trade has in fact no role to play beyond speeding up convergence (through Heckscher-Ohlin resource reallocation effects) and determining the steady-state world prices. The long-run growth rate itself remains purely a function of technological change and this process is not influenced by trade in the standard models.

[7] This was confirmed by simulations with a three-region model of endogenous technical change and spatial diffusion. A wide range of outcomes could emerge (see Nijkamp et al. 1991).

For example, the traditional neoclassical trade-and-growth model (Oniki and Uzawa 1965), suggests that two trading regions (with an identical rate of growth of labour supply) 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 restrictive assumptions of equal labour force growth and identical technological change are in fact required to ensure a stable long-run steady state in which relative prices (and therefore the terms of trade) are constant. Nijkamp and Poot (1993a) show that when the Oniki and Uzawa trade model is extended to include the model of technological change described in the previous section, a steady state is unlikely to exist and the terms of trade will continue to change. A qualitatively similar result is obtained by Lucas (1988) in a model of learning by doing and trade.

The description of technological change as a process of imperfect competition and increasing returns through increases in the variety of goods or improvements in product quality lead naturally to the question what the impact of trade would be under these more realistic assumptions of the new growth models. Grossman and Helpman (1991) provide an extensive discussion of the links between innovation, trade and growth in the open economy. Several new "trade and growth" models have been formulated. Rivera-Batiz and Romer (1991) show that when R&D activity is driven by the monopoly rights of producers to sell new intermediate goods, economic integration of these types of economies (assuming they are structurally identical) can raise the world growth rate. Thus there are both static and dynamic gains from trade in this type of model. However, Rivera-Batiz and Xie (1993) show that when the countries have different sizes and diverging resource endowments, economic integration will lower the growth rate of a country with a high (autarky) growth rate, while it will raise the growth rate of a country with a low (autarky) growth rate. Devereux and Lapham (1993) find that the post-integration equilibria in these types of trade and growth models may be unstable. Moreover, a specialisation based on comparative advantage leads to a sub-optimal investment in R&D activities by resource-rich economies (Grossman and Helpman 1994).

The Oniki and Uzawa trade- and growth-model assumed that the labour-augmenting technical change affects both the consumption and the investment goods sectors equally. In contrast, the new growth models describe how labour productivity improvements can vary between sectors, or how a trade advantage is generated by product innovations such as is described in the product cycle theory (Vernon 1966; Krugman 1979). Alternatively, it may be the level of activity in specific sectors which provides a "learning by doing" spillover benefit for the whole economy. In this case it is straightforward to show that an increase in the supply of the resource used intensively in the knowledge-generating sector speeds up growth (Grossman and Helpman 1990a). Similarly, the market allocation of resources to this sector is suboptimal because firms do not take a spillover benefit into account. Not surprisingly, the presence of a positive externality implies that subsidising the R&D sector improves welfare.

In a multi-regional context, the capture of spillover benefits from other regions increases growth, but what matters now from the policy perspective is which of the regions has a comparative advantage in the R&D sector. If subsidies are given to regions which are better at manufacturing rather than innovating, the overall growth rate may decline.

A typical model of comparative advantage and long-run growth is described by Grossman and Helpman (1990b). In their model, there are three sectors: an R&D sector, which produces blueprints for new products and also generates increases in the stock of knowledge, an intermediate goods sector and a final consumption goods sector. Resources devoted to R&D raise the number of available varieties of differentiated inputs in final production and this in turn raises total factor productivity. If this model is applied to two regions, each which fixed primary resources, a steady-state growth rate can be computed and its sensitivity to policies analysed. For example, a small R&D subsidy in both regions increases in this model the rate of growth, while a national trade policy that switches spending toward the consumer good produced by the region with a comparative advantage in R&D will cause long-run growth rates to decline. Diffusion can also have a significant effect on the long-run growth rate in this type of model. Moreover, it is also possible to study environmental externalities and environmental policies in this context (Elbasha and Roe 1996).

The increasing returns due to economies of scale or technical change in many of these models generates a sensitivity to initial conditions. It is intuitively clear that “uneven development” is a necessary outcome of such a situation: an initial discrepancy in capital-labour ratios between regions will be reinforced over time. Trade specialisation may also generate such uneven development. Kugman (1981) provides a well known example of this situation. Krugman assumed 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. Kubo (1995) formulated an extension of Krugman’s model in which there is an interregional externality in the form of spillovers of knowledge or other benefits of regional agglomeration. In this case, a range of stable or unstable development patterns may emerge with the actual outcome dependent on the values of the parameters.

Production factor growth and commodity trade may also reinforce each other through technical change. Lucas (1988) suggested that a difference in human capital accumulation is one of the main causes of a difference 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). Lucas' (1988) model of trade and growth has features similar to Krugman's (1981) model, although the increase in the efficiency of the Ricardian production technology in the former 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 with the direction of specialisation determined by the initial conditions.

