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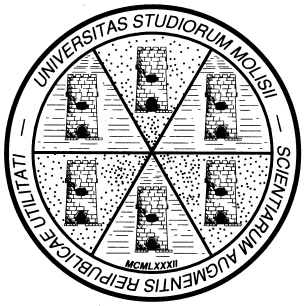

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Endogenous Growth in Open Economies: A Survey of Major Results

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ENDOGENOUS GROWTH IN OPEN ECONOMIES: A SURVEY OF MAJOR RESULTS

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Abstract

Endogenous growth has set a new paradigm for macroeconomic analysis. This paper overviews the most relevant theoretical contributions of this literature for the analysis of open economies, highlighting their implications both for the effects of cross-country integration on output convergence and for the overall growth performance of the integrated economy, as compared to that of an identical group of autarchic countries. The literature is divided into three major classes, studying, respectively, the effects of factor mobility, the role of international trade, and the consequences of technology diffusion. The main conclusion is that knowledge spillovers can go a long way in explaining the differences in growth performances across countries, but additional research is needed to completely understand the mechanisms driving their international diffusion.

Keywords: endogenous growth, open economies, international spillovers

JEL Classification: O4, F2

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1. Introduction1

Endogenous growth has set a new paradigm for macroeconomic analysis. Although Solow's (1956) fundamental contribution solved the instability problem of Domar's (1946) and Harrod's (1939) models, the solution proposed has the drawback that "increasing the rate of *per-capita* growth is not only not easy in this model, it is impossible unless the rate of technological progress can be altered deliberately" as Solow (1994, p. 49) himself recently remarked. Indeed, neoclassical theory lacks one key aspect to be a complete theory of economic growth: the capability of explaining endogenously the determinants of the long-run equilibrium rate of growth. Romer's (1986) seminal paper showed how to solve this problem by finding the conditions under which an intertemporal Ramsey-type model can have an equilibrium characterised by a constant (or even increasing) rate of growth of output per capita. This key result opened an entire field of research aimed at analysing the determinants of long-run growth within a general equilibrium framework.

Growth literature has traditionally been driven by a desire to understand why some countries grow faster than others. Authors like Romer (1986) and Lucas (1988) show that differences in production technology or human capital accumulation are sufficient to generate asymmetries in the long-run equilibrium rate of growth of total output. This stands out against the conclusion of the neoclassical model, where technological differences can only affect the convergence path to the long run equilibrium, itself characterised by an exogenously given rate of growth. An obvious consequence was that the introduction of the endogenous growth paradigm heavily influenced the comparative analysis of the long-run behaviour of different countries.

[1] This paper is a revised version of the introductory chapter of my Ph.D. thesis at the University of Southampton. I would like to thank John Driffill, my supervisor, Danny Quah and Akos Valentiny, my examiners, Andrea Brandolini and Roberto Turrini for comments and suggestions. All remaining errors are of course my own responsibility.

However, the first models proposed had only abandoned the hypothesis of diminishing returns to human or physical capital: “this stage of the revival could be described as a return to generalised Domar, but with sophisticated bells and whistles” (Solow, 1994, p. 49). In fact, the key policy prediction of this class of models is that any factor augmenting the rate of capital accumulation causes an acceleration in the long-run equilibrium rate of growth, a conclusion also reached by the literature developed before the neoclassical revolution. This framework has been criticised for its dependence on the assumption of constant returns to capital, a clear symptom of theoretical fragility despite the fact that “capital” is interpreted here as a collection of accumulable inputs. This notwithstanding, models of endogenous growth with constant returns to capital may have an important role as a simplified tool, suitable for studying the macroeconomic behaviour of growing economies, possibly interacting with each other.

A second wave of models dropped the assumption of constant returns to capital, studying more carefully the determinants of technological progress, which in the neoclassical framework was left aside as a residual (e.g., Romer, 1990, and Aghion and Howitt, 1992).

Two other aspects that the endogenous growth literature did not initially give the attention they deserved are the effects of factor mobility and free trade: “Growth theory traditionally has treated each country as if it were an island unto itself. Extensions of the theory to a world with international trade and capital flows have been left aside as esoteric exercises for algebra lovers. If ever this practice was defensible, surely it is no longer. Countries trade with one another, communicate with one another and learn from one another more than ever before” (Grossman and Helpman, 1994, p. 38). In fact, any satisfactory analysis of the reasons permitting the existence of differences in the long-run equilibrium rates of growth across nations needs to be conducted using multi-country models. There are at least three effects of international integration that can modify factor returns and, eventually, the equilibrium level or the rate of accumulation of the state variables governing the economy. First is the possibility of moving factors to countries where their marginal productivity is higher. Second is international trade in final goods, which may alter the equilibrium price vector with respect to the case of autarchy, also modifying factor returns. Third is international knowledge spillovers, which may alter the rates of return of research and development activities and therefore

the equilibrium rate of knowledge accumulation.

The first analyses of the asymmetries in the growth performance of different countries based on open-economy endogenous growth models made it suddenly clear that the new paradigm was going to open many more problems than it could solve. The convergence result, which characterises neoclassical growth theory, is in fact generally no longer valid, with consequences for the expected process of evolution of worldwide income distribution that are obviously not reassuring. This highlighted the necessity to study more closely whether there exist forces permitting slower growing countries to catch up with more developed economies, even within a framework in which the automatic transfer of capital to regions where its productivity is supposed to be higher – due to its scarcity – is no longer at work.

The literature on open-economy endogenous growth has reached different conclusions, depending on the main object of its analysis: factor mobility, trade, and knowledge diffusion. This paper surveys the major theoretical contributions on these three fields of research. Its aim is to give an overview of the models, highlighting their implications for output convergence and the growth performance of the integrated economy relative to that of an identical group of autarchic countries. The main conclusion of the survey is that knowledge spillovers can go a long way in explaining the differences in growth performances across countries, but more theoretical research is needed to completely understand their mechanisms of diffusion.

The remainder of the paper is organised as follows. Section 2 briefly describes the major empirical findings with which theoretical models must be made consistent, and possibly explain. Section 3 studies the effects of factor mobility. Section 4 presents models of trade and growth. Section 5 studies the role of cross-country and cross-region spillovers. The final section briefly concludes. The appendix presents some benchmark closed economy models of endogenous growth.

