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Economic Convergence through Savings, Trade and Technology Flows

Lessons from Recent Research

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[Abstract] This paper reviews the theoretical and empirical literature on income disparity between countries and convergence in *economic growth*. New theoretical models modify and often reverse the prediction of convergence in the traditional neo-classical model of economic growth. A particular feature of the recent literature as compared to traditional studies of economic growth is that it acknowledges interdependence between countries. International capital flows, trade in goods and (maybe most important) international technology flows influence individual countries growth performance. The empirical literature on the dynamics of the international distribution of income per capita reveals massive unconditional divergence in income levels. For sub-samples of countries on the other hand, the data support the conditional convergence hypothesis: when other factors are accounted for, there is a tendency for income per capita to converge. For the OECD countries, as well as for some other countries, knowledge flows, either embodied in traded goods or disembodied seem to be important for whether poorer countries are able to catch up with richer ones.

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1. Introduction

In recent years there has been increasing interest in economic growth and the forces determining countries' income levels. While growth economics was stagnant both empirically and theoretically two decades ago, there is now a large and fast-growing literature on growth theory and growth empirics. An important ingredient in this literature is analyses of whether the huge inequalities in income per capita between countries will tend to disappear or widen over time. While traditional growth economics in its simplest forms predicts convergence in per capita income levels through decreasing returns to physical and human capital, recent literature has identified several possible mechanisms through which convergence, or the lack of it, may occur. Generally, recent theories are less optimistic on world income differences than the traditional theory. A large part of the literature predicts massive divergence, while other contributions discuss the conditions under which convergence may be an outcome.

The new and old literatures on economic growth have in common that technological change is regarded as the main driving force for growth. Therefore an essential ingredient in the literature is how an economic system reacts to technological change. What distinguishes new and older theories, or exogenous and endogenous growth theories, however, is that the recent literature aims at explanations of technological change itself. As such these theories are two-way theories: technological change explains economic development, but economic development also influences technological change. This expansion of theorising widens the topic of study: The topic of growth economics is not only how economies interact given a certain pattern of technological change, but also, indeed, the various mechanism through which economic interaction influences technological change.

The recent wave of new growth theories, and the availability of new data, have spurred a large empirical literature on growth and convergence. Roughly speaking, this literature can be classified into three different traditions. The first one is the large set of studies based on cross-country growth regressions. In this part of the literature growth rates in a set of countries, for one or for many periods, are regressed on a series of variables. These studies have revealed that, as an empirical regularity, initial income tends to reduce subsequent growth rates when other variables are accounted for. This is taken as evidence of conditional convergence. The second tradition is the studies of total factor productivity, the so-called growth-accounting tradition. This tradition relies more on stringent (and controversial) theoretical assumptions but it has the potential of explaining determinants not only of income, but also of productivity. This approach has been used particularly intensively for growth in developed countries for which better data are available.

The plans for the rest of this paper are first to give an overview of some basic facts about world income distribution. Thereafter I will provide a guided tour in growth theory. Focus will be on what theory has to say about convergence and how savings, international trade and technology flows may influence the results. This will serve as a backcloth for my discussion of empirical measures of convergence and the findings in existing studies. I conclude by summing up and presenting some thoughts on what is learnt and what we should learn more about.

The title of this paper is *Economic Convergence through Savings, Trade and Technology Flows*. As such the topic is wide and broad. I will therefore limit my review to

a) studies of countries,
b) that part of the literature which is most relevant for the question of convergence in terms of income per capita, and
c) what that literature has to say on the effects of savings, trade and knowledge flows for the relative economic destiny of countries.

Even within these limitations it is not possible to cover more than a selection of the most important contributions.

2. Divergence and convergence: some stylised facts

There are large differences in income per capita among countries in the world. In 1990, the richest country in the world was 45 times richer than the poorest. This number had increased from 32 in the period from 1960. These are extreme cases – of course. A measure of inequality that only takes into account the ratio of maximum to minimum conceals everything in between. Still, as will become clear, massive divergence in income levels is characteristic of capitalist economic development.