Many of the "new growth theory", "new economic geography" and "new international economics" models have in common a possibility of multiple stable or unstable equilibria and a sensitivity to initial conditions. Consequently, they point to 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. For example, 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 in the Lucas (1988) model. 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. Thus, this dynamic trade model suggests again a persistent pattern of uneven development. Markusen (1996) recently emphasised that industrial policy consequently favours the highly urbanised high-income regions and that a top-down regional policy continues to be desirable to avoid increasing inequities between regions.

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. For a recent contribution of the link between cumulative causation and trade, see Venables (1996).

A challenge in modelling regional growth with cumulative causation effects 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 Newly Industrialised Economies has been associated with a growth of exports in products initially not produced in these countries.

4. Transitional dynamics: convergence or divergence

Parallel to the development of the new models of growth which we discussed in the previous two sections, a related empirical literature has burgeoned. However, this literature has not attempted as yet to verify empirically whether the new sophisticated models provide an adequate description of cross-section or intertemporal differences in growth rates. It is often difficult to derive from the new theories estimable equations, for example because the behaviour away from the steady state is theoretically uncertain. Also, some of the variables of the new models such as knowledge are hard to measure (Mankiw 1995).

Because it is possible to describe exactly in the Solow-Swan model how an economy develops over time from any initial position, and therefore how the transition to the steady state will be made, much of the literature on transitional dynamics and convergence is based on this traditional model (e.g. King and Rebelo 1993). Indeed, some research suggests that the empirical evidence on convergence is not consistent with theories in which trend growth rates differ across economies endogenously (Evans and Karras 1996).

There are two notions of convergence. *Weak* convergence, also called β-convergence, takes place when low income regions or countries grow faster than high-income ones, all else being equal. *Strong* convergence, also called σ-convergence, takes place when the standard deviation of the distribution of income across regions or countries declines. β-Convergence is a necessary but not sufficient condition for σ-convergence (Sala-i-Martin 1996). In simple terms, β is the slope coefficient from a regression of the growth of real income on the logarithm of its level. Convergence to the steady state would imply a negative coefficient. This type of regression can be carried out both with time-series data or with cross-section data. In the former case, the specification would be

$$log\,(y_t/y_{t-1}) = a - (1 - e^{-\beta})\; log\,(y_{t-1}) + u_t \tag{23}$$

for a time series of observations $t = 1, 2, ..., T$ while in the case of a cross section of regions or countries $i = 1, 2, ..., I$ the regression equation is

$$(1/T)\; log\,(y_{iT}/y_{i0}) = a - [(1 - e^{-\beta T})/T]\; log\,(y_{i0}) + u_{i0,T} \tag{24}$$

where 0 and T now refer to two points in time over which growth is computed. When the estimated Eqs. (23) and (24) provide a good fit, this would suggest so-called absolute convergence. In practice, there are many structural differences between countries or regions which would influence a cross-section equation or shocks to the growth process which would affect the time series equation. Consequently, research in this area usually proceeds to estimate (23) and (24) with a range of additional variables added and a significant β in this situation is referred to as conditional β convergence. Some data sets may in fact permit estimation with pooling of cross-section and time-series data (e.g. Knight et al. 1993).

Barro and Sala-i-Martin (1995) show how the value of β is related to the parameters of the Solow-Swan model with a Cobb-Douglas production function for a growth process that is actually described by this model. They find that $\beta = (1 - a)(x + n + \delta)$. Using the parameter values given in Sect. 2, we get $\beta = (1 - 0.75)(0.02 + 0.01 + 0.05) = 0.02$. This suggests that 2% of the gap between the current income and the steady state is reduced each year.

There is indeed some evidence of convergence at this rate. This evidence is stronger for regions than for countries and, within a cross section of countries, stronger for similar nations than for a broader cross section. For example, Barro and Sala-i-Martin (1992) and Sala-i-Martin (1996) find convergence across the states of the USA, prefectures of Japan and five European countries. Similarly, Andres et al. (1996) find convergence among OECD countries. Persson (1994) finds convergence across Swedish counties. Even Quah (1996), who is generally sceptical of claims of strong convergence in economic growth, finds evidence of such convergence across US states. Ben-David (1996) finds that convergence is stronger among countries that have strong trading relationships.

The speed of convergence is similar in many empirical studies, namely about 2% per year and therefore only consistent with the Solow-Swan model when capital is interpreted as including human capital (so that the share of capital in income is as high as 75%). Using more conventional parameter values, Mankiw (1995) finds that the Solow model suggests convergence at a speed of 4% per year, i.e. faster than is actually the case, although Cashin and Loayza (1995) find a speed of convergence at this rate after controlling for the effect of net international migration in a sample of nine South Pacific countries.