2.Some stylised facts

The empirical literature on the determinants of growth and convergence is immense. At the same time when the theoretical endogenous literature had its start, with Romer's (1986) paper, a new strand of empirical research on growth and convergence also initiated, with the seminal contribution of Baumol (1986). This

literature grew extensively in the following years.[2]

In the following I present some of the most widely accepted stylised facts on cross-country growth that the theoretical literature presented in the following sections either takes as starting points or seeks to explain.

The first question that arises when studying cross-country growth is that of convergence, one of the most controversial and debated issues in the empirical literature. Following Galor (1996), three competing hypotheses can be considered: absolute convergence, which implies that per capita incomes of different countries converge to a common level, independently of their initial conditions; conditional convergence, which implies convergence to a common level, independently of the initial conditions, only for those countries that share identical structural characteristics (i.e., technologies and preferences); and club convergence, which implies convergence to a common level only for countries that are identical in their structural characteristics and also share similar initial conditions.

At the world level, absolute convergence has been neatly refused by the data (see, in particular, Barro, 1991). Evidence in favour of conditional convergence has been found by a large number of studies, starting from the seminal contributions of Barro and Sala-i-Martin (1991 and 1992). However, these results have been heavily criticised, especially on methodological grounds (see, for example, Friedman, 1992, and Quah, 1993a). Besides, Galor (1996) shows that the findings of the so called "Barro regressions" do not permit to discriminate between conditional and club convergence. Indeed, using a different empirical methodology, Quah (1993b and 1997) and Durlauf and Johnson (1995), among others, find clear evidence of club convergence, with richer countries approaching a high level equilibrium, and poorer countries drifting apart.

[2] Detailed surveys can be found in Barro and Sala-i-Martin (1995), Durlauf and Quah (1999) and Temple (1999).

A second aspect, closely linked with the analysis of cross-country growth, is factor mobility. Indeed, perfect international factor mobility would eliminate the effect of initial conditions on convergence, leaving the stage only to differences in the structural characteristics of countries. However, as shown by Feldstein and Horioka (1980) and the following empirical literature, factor mobility is anything but perfect (for a survey, see Obstfeld, 1995). This implies first that it may be sensible to study convergence in models that do not account for capital mobility and, second, that explanations of differences in the growth performance of countries that can also account for imperfect capital mobility have a stronger explanatory power than others.

A third aspect that is particularly relevant when analysing open economy models of growth is the effect of international trade on the overall performance of the integrated area. The existence of a positive correlation between a country's degree of openness and its growth performance is a well accepted empirical regularity, but many criticism have been raised on the direction of causality of this relationship. Indeed, it is very easy to make a case for a link going from growth to trade, and not the other way round. In a recent contribution, Frankel and Romer (1999) have offered evidence in support of the view that causality goes from trade to growth. However, the issue is still debated.

Finally, a recent strand of empirical literature has analysed the role of technology transfers. Coe and Helpman (1995) show that foreign R&D has large effects on domestic total factor productivity, a result confirmed also by the analyses of Eaton and Kortum (1996) and Brecher *et al.* (1996). These findings have strong theoretical implications, as they highlight a different way of achieving income convergence than through factor mobility.

3.Factor Mobility in Open Economy Models of Endogenous Growth

Open-economy models of endogenous growth study the effects of both capital and labour mobility. This is a natural class of models to start from, given the strong implications that factor mobility has for output convergence in the Solow model.3 For the neoclassical theory, differences in the rates of growth between countries can easily be explained by the distance of a country's stock of capital from its long-run equilibrium: the lower the available stock of capital (and the larger the propensity to save out of total income), the higher the rate of growth of the economy. This framework is therefore capable of explaining different rates of growth for perfectly identical countries simply by assuming that their initial conditions are different.

Cass (1965) and Koopmans (1965) extended the basic neoclassical model by solving endogenously for the rate of saving. Within this framework, differences in the rates of growth of countries can also depend on the intertemporal elasticity of substitution of consumption and on the rate of time preference, the determinants of the propensity to save. However, this is possible only up to the point in which the long-run equilibrium is reached. After that, countries can have different growth performances only as a result of more or less rapid technological progress, which is exogenously given.

With constant returns to capital, the neoclassical story is no longer sustainable: different growth performances between independent countries can only be explained by asymmetries in the technology adopted or in consumers' preferences. The following section presents a basic framework that can be used to analyse the effects of capital mobility; section 3.2 considers the role of taxation. Finally, labour mobility is briefly discussed. In the models presented in this section the role of international trade is left aside, assuming that the same tradable good is produced in both countries.

[3] A more detailed analysis of the implication of this class of models is in Turnovsky (2000).

3.1 Capital Mobility

The immediate implication of opening up Rebelo's (1991) model4 to the case of two countries with perfect capital mobility is that either they have the same long-run rate of growth, or capital concentrates in the country where its marginal productivity is higher. Such a result is difficult to accept, as it means that either the two countries are identical, or they experience complete divergence in the levels and growth rates of output, with the disappearance of one of the two.

Bertola (1993) confirms the result of Rebelo (1991) for the case in which also labour is a factor of production, but it is immobile.[5] In the absence of cross border externalities,[6] physical capital flows to the country where productivity is higher, leaving immobile labour in the other country, unproductive. This implies, on one side, the achievement of a higher rate of growth of the integrated economy, because capital is employed where it is most productive; on the other side, complete divergence of the level and rates of growth of production across countries, as the least productive of the two has no physical capital.

The conclusion that integration leaves one of the two countries unproductive, unless they have identical characteristics, is common to all early endogenous growth models, but has at least two major unattractive features. First, contrary to the predictions of the neoclassical model, it implies that differences in the level of welfare among countries are not going to diminish as a result of the free play of market forces. Second, it is at odds with the empirical evidence, which clearly shows that different and integrated countries can have very different growth performances for very long time periods.

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[4] See the appendix for a brief presentation of Rebelo's (1991) and other benchmark models of endogenous growth.

[5] Bertola (1993) considers the following production function: $Y = AK^{\alpha}L^{1-\alpha}$, where Y is total output, A is a positive constant, K and L are capital and labour inputs, respectively, and $\alpha \in (0,1)$ is the share of capital in production. The case with mobile labour is described in section 3.3.