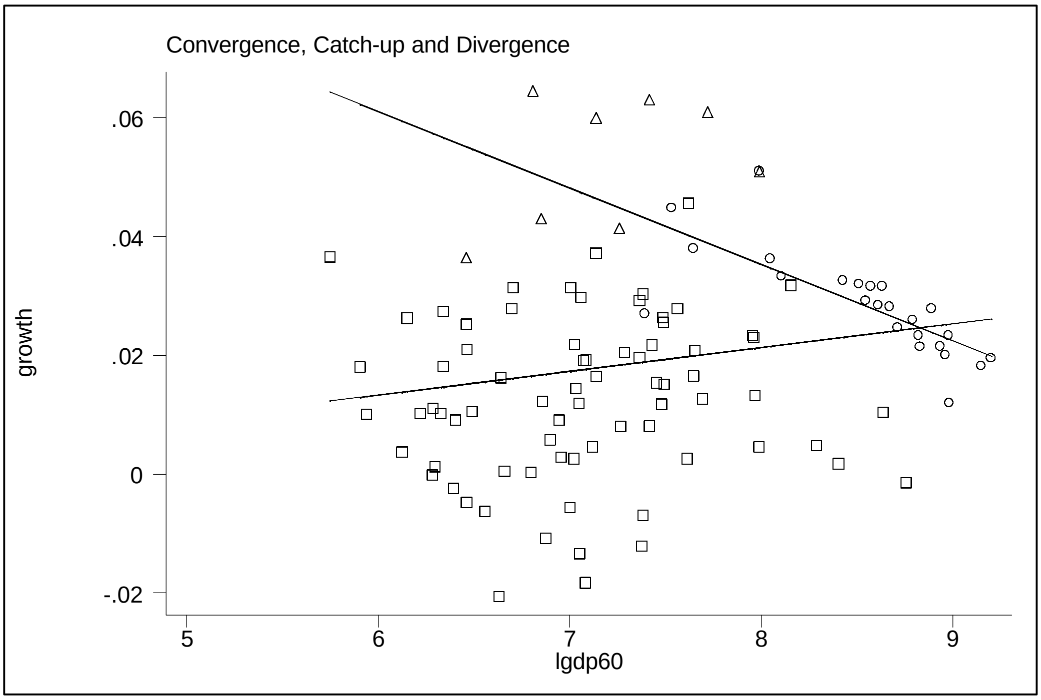
It should be underlined at this stage, however, that the topic here is convergence versus divergence in terms of per capita income in the countries in the world. This issue is different from the issue of whether inequality between people is increasing or decreasing. Datasets of GDP per capita in countries in the world are not informative of internal inequality in countries. Neither will this paper address how unequal size of countries in terms of population influence inequality.[1]

It should be noted that long-term development necessarily has been characterised by divergence. The richest countries in the world have been growing, not entirely steadily, but at positive rates at above 1.5 per cent annually, at least since 1870, as the long run data of Angus Maddison shows (Maddison, 1995). As illustrated by Lant Pritchett, this has only been possible because growth rates in the developed economies have systematically been higher than in poor countries. If growth rates in poor countries had been higher than in the richer ones, the level of income in the poorest countries would have been far below subsistence levels in 1870 (Pritchett, 1997). Therefore, in the long run, capitalist development has been characterised by divergence. This is in line with the hypothesis of Simon Kuznets (Kuznets, 1955) of an inverted U-shaped relationship between inequality and development: Inequality will first tend to increase with growth, because growth at first only influences a few. Only later, there might be potential for convergence if the faster growth becomes widespread. Therefore, the hypothesis of convergence is rejected on long-term historical data covering many countries.

Recent studies of growth have been more occupied with shorter time spans, in particular the post-war period. These studies reveal the same pattern of global economic growth: There is no systematic negative relation between initial levels of income and subsequent growth. If there is any connection between growth and initial levels of income, it is positive. This is revealed in figure 1 that graphs growth rates in the period from 1960 to 1990 against the log of GDP per capita level in 1960 for a sample of 104 countries.

[1] Melchior (2001) and Melchior and Telle (2001) discuss whether inequality between persons in the world has increased or decreased during the last decades. They find that inequality may have decreased from 1960 onwards, mainly as a result of high growth rates in populous countries, in particular China.

Figure 1



Source: The Penn World Tables, Mark 5.6.