A by-product of the regression equations specified above is that the additional explanatory variables may lead to some insight into the causes of differences in growth rates. For example, Barro and Sala-i-Martin (1992) explain the persisting differences in steady-state growth rates in rather ad hoc fashion by school enrolment rates and government consumption expenditure (excluding education and defence). A cross-section of countries shows in their research a lesser tendency to convergence. Similarly, Mankiw et al. (1992) show that the textbook Solow-Swan model needs to be augmented to make the model useful in explaining differences in income per capita across countries. They find that introducing human capital accumulation explicitly (measured by secondary school enrolment rates) has the same type of positive effect on income per head as the savings ratio s^* in the standard Solow model. The augmented model provides some evidence of inter-country convergence, although again at a slow rate.

Regional openness and interconnectedness may of course be responsible for the somewhat more convincing patterns of convergence observed at the regional level than in cross-country comparisons. For example, Barro and Sala-i-Martin (1992) point to diffusion of technological change having the potential of generating convergence even if the marginal product of capital is not declining. Nonetheless, despite well known historical evidence of convergence of incomes across states of the USA (e.g. Easterlin 1960), there are fairly lengthy periods during which one can observe divergence[8] and the evidence that factor mobility operates as an equilibrating process is also rather inconclusive.[9] Richer models are needed to explain such observations.

A vast literature has emerged during the last decade on which factors, in addition to the convergence effect, explain differences in growth rates between regions or countries. A review of this literature is beyond the scope of the present paper, but see inter alia Kormendi and Meguire (1985), Baumol (1986), De Long (1988), Dowrick and Nguyen (1989), Barro (1991) and Barro and Sala-i-Martin (1992). However, Levine and Renelt (1992) find that many of the regression models may suffer from specification errors and the results are not very robust. Moreover, Evans (1995) shows that the usual approach of estimation with OLS is in this context inappropriate.

In recent years, several studies have also attempted to focus on specific variables which are often considered to be important from the growth perspective. For example, De Long and Summers (1991) find that equipment investment can raise growth rates, and more strongly than investment in structures. Perroti (1996) finds that a lower income inequality raises growth rates, while Barro (1996) finds that political freedom has a positive effect on growth. Finally, Devarajan et al. (1996) show that the composition of public expenditure can have an important effect on growth. Specifically, governments of developing countries appear to have allocated relatively too many funds to public capital expenditures, at the expense of current expenditures.

5. Alternative approaches

Although the Solow-Swan model was also extensively used for the purpose of studying the growth of regions, of which Borts and Stein (1964) is a well-known example, dissatisfaction with this model led to a search for alternatives. This dissatisfaction was due to several reasons. Firstly, the neoclassical model predicted convergence, which contradicted with many case studies of uneven development. Secondly, the theory did not provide any guidance regarding policy instruments which could help to raise the growth rate. Thirdly, the macro focus of the neoclassical model is inadequate to explain any regional differences in growth rates which may be due to significant differences in sectoral composition. In this context it is useful to note that Bernard and Jones (1996) found recently, using data on 14 OECD countries, that there is a lack of convergence in manufacturing while aggre-

[8] The periods 1840–1880, 1920–1940 and 1970–1980 are periods of interregional divergence in the USA. See also Carlino and Mills (1996).
[9] See for example the discussion in Armstrong and Taylor (1985, pp. 118–121).

gate convergence results may be driven by services. Fourthly, the neoclassical model in a regional setting only permits the study of regions as point economies, with a possible interaction through factor flows, but it does not address the distribution of economic activity over continuous space.

Consequently, many alternative approaches were proposed during the 1960s and 1970s, such as the export base model, econometric models, (multi-regional) input-output and computable general equilibrium models; multisector development planning models, cumulative causation dynamic models etc. (see e.g. Richardson 1973). Some of the current endeavours to obtain a precise micro-level description of all sectors and the requirements for general equilibrium could already be found in the optimal space-time development models of regional science literature (e.g. Isard et al. 1979). However, the questions of the existence, uniqueness and stability of optimal solutions could not yet be addressed at the time.

The rather secondary role of trade in the neoclassical model led to a significant popularity of Keynesian modelling with a heavy emphasis on demand considerations. For example, output growth in a region is driven in the well-known Kaldor-Dixon-Thirlwall model 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 (Verdoorn 1949). This model explains 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.