The first aspect has given way to a strand of theoretical literature looking for conditions under which the level of output and its rate of growth in different countries can converge to a common level. The main forces driving this result, related essentially to knowledge spillovers, will be discussed in section 5. The second aspect, the persistence of different growth performances in apparently integrated economies, has been studied in connection with the degree of factor mobility. Indeed, when factors cannot move freely from one country to another, returns can differ between countries, thus permitting different growth performances.

Buiter and Kletzer (1991), for example, consider the case when human capital is one of the accumulable factors of production, together with physical capital.[7] In a two-country framework with perfect capital mobility, they show that if human capital can be produced only using non-transferable inputs, such as the human capital of the past generations, levels and rates of growth of output in the two countries can differ permanently. To see this, it is sufficient to rewrite the basic human capital accumulation function in Lucas' (1988) model, equation (A5) in the appendix, as

$$\dot{H}_i = \varphi_i (1 - f_i) H_i , \tag{1}$$

where i = 1,2 identifies the country considered, φ1 and φ2 are exogenous constants, with φ1>φ2, H is the level of human capital and fi is the fraction of time that agents of country i devote to production. Perfect physical capital mobility implies that:

$$r_{K_1} = \alpha A K_1^{\alpha-1} (f_1 H_1)^{1-\alpha} = \alpha A K_2^{\alpha-1} (f_2 H_2)^{1-\alpha} = r_{K_2} . \tag{2}$$

where K_i and r_{K_i} (i = 1,2) are, respectively, the physical capital input and its rate of return in country i, and $\alpha \in (0,1)$ is the share of physical capital in production.

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[6] The case with of cross-border externalities is presented in section 5.

[7] For a benchmark, closed economy model with these characteristics, see Lucas (1988). A simplified version is also presented in the appendix.

Therefore, the only condition that must be satisfied for a steady state equilibrium to exist is:

(3) $$\frac{K_1}{H_1} = \frac{K_2}{H_2},$$

which implies that the equilibrium rate of growth is higher in country 1 than in country 2 (and therefore output levels in the two countries diverge):[8]

(4) $$g_1 = \frac{\varphi_1 - \rho}{\sigma} > \frac{\varphi_2 - \rho}{\sigma} = g_2 .$$

In this framework, international physical capital mobility has no effects on the equilibrium rate of growth of the integrated economy, which would asymptotically converge to that of the fastest growing country even in absence of factor market integration; however it may have short run effects on the equilibrium rate of growth of each economy.

A different consequence of international capital mobility, the increased possibility of risk diversification, has been studied by Obstfeld (1994) and Deveroux and Smith (1994). Obstfeld (1994) constructs a model where agents can choose between two types of investment: one is more efficient, but is characterised by an idiosyncratic risk, the other is less efficient, but it is completely safe. Under these hypotheses, he shows that in an open economy framework, when a larger number of projects is available, investors can diversify away the idiosyncratic risk associated with the more efficient investment. As a result, they devote a larger share of savings to financing the risky investment, reaching an equilibrium with a higher long-run rate of growth. By contrast, Deveroux and Smith (1994) consider only the possibility of investing in risky projects, reaching the opposite conclusion. In fact, international risk sharing makes it possible to

[8] This result is not confirmed if physical capital is also needed in order to produce human capital (e.g., if $\dot{H} = \varphi(1-f)H^{\beta}K^{1-\beta}$, $\beta \in (0,1)$).

diversify away country specific income risk, reducing the incentive for precautionary saving. In turn, this has a negative effect on both capital accumulation and growth.

Both these models consider the case of a small open economy opening to international capital mobility, with the only indirect implication for convergence that a country joining an integrated area increases its rate of growth to that of the whole area.

3.2 Taxation

Another way of altering the incentives to accumulate physical or human capital is taxation. Rebelo (1992) and Milesi-Ferretti and Roubini (1994) consider the possibility of changing the returns to investment by means of taxation, in order to offset cross-country differences in the marginal productivity of capital.

Rebelo (1992) analyses the key issue of taxation of foreign investment. In particular, he points out that it is possible to avoid outflows of capital to countries with higher productivity if taxes on foreign returns are sufficiently lower than those on domestic returns. Assuming that returns to investments abroad are not taxed in the foreign country, using the framework of Rebelo's (1991) model – as described in equations (A2) and (A3) –, this requires setting domestic taxes on foreign investments at a level such that $\tau^F A^F = \tau^H A^H$, where τ^F, τ^H, A^F and A^H are, respectively, the rate of taxation of foreign and domestic investments and the average and marginal productivity of capital abroad and in the home country.[9]

Milesi-Ferretti and Roubini (1994) present a two-factor model of endogenous growth where human capital accumulation requires also the use of physical capital as a factor of production. They show that, if taxes are levied on residents' income, there is unique value of taxation on labour and capital income that guarantees the returns on

[9] If investments abroad are taxed in the foreign country, this might simply imply a less than complete credit on taxes paid abroad.

domestic and foreign investments to be equalised, and that the tax on income from domestic and foreign assets which maximises welfare is nil.

In these frameworks, taxation reduces the equilibrium rate of growth of the integrated economy, because it impedes the utilization of capital where it is most productive. However, it favours convergence, hindering the desertification of the least productive country.[10]

3.3 Migrations

Bertola (1993) shows that the same results of allowing perfect capital mobility in Rebelo's (1991) model are obtained in an endogenous growth model with perfect international labour mobility: either the two countries are identical and grow at the same rate, or workers move to the most advanced nation leaving the other empty and unproductive. Capital and labour mobility produce therefore the same result.

A different class of models of migrations and growth consider instead the role of human capital, under hypothesis of constant returns to scale in its accumulation, as in the case of equation (A5) in the appendix. Lucas (1988) assumes a production technology with an externality equal to the average level of human capital, h:

$$Y = AK^{\alpha}(fH)^{1-\alpha}h^{\gamma}, \tag{5}$$

where $\gamma \in (0,1)$ is a constant, $f \in (0,1)$ is the share of time devoted to work, and the other variables are as defined earlier. Within this framework, migrations to the more developed countries are induced by the fact that the factor share of labour, adjusted for its human capital level, is an increasing function of the average level of education: $wfH = (1-\alpha)Yh^{\gamma}$. The implication of this model for convergence are not reassuring, as more developed countries are likely to attract progressively more workers, making less

[10] On welfare grounds, such interventions are justifiable if lower productivity of capital in one country is a temporary phenomenon, for example because some learning of new techniques is in place.

developed nations disappear asymptotically. The overall rate of growth converges to that of the faster growing country.