The figure does not give support to the hypothesis that there is a clear connection between initial levels of income and the subsequent growth rate. If there is any relationship, it is negative. This is demonstrated by the positive sloping regression line included in the figure. The coefficient of initial income is not significant, however.

The observations in the figure are of three categories. The triangles are the East Asian tiger economies. The figure confirms the common knowledge that these countries have had very high growth rates the last three decades. The circles are the OECD countries. For these countries, there seems to be a convincing impression of a negative relationship between growth and log of initial GDP. The regression line for these countries is negatively sloping and highly significant (at a p-level below 1 per cent). The squares in the figure are the rest of the countries in the world.

Growth theory for countries should therefore be able to explain a) divergence between most countries in the world, b) very high growth rates for some countries and c) convergence between some countries that share particular characteristics (like the OECD countries).

The development described in Figure 1 has been the outcome of a period that has also been characterised by a dramatic increase in world trade in goods, again according to Maddison (1991), from 8 per cent of world total GDP in 1960 to almost 14 per cent in 1990. During the same period, there has also been an enormous increase both in international direct investments and cross-border financial transactions (UN, 1999 and IMF, 1997).[2]

3. Growth theory and convergence: a selective review

The economic destinies of countries have been a major interest of economists for long. I will review some main conclusions from both recent and older growth theory in order to highlight where they differ and how they might contribute to an understanding of the development just described.

Most theories on economic growth rely on some notion of either physical or human capital. Economies use some of its disposable income on savings. Savings are translated into investments that result in increased capacity for production. Therefore, the relationship between savings and production and the returns from investments are important determinants for long-term economic growth. Before I focus on interdependent countries, I will briefly sketch one important demarcation line in growth theory.

3.1 Neo-classical versus endogenous growth

The traditional neo-classical growth models that emerged in the 1950s are based on the neo-classical production function in which there is constant (or decreasing) returns to scale, substitution possibilities between all factors of production and decreasing returns to all of them individually (see e.g. Solow, 1956). Solow's model demonstrated that equilibrium growth was not a knife-edge problem of balancing growth of the labour force with growth in physical capital due to investments.

In the neo-classical growth models technological change is assumed being labour augmenting[3], exogenous and equal to all production entities. Constant returns

[2] There is not consensus, however, whether the recent wave of globalisation has resulted in larger net capital flows as compared to earlier periods. See Obstfeld (1998).

[3] The assumption that technological change is labour augmenting may formally be captured by letting technology enter the production function as multiplicative to labour. Thus, we may write Y=F(K,AL), where Y indicates production, K capital, L labour and A is the technology parameter. This stands in

to scale and decreasing returns to each factor of production make the model consistent with perfect competition.

In the neo-classical growth model, the engine of growth in the *short run* is capital accumulation. By savings and investments, a country increases its production capacity. Increased capacity in turn increases the potential to save. However, since decreasing returns to each factor of production are assumed, the incremental gain from capital decreases as production becomes more capital intensive. The only source of increased per capita income in the long run is technological progress, meaning that more is produced by the same amount of factors of production.

This may be illustrated in terms of the most simple neo-classical growth model in which there is no technical progress. Let production be according to a Cobb-Douglas function, assume a constant savings rate and disregard depreciation. Let a dot above a variable denote the derivative with respect to time. In this case the economy will be characterised by the following equations:

$$Y = AK^{a} L^{1-a}$$

$$\frac{\dot{Y}}{Y} - \frac{\dot{L}}{L} = \frac{\dot{A}}{A} + a\frac{\dot{K}}{K} - a\frac{\dot{L}}{L} = a\left(\frac{sY}{K} - \frac{\dot{L}}{L}\right) = a\left(sA\left(\frac{L}{K}\right)^{1-a} - \frac{\dot{L}}{L}\right), \quad \text{iff } \frac{\dot{A}}{A} = 0$$

In the equations Y denotes production, A denotes the economy's technological level, K is capital, L is labour and s is the savings rate. α is the share of capital in production.

The lower equation describes the growth rate in production per capita. This growth rate will be increasing in the savings rate, but as capital accumulates, the contribution from savings will decrease. If there is not technological progress, growth will cease when the contribution from savings equals the growth rate in the working population. In that case, the first term in the brackets equals the second.