In more formal terms, output growth is assumed to be export-led:

$$\tilde{Y} = \omega \tilde{X} \tag{25}$$

where $\tilde{}$ refers again to a rate of growth and X to the volume of exports. The export demand function has constant price and income elasticities

$$\tilde{X} = -\eta \tilde{p} + \xi \tilde{p}^f + \pi \tilde{Y}^f \ . \tag{26}$$

Price inflation results from fixed mark-up pricing on production costs, which in turn depend on unit wage costs w and labour productivity. Thus, in rate of change terms

$$\tilde{p} = \tilde{w} - \tilde{y} \ . \tag{27}$$

Central to this growth model is that labour productivity is partly dependent on growth of output itself, i.e. Verdoorn's Law:

$$\tilde{y} = \kappa + \lambda \tilde{Y} \ . \tag{28}$$

This equation is the result of inductive macroeconomic research and increasing returns may be the driving force behind it. However, the key weakness of this approach is that it does not explain which processes at the micro-level cause the positive feedback effect from output growth on productivity growth. Nonetheless, an extensive literature exists regarding the empirical evidence for the Verdoorn equation (reviewed in e.g. Bairam 1987). This literature 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 (28). By and large, the empirical evidence suggests that λ is positive.

The reduced form of the model (25)–(28) is readily computed and suggests a constant rate of growth of income per worker:

$$\tilde{y} = \kappa + \frac{\lambda\omega[-\eta(\tilde{w} - \kappa) + \xi\tilde{p}^f + \pi\tilde{Y}^f]}{1 - \lambda\omega\eta} \ . \tag{29}$$

This model has unrealistic implications if it is considered in an explicit two region situation in which income growth in either region affects growth in the other region through trade between them. It is fairly straightforward to compute the reduced form for the per capita income growth rates in both regions, but dependent on the choice of parameters, these growth rates could obviously differ and would suggest a persisting trade imbalance (Nijkamp and Poot 1993a). Krugman (1989) noted 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.[10] The Kaldor-Dixon-Thirlwall model is itself not informative about the processes which would ensure that the growth rates which this model generates would be consistent with long-run balance of payments equilibrium.

For example, 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 less competitive, region. Indeed, if the Verdoorn effect is strong enough, a situation of "immiserising" growth may be 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.

The model discussed above does not take into account explicitly the possibility of factor flows 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

[10] 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.

growth rates in per capita incomes, but the latter are again likely to be themselves affected by net migration. Moreover, production capacity limits are assumed unimportant here. In essence, the model describes the properties of a demand-driven steady-state growth path rather than full dynamics.[11] Yet it does make explicit that an exogenous shock to trade can have a long-term impact on the equilibrium growth rate, although our discussion suggests 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.[12] Recently, Targetti and Foti (1997) showed that a blending of the ideas of neoclassical conditional convergence, Kaldorian technological progress and export-led demand growth can be fruitful for cross-section econometric explanations of country growth rates, although their results are quite sensitive to the choice of groups of countries.

The various approaches discussed in this paper have in common the interpretation of economic growth as a moving macroeconomic equilibrium in which the underlying processes can be described in rather mechanical terms. An alternative approach is to consider regional growth as the result of (un)stable evolution in a system of competing regions. Evolutionary economics has tried to examine the space-time trajectories of dynamic complex systems on the basis of biological metaphors (see for an excellent overview Nelson 1995). Notions like predator-prey, resilience, fragility and shocks are used to map out the various types of dynamics that may emerge once a system of open economies with indigenous externalities is described by nonlinear complex (synergetic) dynamics (see Nijkamp and Reggiani 1997). In such cases, a wide spectrum of dynamic behaviour may emerge, in particular if the parameters defining the architecture of a system are also becoming time-dependent in the long-run. Evolutionary theories of economic growth have already existed for some time (see, for example, the overview of Nelson and Winter 1974). Yet there is still a great potential for further in-depth study of economic growth and dynamics in a multiregional system by means of evolutionary economics.

6. Conclusions

In this paper we have surveyed the literature on the new models of economic growth which have been developed during the last decade. We have contrasted these with the earlier theories and with the common alternative approaches of studying regional development. Despite their macro-level orientation, the strength of the new models is that they give better insight into

[11] It is possible to introduce lags in the behavioural equations. Dixon and Thirlwall (1975) showed 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.

[12] 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”.

the economic dynamics in an open system, specifically with respect to spatial interdependencies in the form of trade, factor mobility and innovation diffusion.

Many new models have been proposed in the literature. Such models capture one or more of the important features of development: sectoral composition, human and physical capital accumulation, natural endowments, economies of scale, trade, technological innovation and diffusion, factor mobility, government policies and market imperfections. However, the design of a coherent and unified framework appears to be far from easy. Moreover, most of the new theories require further extensive empirical scrutiny. In such empirical work it will be important to distinguish between transitional dynamics and long-run steady-state tendencies.