Similar implications are drawn by Burda and Wypsloz (1992), who extend Lucas's (1988) framework by considering a two-country model with human capital accumulation in which labour is freely mobile, but the adjustment of the stock of physical capital is subject to a convex cost. Under these assumptions, if before integration the level of human capital is not identical in all countries, workers tend to move to the most developed one. Despite the increase in the size of the labour force and the reduction in the aggregate level of human capital, the rate of return of physical capital remains higher in the most developed country, maintaining an incentive to migrate until complete polarisation is achieved. As the optimal long-run allocation of workers would instead imply the equalisation of aggregate levels of human capital from the first moment after migrations are allowed, policy restrictions on migration would be beneficial.[11]

The models presented in this section can explain differences in the equilibrium rates of growth across countries that do not degenerate into complete polarisation only if some factors are immobile. In section 5 it will be shown how considering a simple extension of this class of models to the presence of cross-country externalities can further help explaining differences in growth performances.

[11] A parallel strand of literature considers the effects of outflows of skilled workers from less developed countries, the so-called "brain drain". Haque and Kim (1995) show that under standard assumptions on the human capital accumulation function, a brain drain always reduces per-capita income. Mountford (1997) criticises this result, showing that if not all skilled workers are allowed to migrate, the positive effect associated with the incentive to accumulate human capital in order to work in a richer country may offset the negative effect of the departure of skilled workers. Beine *et al.* (2001) rationalise these results showing that a brain drain has indeed two effects: the negative one suggested by Haque and Kim (1995) and the positive one suggested by Mountford (1997).

4.Endogenous Growth and Trade

The effects of trade on a country's equilibrium rate of growth are certainly one of the aspects most extensively analysed in the economic literature.12 One of the most interesting results, found well before the development of the endogenous growth framework, is the possibility that technological improvements may result in welfare losses for the countries where they took place. The extension of this result to the case of growing economies is straightforward: when the elasticity of substitution in consumers' utility function is sufficiently low, technological improvements taking place in the sectors producing exportable goods causes their prices to fall relative to those of imported goods, reducing the country's total income. This is the result of two opposing forces: a positive "income effect", associated with the possibility of producing larger amounts of goods for a given amount of labour, and an ambiguous "substitution effect" – which may indeed be negative –, producing a shift in income distribution in favour of producers of imported goods. Obviously, a welfare loss is not possible when technological progress affects the import sectors (or when it is equivalent in all sectors).

From the point of view of the mechanisms driving the growth rate, the literature on trade and growth can be roughly divided into two main streams. In the first, endogenous growth is the result of a serendipitous process of learning-by-doing, as in Romer's (1986) model. In the second, the increase in total productivity is the result of specific research activities carried out by profit maximising agents, as in Romer's subsequent work (1987 and 1990).

4.1 Learning-by-doing

In models with learning-by-doing, comparative advantages and growth are intrinsically related to trade. Historically, this aspect has been studied within the framework of Ricardian models, where labour is the only factor of production and

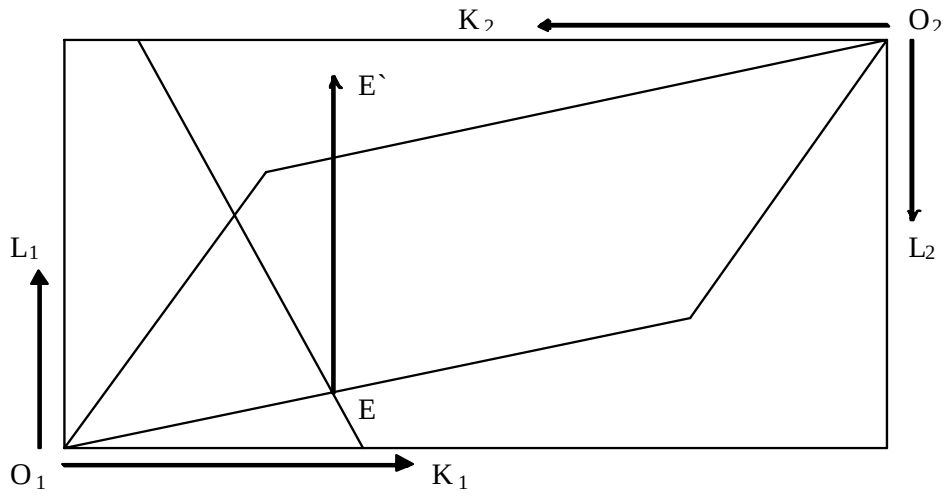
[12] See Grossman and Helpman (1995) for a survey of models of trade and growth.

technical progress is exogenous. The results of this literature depend mainly on the assumptions about the extent of externalities. If they are national, a country with a comparative advantage in the production of a good for which the technology displays learning-by-doing sees its specialisation reinforced once trade is permitted (Krugman, 1987, and Lucas, 1988), because the increase in the level of production of the good that is exported augments the relative efficiency of its production technology relative to that of other countries. Conversely, if externalities are global, trade does not affect each country's specialisation.

The implications of this analysis for convergence and the overall growth effects are straightforward. With national externalities, the specialization induced by international trade increases the size of production within each country, augmenting the positive effect of externalities on productivity and output growth. However, with limited factor mobility, specialization works against convergence, unless the rate of learning is identical in the two countries. With global externalities trade has no effects on each country's specialization and on convergence. In both cases, the overall rate of growth of the integrated economy increases because of trade.

Learning-by-doing with global spillovers has no effects on trade patterns also in the framework of a Hecksher-Olhin model without specialisation. But if knowledge spillovers are national and do not affect the productivity of all factors of production uniformly, factor price equalisation cannot be sustained indefinitely. This can be easily seen, in the case of two countries, by considering the standard Edgeworth box proposed by Dixit and Norman (1980). If the productivity-adjusted factor endowments grow asymmetrically because of sector and country specific learning-by-doing, their position in figure 1 shift from E towards E', eventually exiting the region where factor prices are equalised. Clearly, without factor price equalisation the implications of the Hecksher-Olhin model for growth and convergence become similar to those of the Ricardian model discussed above.