For relative growth performance, the predictions of the neo-classical model are clear-cut: In the very long run, all countries will achieve the same growth rate in

contrast to Hicks-neutral production functions of the form Y=AF(K,L). The assumption that technological progress is labour augmenting can be shown to be a necessary condition for the existence of a steady-state growth path (Barro and Sala-I-Martin, 1995, Ch. 2). This is therefore also assumed in most subsequent formal models of growth. Note that the commonly used Cobb-Douglas production function, $Y=AK^{\alpha}L^{1-\alpha}$, satisfies both criteria.

per capita income. In absence of exogenous technological progress, growth will cease in the long run, and all countries will converge towards the same level of income per capita, given that they have the same savings rate. Poorer countries are predicted to grow faster than richer ones, as poorer countries are less capital-intensive economies and enjoy higher returns from their investments.

The above predictions are based on very severe assumptions. First, savings rates may vary. In this case the model predicts convergence, but to individual levels. Second, the assumption that countries' macro-production functions are Cobb-Douglas, or that production is due to decreasing returns to capital at all, is nothing more than an assumption.

Figure 2 illustrates the critical role of these two assumptions. The vertical axes denote growth (in total income). The horizontal axes denote capital intensity in the economy (defined as capital per worker). In part A of the figure, the traditional neo-classical world is graphed. The downward sloping line shows the contribution from savings. As the economy grows and becomes more capital intensive, the contribution from savings decreases. At the point where this contribution equals the growth rate of the population, growth in per capita income vanishes. If the capital intensity grows above the equilibrium level, it will fall back to this level. The dynamics is illustrated by the arrows below the figures. The dotted line in panel A of the figure indicates the effect of reduced savings rates: The level of income per capita decreases but the mechanism that reduces the long-run growth rate remains.

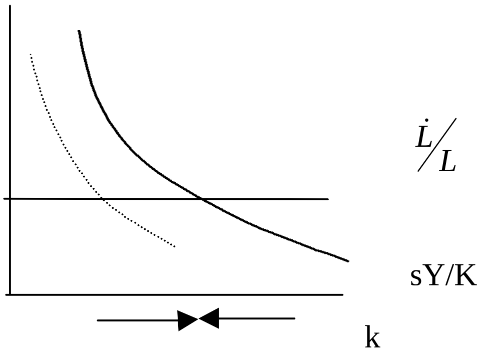
Part B of the figure illustrates the possibility that contribution from capital accumulation first falls, then rises and thereafter falls again. There might be several reasons for a pattern like this; one is that savings vary with income. Another possible reason is that as an economy grows structural changes may push the economy from phases of decreasing returns to phases in which there are increasing returns. Thereafter, as the economy has grown modern, the economy encounters diminishing returns. Part B is a graph depicting three equilibria. The first is a poverty trap. If capital intensity increases above this equilibrium, the resulting capital accumulation will be too small to sustain the implied income per capita. Therefore growth in income per capita will be negative and the economy falls back into the poverty trap. The second equilibrium is an unstable one. Slight deviations from this equilibrium will either force the economy back into the poverty trap or to the third equilibrium in which income is higher and stable.

The possibility of constant returns to capital is graphed in part C of the figure. In this case savings determine the long-run growth rate. If the contribution from savings is higher than the population growth (as illustrated in the figure), there will be constant growth in income per capita. If the contribution from savings is lower than the population growth, there will be negative growth and the economy vanishes. As I will come back to, one important contribution from recent growth theory is that it, in different ways, explains how constant returns from savings, either in physical or in human capital, can be plausible.