Much of the current literature adopts a macro perspective, albeit with carefully specified micro foundations. A common problem in empirical macroeconomics is that the macro data are sometimes unable to permit the researcher to conclusively choose between competing theories. For example, this problem has reduced what we can learn for policy formulation from the large literature on cross-country and cross-region growth regressions (see also e.g. Mankiw 1995).

Both the export-led growth model and the general equilibrium 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. Moreover, some models with increasing returns due to endogenous technical change suggest that there is a tendency for a highly interdependent system to be unstable, with a likelihood of “uneven development”. While the new growth models 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. In particular, a better integration of micro- and macro-level approaches is required.

For example, the locational aspects of R&D creation, diffusion and adoption deserves much closer attention. To some extent, this issue is comparable to the infrastructure debate as presented, among others, in Biehl et al. (1986) and Nijkamp (1986). Production theories may be used to assess the implications of a favourable infrastructure in particular regions with respect to differential competitiveness. Endogenous growth initiatives may also be relevant in this context. The lumpiness of infrastructure means that the regional benefits may only be expected in the long run, while investments are to be made in the short run. Thus, financial resources have to be set aside which may have an uncertain future return, in particular since the demand responses to supply of public infrastructure are difficult to gauge. The same applies to unforeseen impacts of economic integration (the European market, NAFTA, etc.). Therefore, issues on the demand side, such as household behaviour, impediments to trade and the institutional structure, should not be ignored either.

In our context, a regional dynamisation of a production function, accompanied by a technological diffusion function with parameters dependent on information barriers on the one hand and competitive behaviour on the other, would provide a promising starting-point. Changing trade patterns, factor flows and public policies can then be incorporated to identify the long-run growth tendencies of the regions in the system.

References

Aghion P, Howitt P (1992) A model of growth through creative destruction. Econometrica 60(2):323–351

Allais M (1947) Économie et interêt. Imprimerie National, Paris

Andres J, Domenech R, Molinas C (1996) Macroeconomic performance and convergence in OECD countries. European Economic Review 40(9):1683–1704

Armstrong H, Taylor J (1985) Regional economics and policy. Philip Allen, Oxford

Arrow KJ (1962) The economic implications of learning by doing. Review of Economic Studies 29 (June):155–173

Arthur WB (1994) Increasing returns and path dependence in the economy. University of Michigan Press, Ann Arbor

Bairam EI (1987) The Verdoorn law, returns to scale and industrial growth: a review of the literature. Australian Economic Papers 26 (June):20–42

Bal F, Nijkamp P (1997) Exogenous and endogenous spatial growth models. TI Discussion Paper 97-022/3, Tinbergen Institute, Amsterdam

Barbier EB (1996) Endogenous growth and natural resource scarcity. Working Paper 45.96, Fondazione Eni Enrico Mattei, Milano, Italy

Barro RJ (1990) Government spending in a simple model of endogenous growth. Journal of Political Economy 98(5.2):S103–125

Barro RJ (1991) Economic growth in a cross section of countries. Quarterly Journal of Economics 106:407–443

Barro RJ (1996) Determinants of growth: a cross-country empirical study. NBER Working Paper No. 5698

Barro RJ, Becker GS (1989) Fertility choice in a model of economic growth. Econometrica 57(2):481–501

Barro RJ, Sala-i-Martin X (1992) Convergence. Journal of Political Economy 100(2):223–251

Barro RJ, Sala-i-Martin X (1995) Economic growth. McGraw-Hill, New York

Baumol WJ (1986) Productivity growth, convergence, and welfare: what the long run data show. American Economic Review 76(5):1072–1085

Becker GS, Murphy KM, Tamura RF (1990) Human capital, fertility, and economic growth. Journal of Political Economy 98(5.2):S12–S37

Ben-David D (1996) Trade and convergence among countries. Journal of International Economics 40:279–298

Bernard AB, Jones CI (1997) Comparing apples to oranges: productivity convergence and measurement across industries and countries. American Economic Review 86(5):1216–1238

Bertuglia CS, Lombardo S, Nijkamp P (eds) (1997) Innovation behaviour in space and time. Springer, Berlin Heidelberg New York

Biehl D et al. (1986) The contribution of infrastructure to regional development. Commission of European Communities, Brussels

Borts GH, Stein JL (1964) Economic growth in a free market. Columbia University Press, New York

Bovenberg AL, Smulders SA (1996) Transitional impacts of environmental policy in an endogenous growth model. International Economic Review 37(4):861–893

Braun J (1993) Essays on economic growth and migration. PhD Dissertation, Harvard University

Brown LA (1981) Innovation diffusion. Methuen, London

Cappellin R (1989) The diffusion of producer services in the urban system. In: Cappellin R, Nijkamp P (eds) Theories and policies of technological development at the local level. Gower, Aldershot