FIGURE 1: FACTOR PRICE EQUALISATION



Clearly, in models of trade and learning by doing, policies that temporarily alter the patterns of trade can affect the long-run specialisation of a country. Matsuyama (1992), for example, considers a two-country economy producing an agricultural good using a constant technology, and an industrial good using a technology characterised by learning-by-doing. Under these hypotheses, he shows that trade may negatively affect a country with an initial comparative advantage in the production of the agricultural good. In fact, if after integration the amount of resources employed in the industrial sector diminishes with respect to autarky, this reduces the industrial sector's scope for development, harming the country's long-run rate of growth and, possibly, also that of the integrated economy.13 Obviously, within this framework, if the country opening up to trade is trapped in an equilibrium where it is specialized in the production of the agricultural good, this also has a negative effect on the rate of convergence.

A similar result is obtained by Young (1991) in a model with two sectors: one producing a numeraire good, the other producing a ladder of new goods for which

[13] In particular, this may happen if the country initially specialized in the production of the agricultural good has a faster rate of learning by doing than its trade partner.

learning-by-doing in each quality type is bounded. Under these hypotheses, the long-run equilibrium can be characterised by a positive rate of growth, measured in terms of the quality of goods developed, only if intra-sectoral knowledge spillovers are sufficiently strong to increase efficiency in the production of higher quality goods. Trade between two countries producing goods of different quality leads then to the specialisation of the less advanced economy in the production of the numeraire good, resulting in poorer growth performance. An interesting finding of the dynamic analysis of this model is that if the less developed country is larger, it is possible that it maintains the production of a sufficient share of quality goods to be able to exploit larger dynamic economies of scale, eventually overtaking the other country.[14]

Mountford (1998) analyses the effect of trade in models of growth with learning-by-doing using a two-country two-sector overlapping generation model. Exploiting the multiple equilibria characteristic of this framework he shows that, in presence of national externalities in production, international trade forces a country trapped in a low growth equilibrium, despite having a higher equilibrium rate of saving, to switch to its high growth equilibrium. In this case, trade and learning-by-doing is associated with convergence and overtaking dynamics, and have a positive effect on the rate of growth of the integrated economy.

Models of learning-by-doing can also give rise to technological leapfrogging across countries. Brezis *et al.* (1993) build a simple model with trade and bounded learning-by-doing, where at some points in time a breakthrough in the production technology occurs. Within this framework, it is possible that the more developed country has such a large advantage in utilising the older technology that it finds it inefficient to adopt the new one, which is therefore taken up only in the less developed one. As production accumulates, learning-by-doing in the country using the older technology slows down, while it accelerates in the other: the formerly less developed

[14] Stokey (1991) develops a model with a similar logic, but with national spillovers in human capital accumulation.

economy therefore overtakes its competitor. The story repeats with inverted roles at the subsequent technology breakthrough, and leapfrogging re-emerges, leading to the alternation of convergence and divergence dynamics.

4.2 Research and Development

The effects of international trade in R&D models of growth are studied mainly within the intra-industry trade framework. Rivera-Batiz and Romer (1991) consider the case in which the R&D technology is similar to that used in the production of intermediate goods:

$$\dot{M} = H_R^{1-\alpha} \int_0^M x(i)^{\alpha} di \,, \tag{6}$$

where M is the number of blueprints available at each point in time, $\dot{M}$ is its rate of change, H_R is the amount of human capital used in research, $x(i)$ is the input of the intermediate good of type i and $\alpha \in (0,1)$. Within this framework, trade increases the value of blueprints by augmenting the demand for each intermediate. This results in higher profitability of research, which is offset by an increase in the interest rate. In turn, this implies a higher rate of saving and, ultimately, a higher equilibrium rate of growth of the integrated economy.[15] As in this model countries are assumed to be identical, the convergence effects of international trade are not discussed.

In this framework only relative endowments of the factors used in the research sector determine the equilibrium allocation of productive activities: if specialisation is not complete, research concentrates in the country with the larger endowment of human capital.[16] When instead R&D also uses the stock of national knowledge as an input, and

[15] The case where the technology in the R&D sector is instead described by $\dot{M} = AHM$, as in equation (A8) in the appendix, is discussed in section 5.2.

[16] This result is an extension of the Hecksher-Olhin theorem to the case where one sector produces blueprints. It applies both to the international extension of Romer's (1990) increasing product variety

spillovers between countries are not perfect, history has indeed a role. In this case the country with the larger stock of accumulated knowledge has a comparative advantage in research, possibily attracting it even if it is not the better endowed with human capital.[17] These models, however, have no direct implications for welfare: factor price equalisation ensures that in equilibrium the rate of growth of consumption is identical in the two integrating economies.

A different approach is taken by Ventura (1997), who studies the effects of growth and convergence within an endogenous growth model in which trade and technological asymmetries interact with each others. He shows that trade induced factor price equalisation implies that wages and the rate of growth of consumption will be identical in all countries. Cross-country differences in labour productivity are therefore only possible if less efficient countries have faster rates of capital accumulation, because only in this way they can have identical rates of growth of wealth and therefore the same spending shares. Thus, if a country starts from a sufficiently low level of the capital to labour productivity ratio, the combination of lower labour productivity and faster capital accumulation determines a higher equilibrium rate of growth of total output. Countries may therefore experience income convergence even for long time spans.

5.Cross-country Spillovers

5.1 Externalities

In section 3 it was shown that endogenous growth models with international factor mobility have quite implausible implications for the convergence dynamics of

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model proposed by Grossman and Helpman (1991b, ch. 5) and to that of Aghion and Howitt's (1992) quality ladder model proposed by Segerstrom *et al*. (1990) and by Grossman and Helpman (1991a).