Figure 2. Savings and growth

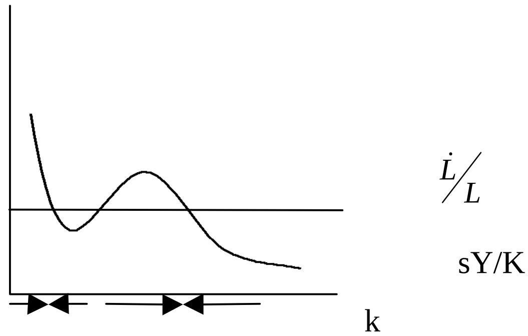
A

growth



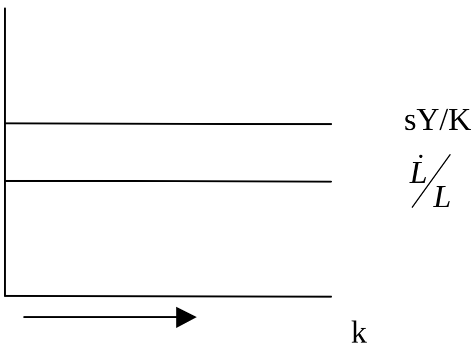
B

growth



C

growth



The neo-classical growth model describes closed economies. If one opens up for international trade, the trading countries will experience a once and for all income gain due to increased static efficiency. Ventura (1997) demonstrates that international trade also has dynamic effects. If international trade results in factor price equalisation, decreasing returns to capital will only apply for the world on average and not for individual countries. The reason is that capital accumulation will not increase production in all industries but only in the most capital-intensive industry (as predicted by the Rybczynski theorem). Thus, when international trade induces factor price equalisation, the traditional source of convergence disappears. However, a weak form of convergence will still be present as more and more countries become more capital intensive.

Financial integration is predicted to give fast convergence, however. If one opens up for capital movements, poor and capital-deficient countries will receive large inflows of capital because these countries have the highest returns to this factor of production. In fact, convergence is predicted to be instantaneous in case of complete capital mobility.[4]

3.2 Escaping decreasing returns

The hypothesis that economic development leads to convergence in income per capita levels is a result of the assumption of decreasing returns to accumulative factors of production (capital above). In recent theories of economic growth focus has been on possible relationships between capital accumulation and productivity. A major shortcoming in the neo-classical growth model is that technological progress is assumed to be exogenous. Endogenous growth theories attempt to explain technological progress as an inherent part of economical mechanisms. The endogenous theories of growth incorporate some of the peculiar characteristics of technology and knowledge.

First, it is taken into account that technological progress is a produced good. Within the class of endogenous growth models two different sources of knowledge creation are being analysed. The first is *deliberate* production of knowledge. Research

[4] Barro *et al.* (1995) discuss capital mobility in the neoclassical growth models. They show that if only a part of capital is internationally mobile, the rate of convergence will slow down as compared to the case when all types of capital are mobile.

and development result in new knowledge that is used to produce new goods, better goods or to improve productivity in goods production. The second is denoted as *learning by doing*: Knowledge is produced unconsciously as people learn from each other and pick up new ideas from others' experience.

Second, it is taken into account that knowledge is a very special good in economical terms. Knowledge is due to massive economics of scale. This is because of two distinct characteristics of knowledge. It can be used without being exhausted. Thus, knowledge is a non-rival good. Knowledge is also cumulative. New knowledge is based on results obtained previously. In this sense, we are standing on 'the shoulders of a giant' (Caballero and Jaffe, 1993).

Third, knowledge is to a certain extent, but not completely, an exclusive good. It is, in different ways, possible to limit others' access to newly developed knowledge, but despite secrecy and patent protection, very often it is difficult to protect property rights to knowledge for longer periods. Both the deficient exclusiveness and the cumulative aspects of knowledge production mean that there are externalities connected to production of knowledge.

Such externalities or technological spillovers form one of the foundations for endogenous growth models. In short, they provide a basis for understanding how increasing return may be consistent with decentralised markets (see Romer, 1986 and Barro and Sala-I-Martin, 1995). When there are technological spillovers, returns from investments in human capital may be increasing for the overall economy, while still being characterised by decreasing returns for the individual economic agents. This may be illustrated by thinking of the production function above as the production function of individual firms. The level of technology in society might well be a function of the capital per worker in society. In this case the model may be formulated according to:

$$Y_i = AK_i^{a} L_i^{1-a}, \qquad \mathrm{A} = \overline{A}\left(\frac{K}{L}\right)^{d}, a + d = 1$$

$$Y = \sum AK_i^{a} L_i^{1-a} = \overline{A} K^{a+d} L^{1-a-d} = \overline{A} K$$

$$\frac{\dot{Y}}{Y} - \frac{\dot{L}}{L} = \frac{\dot{K}}{K} - \frac{\dot{L}}{L} = \left(\frac{sY}{K} - \frac{\dot{L}}{L}\right) = \left(s\overline{A} - \frac{\dot{L}}{L}\right)$$