Carlino G, Mills L (1996) Convergence and the U.S. states: a time-series analysis. Journal of Regional Science 36(4):597–616

Cashin P, Loayza N (1995) Paradise lost? Growth, convergence and migration in the South Pacific. IMF Staff Papers 42(3):608–641

Cass D (1965) Optimum growth in an aggregative model of capital accumulation. Review of Economic Studies 32(3):233–240

Choi JP (1994) Irreversible choice of uncertain technologies with network externalities. Rand Journal of Economics 25:382–400

Conlisk J (1967) A modified neo-classical growth model with endogenous technical change. Southern Economic Journal 34(October):199–208

Davies S (1979) The diffusion of process innovations. Cambridge University Press, Cambridge

De Long JB (1988) Productivity growth, convergence, and welfare: comment. American Economic Review 78(5):1138–1154

De Long JB, Summers LH (1991) Equipment investment and economic growth. Quarterly Journal of Economics 106(2):445–502

Devarajan S, Swaroop V, Zou H (1996) The composition of public expenditure and economic growth. Journal of Monetary Economics 37(2):313–344

Devereux MB, Lapham BJ (1993) The stability of economic integration and endogenous growth. Discussion Paper No. 878, Institute for Economic Research, Queen's University, Canada

Dixon R, Thirlwall AP (1975) A model of regional growth-rate differences on Kaldorian lines. Oxford Economic Papers 27:201–214

Domar ED (1946) Capital expansion, rate of growth, and employment. Econometrica 14(April):137–147

Dosi G (1988) Sources, procedures, and microeconomic effects of innovation. Journal of Economic Literature 88(3):1120–1171

Dowrick S, Nguyen D (1989) OECD comparative economic growth 1950–85: catch-up and convergence. American Economic Review 79(5):1010–1030

Drugeon JP (1996) Impatience and long-run growth. Journal of Economic Dynamics and Control 20:281–313

Easterlin RA (1960) Interregional differences in per capita income, population, and total income, 1840-1950. In: Conference on Research in Income and Wealth, NBER Studies in Income and Wealth, vol 24

Ehrlich I (1990) The problem of development: introduction. Journal of Political Economy 98(5.2):S1–S11

Elbasha EH, Roe TL (1996) On endogenous growth: the implications of environmental externalities. Journal of Environmental Economics and Management 31:240–268

Evans P (1995) How to estimate growth regressions consistently. Department of Economics, Ohio State University, mimeo

Evans P, Karras G (1996) Convergence revisited. Journal of Monetary Economics 37:249–265

Frenkel JA, Razin A (1987) Fiscal policies and the world economy: an intertemporal approach. MIT Press, Cambridge, Mass.

Fujita M, Krugman P, Mori T (1995) On the evolution of hierarchical urban systems. Discussion Paper No. 419, Institute of Economic Research, Kyoto University

Garegnani P (1970) Heterogeneous capital, the production function and the theory of capital. Review of Economic Studies 37:407–436

Giaoutzi M, Nijkamp P (eds) (1988) Informatics and regional development. Gower, Aldershot

Gordon RH, Bovenberg AL (1996) Why is capital so immobile internationally? Possible explanations and implications for capital income taxation. American Economic Review 86(5):1057–1075

Gorter C, Nijkamp P, Poot J (forthcoming) Crossing borders: regional and urban perspectives on international migration. Avebury, Aldershot

Grossman GM, Helpman E (1990a) Trade, innovation and growth. American Economic Review 80(2):86–91