[17] A further extension is considered by Martin and Ottaviano (1996), who apply the lab-equipment model of R&D and growth described with equation (6) to the study of growth in a two regions economy, where transport costs are incurred in order to transfer goods from one region to the other. In this case

integrating countries. More plausible predictions can be obtained with a simple extension of the framework proposed by Romer (1986) to the case of positive cross-country externalities in production. Alogoskoufis and van der Ploeg (1991) develop a multi-country model where the externality that makes the aggregate technology linear has a cross-border dimension:

(7) $$Y_i = A_i K_i^{\alpha} k_i^{\beta} k_j^{1-\alpha-\beta},$$

where Y_i (i = 1,2) is total output in country i, K_i is the level of capital of the representative agent in country i, k_i is the average level of capital in country i, $\alpha,\beta \in (0,1)$, and A_i is a constant such that $A_1 > A_2$. Assuming perfect capital mobility, interest rate equalisation implies that in equilibrium the rate of growth of total output is given, in both countries, by:

(8) $$g = \frac{r-\rho}{\sigma},$$

where $r = r_1 = A_1\alpha\left(\frac{k_1}{k_2}\right)^{\alpha+\beta-1} = A_2\alpha\left(\frac{k_2}{k_1}\right)^{\alpha+\beta-1} = r_2$, and therefore Y2 > Y1. Hence, although the equilibrium rates of growth converge to a common value, the level of output remains higher in country 1 than in country 2. One of the results obtained by opening up Rebelo's (1991) model – the equalisation of rates of growth among countries – is therefore strengthened to the case of technology differences. The other result – the concentration of capital in the country where productivity is higher – no longer holds.

A similar result is obtained also allowing for labour migration. Bertola (1993) considers an extension of the previous framework allowing for the presence of labour as a factor of production:

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agglomeration fosters growth by making it possible to pay a lower price (not affected by transport costs) for an identical amount of the intermediate inputs necessary for research.

(9) $$Y_i = A_i K_i^{\alpha} k_i^{\beta} k_j^{1-\alpha-\beta} L_i^{\gamma},$$

where L_i is labour, $\gamma \in (0,1)$ and other variables are as defined above. Under this hypothesis, an equilibrium with wage and interest rate equalisation always exists. However, when international externalities are small, so that $2(1 - \alpha - \beta) < \gamma$, this equilibrium is unstable and labour mobility leads instead to desertification of one of the two countries. Indeed, when externalities are not sufficiently large to offset higher productivity in country 1, the model's predictions collapse to those of the standard case with perfect factor mobility presented in section 3.

In a related class of models it is assumed that the accumulable factor is human capital. Extending the previous analysis to this case is straightforward, and similar results are obtained. In fact, if human capital accumulation is characterised by positive international spillovers, it may be possible that the equilibrium rate of growth in a developing country is higher than that in a developed one, until the levels of human capital converge. Moreover, the equilibrium rate of growth of the integrated economy turns out to be higher than without spillovers. Tamura (1991) shows this result, considering the following human capital accumulation function:

(10) $$\dot{H}_i = \varphi H_i^{\alpha} H_j^{1-\alpha},$$

for $i,j = 1,2$ and $i \neq j$. In this case, if $H_1 > H_2$, it is straightforward to see that $g_{H_1} = \varphi\left(\frac{H_1}{H_2}\right)^{1-\alpha} < g_{H_2} = \varphi\left(\frac{H_2}{H_1}\right)^{1-\alpha}$ until the two levels of human capital, as well as their rates of growth, are equalised.[18]

[18] This human capital accumulation function allows for scale effects on growth. Interpreting the same functions in terms of the average level of human capital would have given the same result leaving aside such an effect.

5.2 Knowledge spillovers

The simple framework presented in the previous section is suggestive of how cross-country externalities can help building models more capable of explaining the dynamics of growth and convergence across countries. However, externalities are not easy to justify. One way of doing it, which is very common in the endogenous growth literature, is to assume dynamic knowledge spillovers in research. This hypothesis is particularly convenient as it permits to introduce constant returns to scale in the production of the accumulable factor – a necessary condition for endogenous growth – within a competitive economy, where profit maximising firms engage in research and development. Contrary to the case where constant returns to scale in physical capital accumulation are made consistent with the existence of a competitive equilibrium by introducing an externality, the R&D models of growth provide a careful analysis of the mechanisms and incentives driving the process of knowledge accumulation. In fact, while physical and human capital externalities are simply introduced from outside, in R&D models knowledge accumulation is introduced as an activity carried on by profit maximising firms. Moreover, the only externality present in the R&D models of growth is dynamic, and descends from the fact that the knowledge produced by a single firm becomes subsequently available to all agents as a starting point for their own research activity.

The rationale behind the hypothesis of dynamic spillovers is that research is non-rival: the use of results from the research activity by one agent does not preclude its use by another agent as well. Moreover, knowledge can only be made excludable by means of legal protection so that if, as it is likely, excludability is not perfect, research by one agent may generate positive spillovers for others undertaking the same activity.

Once the presence of spillovers is recognised, it is straightforward to extend the analysis to the case when it has a cross-country dimension. Rivera-Batiz and Romer (1991) study the effects of international knowledge spillovers by extending Romer's

(1990) increasing product variety model of R&D and growth to the case of two identical countries.[19] In that model, the equilibrium rate of growth of total output is an increasing function of the level of knowledge available for research, proxied by the number of blueprints, *M*. When an economy integrates with another, its stock of knowledge increases from M to $M+\vartheta M^*$, where M^* represents the level of knowledge in the foreign country, and $\vartheta \in (0,1)$ is a parameter measuring the degree of knowledge spillovers. Assuming no duplication in research, the rate of growth of total output in an integrated economy is therefore higher than in the closed economy case:

$$g_Y = g_M = AH\left(1+\frac{\vartheta M^*}{M}\right). \tag{11}$$

Another way of interpreting the result is by calculating the equilibrium rate of growth of the integrated economy: as integration enlarges the size of the labour force in the research sector, in the case of perfect knowledge spillovers (i.e., with $\vartheta = 1$) the equilibrium rate of growth increases to:

$$g_{Y+Y^*} = g_{M+M^*} = A(H+H^*) = 2AH. \tag{12}$$

An enlargement of the absolute size of the labour force employed in research, coming from the integration of two countries that previously devoted their resources to redundant research activity, is therefore associated with an increase in the equilibrium rate of growth of both nations. Obviously, within this context the introduction of barriers reducing the scope for knowledge spillovers, which are often associated with trade in goods, has very sizeable effects, as it dampens not only the level but also the equilibrium rate of growth of total output in the two economies.