Thus, individual firms face diminishing returns to K_i and L_i as they regard the average level of technology as exogenous. However, if all firms expand K_i, then K/L expands as well and provides a spillover that raises the productivity of all firms. In the model framework assumed here, δ denotes the quantitative effect of this spillover effect. Here it is assumed that the capital share α and δ sums to one. Therefore Y is homogeneous of degree one and there are constant returns to capital at the social level. The constant social returns to capital will yield endogenous growth in the long run. This is the situation graphed in part C of Figure 2. In the present context, K_i may be interpreted as a mixture of human and physical capital or only as human capital.

3.3 Complete spillovers

Since spillovers form one foundation for the new growth theories, their extent and scope may be determinant for whether new growth theory produces different predictions on convergence as compared to the neo-classical story. When spillovers are complete, i.e., when positive externalities from knowledge are both relevant and available for all agents independent of industrial specialisation, distance and borders, there will be convergence. In this case, the difference between the neo-classical model and the endogenous growth theory is that the growth rate is explained rather than being assumed. The explained growth rate will be common to all and technology is still a global public good.

3.4 Bounded spillovers

If spillovers are confined within distinct economies however, growth will depend on accumulated knowledge for the economy in question (Grossman and Helpman, 1991 and 1995). This applies to countries, economic sectors or regions. If spillovers are confined within country borders, growth rates between countries will be determined by the size of each individual country. Therefore growth rates between countries will normally differ. Rivera-Batiz and Romer (1991) discuss the implications of economic integration in this context. They show that with nationally bounded technology spillovers, international trade may not increase growth rates, though static efficiency gains from trade remain. If integration increases the knowledge base used in research in each country, however, integration might well increase long-run growth rates.

Lucas (1988) and Young (1991) are two examples of growth models in which divergence occurs because of bounded spillovers and where divergence will typically be more pronounced when countries integrate. Lucas builds on Krugman (1986) and develops the framework of *dynamic comparative advantages* in which spillovers are confined to industries. Countries specialise their production in the sectors in which they have a (static) comparative advantage. Productivity evolves over time as a function of aggregate past production. If some industries happen to have a potential for higher productivity growth than others, countries specialised in these industries will experience higher growth rates than other countries do. This opens the possibility for diverging economic development.

In the simplest models of endogenous growth, spillovers are thought of as an automatic effect of production or investments. There is a large set of models that refine the concepts of technological change and knowledge spillovers. In several models, research activities are introduced as a distinct economic sector (see, for instance, Romer, 1990). Researchers generate innovations that are sold monopolistically as blueprints to producers of goods. Goods producers produce distinct varieties based on these blueprints that are sold under monopolistic competition to consumers. Profits are squeezed away by free entry in the goods-producing sector. In the R&D sector, it is assumed that entry occurs until expected profits, which is equal to the price a producer is willing to pay for the blueprint, equal the return to human capital. Consumers are able to absorb all new varieties of goods because their utility function is assumed to be an increasing function of the number of goods (not only the amount consumed of each). In Romer's model, there are dynamic increasing returns in the R&D sector generated by technological spillovers. In particular, it is assumed that the R&D sector employs researchers who make use of aggregated knowledge available in the economy. Their products are new blueprints, but their research also adds to society's knowledge stock. By steadily increasing productivity in the research sector, unbounded growth is made possible through knowledge spillovers. Romer's model does not predict convergence. Growth will be an increasing function of the workforce employed in R&D and of aggregated knowledge. Romer's model predicts dynamic effects of economic integration in two different ways: First, by trade an economy gets access to a larger flow of new varieties. This generates higher growth in consumption. Second, economic integration allows national researchers to draw on a larger knowledge base in their research. This is expected to increase their efficiency.