Grossman GM, Helpman E (1990b) Comparative advantage and long-run growth. American Economic Review 80(4):796–815
Grossman GM, Helpman E (1991) Innovation and growth in the global economy. MIT Press, Cambridge, Mass
Grossman GM, Helpman E (1994) Endogenous innovation in the theory of growth. Journal of Economic Perspectives 8(1):23–44
Harrod RF (1939) An essay in dynamic theory. Economic Journal 49 (June):14–33
Hatta T (1976) The paradox in capital theory and complementarity of inputs. Review of Economic Studies 43:127–142
Inada K (1963) On a two-sector model of economic growth: comments and a generalization. Review of Economic Studies 30(June):119–127
International Monetary Fund (various years) International Financial Statistics. International Monetary Fund, Washington, DC
Isard W, Liossatos P, Kanemoto Y, Kaniss PC (1979) Spatial dynamics and optimal space-time development. North-Holland Publishing Company, Amsterdam
Jones H (1975) An introduction to modern theories of economic growth. Nelson, London
Jones LE, Manuelli RE (1997) Endogenous growth theory: an introduction. Journal of Economic Dynamics and Control 21(1):11–22
Jones LE, Stokey NL (1992) Introduction: symposium on economic growth, theory and computations. Journal of Economic Theory 58:117–134
Jovanovic B (1995) Research, schooling, training and learning by doing in the theory of growth. Department of Economics, University of Pennsylvania, mimeo
Kaldor N (1957) A model of economic growth. Economic Journal 67:591–624
Kaldor N (1970) The case for regional policies. Scottish Journal of Political Economy 17(3):337–348
Kamien MI, Schwartz NL (1982) Market structure and innovation. Cambridge University Press, Cambridge
Keller W (1996) Absorptive capacity: on the creation and acquisition of technology in development. Journal of Development Economics 49(1):199–227
King RG, Rebelo ST (1993) Transitional dynamics and economic growth in the neoclassical model. American Economic Review 83(4):908–931
Knight M, Loayza N, Villanueva D (1993) Testing the neoclassical theory of economic growth. IMF Staff Papers 40(3):512–541
Koopmans TC (1965) On the concept of optimal economic growth. In: The econometric approach to development planning. North-Holland, Amsterdam
Kormendi R, Meguire P (1985) Macroeconomic determinants of growth: cross-country evidence. Journal of Monetary Economics 16:141–163
Koski H, Nijkamp P (1996) Timing of adoption of new communication technology. TI Discussion Paper 96-61/5, Tinbergen Institute, Amsterdam
Kremer M (1993) Population growth and technological change: one million B.C. to 1990. Quarterly Journal of Economics 108(3):681–716
Krugman P (1979) A model of innovation, technology transfer, and the world distribution of income. Journal of Political Economy 87:253–266
Krugman P (1981) Trade, accumulation and uneven development. Journal of Development Economics 8:149–161
Krugman P (ed) (1988) Strategic trade policy and the new international economics. MIT Press, Cambridge, Mass
Krugman P (1989) Income elasticities and real exchange rates. European Economic Review 33:1031–1054
Krugman P (1991) Geography and trade. MIT Press, Cambridge, Mass
Krugman P (1995) Development, geography and economic theory. MIT Press, Cambridge, Mass
Kubo Y (1995) Scale economies, regional externalities, and the possibility of uneven regional development. Journal of Regional Science 35(1):29–42
Kubo Y, Kim H (1996) Human capital, imported technology and economic growth: a comparative study of Korea and Japan. Discussion Paper 695, Institute of Policy and Planning Sciences, University of Tsukuba

Levine R, Renelt D (1992) A sensitivity analysis of cross-country growth regressions. American Economic Review 82(4):942–963
Lewis WA (1954) Economic development with unlimited supplies of labor. Manchester School of Economics and Social Studies 22 (May):139–191
Lucas RE (1988) On the mechanics of economic development. Journal of Monetary Economics 22(1):3–42
Lucas RE (1990) Why doesn't capital flow from rich to poor countries? American Economic Review 80(2):92–96
Malthus TR (1798) An essay on the principle of population, 1986 edition. W. Pickering, London
Mankiw NG (1995) The growth of nations. Brookings Papers on Economic Activity 1:275–310
Mankiw NG, Romer D, Weil DN (1992) A contribution to the empirics of economic growth. Quarterly Journal of Economics 107 (May):407–438
Markusen A (1996) Interaction between regional and industrial policies. International Regional Science Review 19(1&2):49–78
Marx K (1867) Capital Vol I, 1967 edition. International Publishers, New York
McCombie JSL (1988a) A synoptic view of regional growth and unemployment: I – the neoclassical theory. Urban Studies 25(4):267–281
McCombie JSL (1988b) A synoptic view of regional growth and unemployment: II – the post-Keynesian theory. Urban Studies 25(5):399–417
Morrill R, Gaile GL, Thrall GI (1988) Spatial diffusion. Sage, Beverley Hills
Myrdal G (1957) Economic theory and underdeveloped regions. Duckworth, London
Nana G, Poot J (1996) A study of trade liberalisation and factor mobility with a CGE model of Australia and New Zealand. Studies in Regional Science 26(2):27–52
Nelson R (1995) Recent evolutionary theorizing about economic change. Journal of Economic Literature 33(1):48–90
Nelson R, Winter S (1974) Neoclassical vs. evolutionary theories of economic growth: critique and prospectus. Economic Journal 84(336):886–905
Nijkamp P (1986) Infrastructure and regional development: a multidimensional policy analysis. Empirical Economics 11:1–21
Nijkamp P, Poot J (1993a) Technological progress and spatial dynamics: a theoretical reflection. In: Kohno H, Nijkamp P (eds) Potentials and bottlenecks of spatial economic development. Springer, Berlin Heidelberg New York
Nijkamp P, Poot J (1993b) Endogenous technological change, innovation diffusion and transitional dynamics in a nonlinear growth model. Australian Economic Papers 32(4):191–213
Nijkamp P, Poot J, Rouwendal J (1991) A nonlinear dynamic model of spatial development and R&D policy. Annals of Regional Science 25:287–302
Nijkamp P, Reggiani A (1997) The economics of complex spatial systems. Elsevier, Amsterdam
Oniki H, Uzawa H (1965) Patterns of trade and investment in a dynamic model of international trade. Review of Economic Studies 32:15–38
Osano H (1992) Basic research and applied R&D in a model of endogenous economic growth. Osaka Economic Papers 42(1/2):144–167
Perroti R (1996) Growth, income distribution and democracy; what the data say. Journal of Economic Growth (June)
Perroux F (1955) Note sur la notion de pôle de croissance'. Cahiers de l'Institut de Science Economique Appliquée, Series D No. 8
Perrson J (1994) Convergence in per capita income and migration across the Swedish counties 1906–1990. Institute for International Economic Studies, Stockholm University, mimeo
Pontryagin LS et al. (1962) The mathematical theory of optimal processes. Interscience Publishers, New York
Quah DT (1996) Empirics for economic growth and convergence. European Economic Review 40:1353–1375
Ramsey F (1928) A mathematical theory of saving. Economic Journal 38 (December):543-559
Ricardo D (1817) On the principles of political economy and taxation, 1951 edition. Cambridge University Press, Cambridge, Mass
Richardson HW (1973) Regional growth theory. Macmillan, London