Within this framework it is not possible to study the effects of knowledge spillovers on convergence, because the analysis concentrates on the case of two symmetric economies. Using instead the more generic specification where production

[19] For a stylised presentation of Romer's (1990) model see the appendix, in particular equations (A8)

of intermediate goods also requires human capital (as in Rivera-Batiz and Romer, 1991), Devereux and Lapham (1994) show that the symmetric equilibrium is unstable: an arbitrarily small deviation from perfect symmetry initiates a process of concentration of research activities in one region, leaving production of intermediate and final goods in the other. However, as in the case of the trade and growth models presented in section 4, this has no effects on the rate of growth of consumption in the two countries.

Recently, the framework of international R&D models of growth has been extended to study endogenous spatial agglomeration, along the lines suggested by Krugman (1991). Baldwin and Forslid (2000) show that the presence of knowledge spillovers in the R&D sector adds one more factor to the circular causation that determines agglomeration: the growth linkage. The parameter space for which a symmetric equilibrium is stable is therefore smaller than in Krugman's (1991) original analysis.[20] Lower transport costs have therefore two consequences: they foster concentration of all economic activities, working against convergence, and they guarantee a higher equilibrium rate of growth of total output for the global economy, thanks to the internalisation of all positive externalities in the R&D process.

Martin and Ottaviano (1999) study instead the effects of differences in the geographical extent of knowledge spillovers on the equilibrium rate of growth of each region. They show that when knowledge spillovers are localised, the rate of growth may differ across regions and incomes may diverge. In this case, a reduction of the transport costs favours the concentration of the R&D activity, and boosts the equilibrium rate of growth of the integrated economy.[21]

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and (A9).

[20] Baldwin and Forslid (2000) also study the case in which cross-region migrations alter the localisation of knowledge – because workers transfer their human capital – showing that, in this case, the tendency towards agglomeration is even stronger than with knowledge spillovers only.

[21] Baldwin *et al.* (2001) study explicitly the effects of a progressive reduction in transport costs, showing that an asymmetric process of growth across countries may emerge, characterized by phases of income convergence followed by periods of divergence.

5.3 Technology adoption

A different strand of literature considers the effects of asymmetries in the rates of technology adoption on the evolution of levels and rates of growth of per capita income across countries. This class of models is particularly suited to study convergence in a non-neoclassical framework. On the contrary, its implications for the equilibrium rate of growth of an integrated economy are less interesting, because convergence implies by itself an increase of the overall rate of growth.

Parente and Prescott (1994) show that different growth performances can easily be explained in a model in which the rate of growth of total factor productivity depends on the level of each country's barriers to the adoption of a common world technology. They consider for simplicity an economy described by the following production function:

$$y = Ak^{\alpha}, \tag{12}$$

where y is output per worker, A is the technology level, k is capital per worker and $\alpha \in (0,1)$ is a constant. They further assume that the technology is not constant but it evolves through time, catching up with the exogenously given (and possibly increasing) world level of knowledge as described by the following function:

$$A = g(X)\left(A - \tilde{A}\right), \tag{13}$$

where $g(\cdot)$ is any increasing and bounded function, X is a set of exogenous variables, and $\tilde{A}$ is the world level of knowledge.

This representation has two implications. First, technology asymmetries can explain differences in the levels of capital and output per worker even in presence of interest rate equalization. In fact, from equation (12) it is clear that the interest rate $r = A\alpha k^{\alpha-1}$ is a function of technology and capital per worker. Countries with lower levels of both capital and technology can therefore match the world interest rate, despite

having a lower level of output per worker.[22] Second, the equilibrium rate of growth of output per worker is an increasing function of the distance of the country's technology from the world frontier, and of the endowment of the factors in X.[23]

Building on R&D models of endogenous growth, Eaton and Kortum (1996) and Brecher *et al.* (1996) have proposed a framework in which the world level of knowledge is not given exogenously, but depends on the research activities of each single country, and on the degree of international knowledge diffusion. Despite possible cross-country differences in the level of productivity, they show that spillovers in R&D guarantee that eventually each country will grow at the same rate.[24]

A similar route is followed by Howitt (2000), who builds a Schumpeterian model of growth with international knowledge spillovers, along the lines of Aghion and Howitt (1992), capable of generating convergence in the growth rates within the group of countries with positive R&D levels, and stagnation for those where research activities are not profitable. Howitt and Mayer-Foulkes (2002) extend this framework, considering the existence of three group of countries: those carrying on leading edge R&D, those implementing efficiently the leading edge technologies developed abroad, and those implementing inefficiently the same leading edge technologies. Whether a country belongs to one group or another depends on the initial skill level of its labour force. Within this framework, countries in the first two groups have the same

[22] Lucas (1990) obtains the same result assuming that there are differences in the level of human capital across countries.

[23] For example, Benhabib and Spiegel (1993) suggest that the rate of adoption of the common technology depends on each country's human capital; Prescott (1998) argues instead that barriers to technology adoption are mainly institutional. Basu and Weil (1998) consider a modified version of equation (13) where spillovers are only possible within countries that have technology levels not too far apart from each other, showing that this framework can also generate conditional convergence.

[24] Using the framework of the R&D models of growth presented in the appendix, the mechanism at work in this class of models is can be represented by substituting equation (A8) with the homologous of equation (13): $\dot{M} = g(X)\left(M - \tilde{M}\right)$, where $\tilde{M}$ is the exogenously given world level of knowledge and the other variables are as defined before.

equilibrium rate of growth, those in the third group experience a lower rate of expansion.