Aghion and Howitt (1992 and 1998), Klette and Griliches (1998) and Barro and Sala-Martin (1995, Ch. 7) take into account the genuine uncertainty of technological change. Instead of modelling research as a deterministic process, it is assumed to be a stochastic process. Innovations are modelled as a Poisson process in which the arrival rate of innovations is assumed to be an increasing function of investments in R&D. The R&D models formalise older ideas of Joseph Schumpeter[5] on *creative destruction.* Drastic innovations force out older vintages of goods and increasing wages due to increased productivity crowd out older goods as time passes. An interesting extension by Howitt (2000) is a model in which researchers' efficiency draw on an existing international knowledge base, but in which some countries do not do R&D. Howitt's model demonstrates how a country's position at the world income ladder may depend on own resources spent on R&D and of subsidies to R&D. For some parameter values, countries will not invest at all, in which case there is no growth.

3.5 Technology gaps

Inspired by Schumpeter is also a less formal and more heterogeneous tradition of studies of technological change and economic growth. Such approaches stress the ability of countries lagging behind a technological forefront to adapt and imitate new technologies. Catch-up is not necessarily an automatic outcome of world economic growth, however. The ability of poorer countries to make use of technology developed elsewhere is a function not only of the rate of innovation at the technological forefront, but is also assumed to depend on their own absorptive capacity and their technological congruence (Abramovitz, 1994). Thus, it is expected that the extent to which poorer countries make use of technology flows from more advanced countries is a function of these poorer countries' institutions, history, social conditions, etc. Among other factors, the level of education and human capital is assumed to be a decisive factor. This is a consequence of the assumption that technology flows are not only outdated blueprints, but also a source of new

[5] Schumpeter (1934) and (1944).

technological development. Thus, catch-up is viewed as a process in which poorer countries both imitate and adapt older technology.

Theories of technology gaps incorporate Posner's and Vernon's theories on economic development (Posner, 1961; Vernon, 1966) into a Schumpeterian view on innovation and imitation. The idea is that new technology is developed in certain countries that are constantly at the technological forefront. The countries at the forefront have the role of developing new products or improving their quality. At the first stage in a product's cycle, there are well-defined property rights on the product's technology. Later on in the product cycle, the production of the good is relocated to other countries. This may be the effect of two independent factors. First, as the advanced country keeps on innovating, older vintages produced under less efficient technology get crowded out because of increasing wages in the frontier country. Second, as a technology grows old, it gets increasingly harder to appropriate its returns. As time passes, the technology becomes a public good. As a consequence of these conditions, other countries further down on the productivity ladder take over production of the older vintages.

Thus, technology gap theories on economic growth take productivity increase at the forefront as given. The focus is on diffusion of technology. Technology gap theories are therefore theories of very conditional convergence: Through diffusion, poorer countries are able to catch up with the world economic leaders. Productivity increases at the forefront, however, increases the length of the ladder to climb. Krugman (1979 and 1986) presents models in which it is demonstrated that productivity increase at the forefront is always to the benefit of both rich and poor countries while catch-up is a benefit for poorer countries, but not necessarily for richer ones. In Krugman (1979) the crowding out effect is formalised, in Krugman (1986) the diffusion effect is analysed.

Fagerberg (1988) presents models in which growth in a set of countries is assumed to be a function of technological distance between the country in question and the world economic leader (the US) and resources devoted to increase the country's absorptive capacity. Fagerberg demonstrates that the outcome of economic development might be both convergence and divergence. Fagerberg proposes that a country's income level will depend on own R&D, R, diffusion of knowledge from abroad, Q, the countries capacity for exploiting knowledge, C, and a constant:

$$Y = ZQ^a R^b C^e$$

$$\frac{\dot{Y}}{Y} = a\frac{\dot{Q}}{Q} + b\frac{\dot{R}}{R} + e\frac{\dot{C}}{C}$$

The technology gap hypothesis is that countries lagging far behind the frontier have a larger potential for catch-up than other countries. The frontier is supposed to be indicated by knowledge in the leading economy in the world, Q*. Therefore:

$$\frac{\dot{Q}}{Q} = h - h\left(\frac{Q - Q*}{Q}\right)$$

Growth will now be given by the expression:

$$\frac{\dot{Y}}{Y} = ah - ah\frac{Q*}{Q} + b\frac{\dot{R}}{R} + e\frac{\dot{C}}{C}$$

The empirical implications of this model are very similar to empirical formulations of the neo-classical growth model. In the technology gap models, poor countries are predicted to have a high potential for growth through technology imports, in neo-classical models, they are predicted to grow fast because of high returns to capital.