Rivera-Batiz LA, Xie Danyang (1993) Integration among unequals. Regional Science and Urban Economics 23(3):337–354
Rivera-Batiz LA, Romer PM (1991) Economic integration and endogenous growth. Quarterly Journal of Economics 106(2):531–556
Romer PM (1986) Increasing returns and long-run growth. Journal of Political Economy 94(5):1002–1037
Romer PM (1989) Capital accumulation in the theory of long-run growth. In: Barro RJ (ed) Modern business cycle theory. Harvard University Press, Cambridge, Mass
Romer PM (1990) Endogenous technological change. Journal of Political Economy 98(5.2): S71–S102
Romer PM (1994) The origins of endogenous growth. Journal of Economic Perspectives 8(1):3–22
Sala-i-Martin X (1996) Regional cohesion: evidence and theories of regional growth and convergence. European Economic Review 40:1325–1352
Samuelson PA (1958) An exact consumption-loan model of interest with or without the social contrivance of money. Journal of Political Economy 66(6):467–482
Schmitz JA (1989) Imitation, entrepreneurship, and long-run growth. Journal of Political Economy 97(3):721–739
Schumpeter JA (1934) The theory of economic development. Harvard University Press, Cambridge, Mass
Scott M (1989) A new view of economic growth. Oxford University Press, Oxford
Smith A (1776) An inquiry into the nature and causes of the wealth of nations. 1937 edition, Random House, New York
Soete L, Turner R (1984) Technology diffusion and the rate of technical change. Economic Journal 94:612–623
Solow RM (1956) A contribution to the theory of economic growth. Quarterly Journal of Economics 70:65–94
Solow RM (1994) Perspectives on growth theory. Journal of Economic Perspectives 8(1):45–54
Stern N (1991) The determinants of growth. Economic Journal 101 (January):122–133
Stokey NL (1988) Learning by doing and the introduction of new goods. Journal of Political Economy 96:701–717
Summers R, Heston A (1991) The Penn World Table (Mark 5): an expanded set of international comparisons, 1950–1988. Quarterly Journal of Economics 106(2):327–368
Swan TW (1956) Economic growth and capital accumulation. Economic Record 32 (November):334–361
Targetti F, Foti A (1997) Growth and productivity: a model of cumulative growth and catching up. Cambridge Journal of Economics 21(1):27–43
Van Dijk J, Folmer H, Herzog Jr HW, Schlottmann AM (1989) Migration and labour market adjustment. Kluwer, Dordrecht
Venables AJ (1996) Trade policy, cumulative causation, and industrial development. Journal of Development Economics 49(1):179–197
Verdoorn PJ (1949) Fattori che regolano la sviluppo della produttivita del lavoro [Factors governing the growth of labour productivity]. L'Industria 1:3–10 [English translation: Thirlwall AP, Thirlwall G, Research in Population and Economics, 1979]
Vernon R (1966) International investment and international trade in the product cycle. Quarterly Journal of Economics 80:190–207
Verspagen B (1992) Endogenous innovation in neo-classical growth models: a survey. Journal of Macroeconomics 14(4):631–662
World Bank (various years) World Bank national accounts. World Bank, Washington, DC
Yoshida M (1995) Compatibility between growth and environmental preservation: threshold effects of the environment on health risks. Institute of Policy and Planning Sciences, University of Tsukuba