One attractive feature of this class of models is that, depending on the assumptions that are made on the pattern of knowledge diffusion, they can easily explain cluster convergence of the kind found in the empirical analysis. The negative side of this flexibility, at this stage, is the lack of strong microeconomic foundations. Parente and Prescott (1999) and Acemoglu *et al*. (2002) take a step in this direction.[25] Parente and Prescott (1999) focus on the reasons why some countries do not adopt leading edge technologies, suggesting that this might depend on the monopoly power of endogenous rent-seeking coalitions of incumbents, which do not permit the entry of firms adopting newer production techniques.[26]

Acemoglu *et al*. (2002) study instead the effects of the trade-off between growth strategies based, on one hand, on higher rates of investment made by experienced managers and, on the other hand, on selection of less experienced but more dynamic entrepreneurs. In particular, they show that the latter policy is less viable if incentive problems limit the access to the market of younger entrepreneurs. Within this framework, the leading countries are those with an innovation-based strategy of growth, built on a stronger selection of good entrepreneurs and young firms. Relatively backward countries, which can benefit from technology spillovers from the leaders, find instead preferable to adopt an investment-based strategy, built on larger firms under the control of older managers, who are more experienced and have lower credit constraint. As backward countries catch-up with the leaders they find it optimal to switch from one strategy to the other. However, the timing of the switch can be sub-optimal, depending on institutional characteristics such as the degree of competition in the product market and the capability of managers of appropriating part of the monopoly rents. Moreover,

[25] The role of knowledge spillovers in the convergence process has also been considered in the framework of north-south models of R&D and growth (see, among others, Segerstrom *et al*., 1990, Grossman and Helpman, 1991c, and Barro and Sala-i-Martin, 1997).

[26] A hint in this direction was already in Lucas (1990).

if credit constraints are strong enough, by using their retained earnings managers can have the power to keep the economy back from switching out of the investment-based strategy, not letting it to reach the world technology frontier.

6.Conclusions

The main conclusion coming from the literature surveyed in this paper is that interactions with other countries play a key role in determining a nation's long-run rate of growth. From a theoretical viewpoint, some of the results of closed economy models of growth are in fact overturned by assuming that capital is mobile across borders, that countries can trade with each other, or that technologies diffuse internationally.

However, the models presented in this survey often move the problem of explaining the differences in countries' growth performances one step backwards. Differences in structural parameters (such as those describing preferences and technologies), disparities in policy variables (such as the rate of taxation), asymmetries in the degree of international mobility of factors of production, dissimilarities in the patterns of technology diffusion, all these should be explained by a theory of growth in open economies, not simply assumed. Some contributions in this direction have already come, but much more need to be done.

Indeed, the only way of explaining differences in output per capita between integrated countries is assuming that at least one factor is immobile between physical capital, human capital, or technology. Moreover, convergence dynamics can only be achieved by assuming some degree of stickiness in factor accumulation or transferability. Once it is recognized that these characteristics are necessary for an endogenous growth model to be able to explain differences in the countries' growth performances, the key point is to choose which factor is the most likely to be immobile. Apparently, the theoretical literature produced so far has reached a broad consensus that the most promising channels in order to explain the differences in growth performances across countries is knowledge diffusion, both in human capital accumulation and in research.

The way in which the spillovers are modelled, however, still lacks the necessary microfoundations: the conclusions reached so far are often based on weaker bases than one would like to have. More careful analyses of the factors determining the shape and

the patterns of international spillovers, capable of matching the findings of the growing empirical research, and of giving a guide to future applied analyses, are still required.

Appendix

Rebelo's (1991) AK model provides the basic analytical framework for understanding the behaviour of endogenous growth models: infinitely-lived identical agents maximise an intertemporal utility function depending on the level of consumption of the single good available:

(A1) $$U = \int_0^{\infty} e^{-\rho t} \frac{c^{1-\sigma} - 1}{1-\sigma} dt ,$$

s.t. $\dot{K} = rK + w - c$,

where c is consumption at each point in time,[27] ρ is the rate of time preference, σ is the intertemporal elasticity of substitution of consumption, K is the stock of capital, which is the only asset available, and w is the wage rate. Profit maximising firms produce a single good, used for both investment and consumption, using a linear technology:

(A2) $$Y = AK ,$$

where $A > 0$ is a constant. Under these hypotheses, it is possible to show that, for $A > \rho$, there exists a unique equilibrium characterised by a constant rate of growth of total output:[28]

(A3) $$g = \frac{A - \rho}{\sigma} .$$

Similar conclusions can be drawn from models with more than one factor of production. As an example, in a simplified version of Lucas' (1988) model, equation (A2) is replaced by a Cobb-Douglas production function, using physical and human capital as inputs:

(A4) $$Y = AK^{\alpha}(fH)^{1-\alpha},$$

[27] Time subscripts are omitted unless strictly necessary.

where $f \in (0,1)$ is the fraction of time that agents devote to production, as opposed to human capital accumulation, H is the level of human capital, and other variables are as defined above. Consumers maximise their intertemporal utility function, identical to equation (A1), subject to an adjunctive intertemporal constraint imposed by the technology for human capital accumulation:

(A5) $$\dot{H} = \varphi(1-f)H,$$

where $\varphi > 0$.

Under these assumptions the economy is characterised by an equilibrium with a constant rate of growth of total output:

(A6) $$g = \frac{\varphi - \rho}{\sigma}.$$

Another class of endogenous growth models is that based on technological progress. Romer (1987) constructed the first of these models where the mechanism for growth depends on the assumption of increasing returns to the variety of inputs in production

(A7) $$Y = L^{\alpha} \int_0^M x(i)^{1-\alpha}\, di\,,$$

where Y is output of the final good which can be used either for consumption or as the only input in the production of intermediate inputs, $x(i)$, L is the number of unskilled workers, M is the number of intermediates available and $\alpha \in (0,1)$ is a constant. R&D activity permits an increase in the number of intermediates available for production using as inputs human capital, H, and knowledge, which is proxied by the number of intermediates already available, M:

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[28] Romer's (1986) model has a similar technology, with $Y = AK^{\alpha}k^{1-\alpha}$, where k is an externality equal to the average level of capital in the economy. In this framework, with decreasing returns to scale at the firm level, it is possible to obtain a competitive equilibrium where the size of each firm is determined.

(A8) $$\dot{M} = AHM,$$

where $A > 0$ is a constant. Under the assumption that consumers maximise the intertemporal utility function (1), the equilibrium rate of growth of the economy is given by:

(A9) $$g = \frac{AH - \rho}{\sigma}.$$

This model displays scale effects: an increase in the size of the skilled labour force is associated with a higher equilibrium rate of growth. This result, which is also found in the quality upgrading model of Aghion and Howitt (1992), is a major point of contention among researchers.[29]

[29] See in particular Jones (1995a, 1995b and 1998). Endogenous growth models not displaying scale effects have been developed, among others, by Young (1998), Peretto (1998), Segerstrom (1998) and Howitt (1999).

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