Verspagen (1991) models catch-up and technology flows in a similar way. Verspagen explicitly opens up for the existence of underdevelopment traps. For countries being way behind the technological leader, the ability to make use of technology flows is limited. Other countries, ranging further up on the productivity ladder, have higher absorptive capacity and are able to keep constant or reduce the technology gap. Thus, Verspagen’s model predicts a world in which there is a club of very poor countries and another club of converging wealthy countries.

3.6 Summing up

Recent growth theory is to a less extent than traditional theory based on assumptions of decreasing returns to physical or human capital. Leaving that assumption also implies that the traditional source of convergence vanishes. In a large class of models, convergence in income per capita is shown to be dependent on whether technology flows are global or local in scope and whether knowledge spills over between industries. Also, when there is international trade, convergence depends on the extent to which prices on goods imported from technological leaders tend to fall over time as technology progresses.

4. Empirical evidence

4.1 Measurement and methodology

In the empirical literature several measures of convergence have been proposed. The first is already mentioned: The lack of an unconditional systematic relationship between the initial level of GDP and subsequent growth rates for the world economy is referred to as unconditional β-divergence. Conditional β-convergence is the occurrence of convergence when other factors are controlled for.

β-convergence, therefore, denotes a negative coefficient for initial level of GDP in a cross-section regression on growth rates for a sample of countries according to the regression equation:

$$g = \frac{1}{T}\log\left(\frac{y_{it}}{y_{i,t-T}}\right) = a + b\,\log\left(y_{i,t-T}\right) + g\mathbf{X}_{i,t-T} + u$$

Above y_{it} denotes GDP per capita in entity i at time t. T denotes the time from the initial year to the last year. u is the regression residual. One distinguishes between conditional β-convergence and unconditional β-convergence according to whether other relevant variables, denoted by the vector **X**, are included or not. Unconditional β-convergence means that β is negative and significant when **X** is left out. Conditional β-convergence means that β is negative and significant when also other explanatory variables are included in the regression. The literature is not conclusive on what variables to include, however. Often variables reflecting openness to trade, the population's educational level, investments and other variables are included. Levine and Renelt (1992) and Barro (1997) provide critical reviews on what conditioning variables to include in cross-country growth regressions. In Section 4.2

below I give an overview of some empirical results in this tradition of cross-sectional studies of economic growth.

The reader should note that the above expression might capture both the neo-classical hypothesis of convergence, the endogenous growth hypothesis with international technology diffusion and technology gap models (when a lag to a frontier is included).

A more restrictive version of convergence is so-called σ-convergence. σ-convergence denotes that the standard deviation of GDP per capita in a sample of countries decreases over time. σ-convergence is a stronger criterion than β-convergence in the sense that absence of σ-convergence can co-exist with β-convergence. The relation between β-convergence and σ-convergence may be derived from the above equation. Rewriting it and setting T=1, a difference equation of $\log(y_{it})$ is obtained. u is assumed a random variable with zero mean and constant variance over time and over our units of observation (absence of autocorrelation and heteroscedasticity). Taking the sample variance of this expression gives:

$$\sigma_{\mathrm{yt}}^{2} = (1+\beta)^{2}\sigma_{yt-1}^{2} + \sigma_{u}^{2}$$

Above σ_{yt}^2 denotes sample variance of the log of GDP per capita in year t and σ_u^2 is the sample variance of u. It is seen that the expression for variance in GDP levels per capita is a function of β. If β is negative (as implied by the β-convergence hypothesis), it contributes to reduced sample variance over time. Variance might nevertheless increase if the contribution from the error term, u, is larger than the contribution from β-convergence.

The second tradition of empirical studies I will review is the analyses of total factor productivity. From the production function presented earlier we have:

$$Y = AK^{\alpha}L^{1-\alpha}$$

$$\frac{\dot{A}}{A} = \frac{\dot{Y}}{Y} - \alpha\frac{\dot{K}}{K} - (1-\alpha)\frac{\dot{L}}{L} = g\mathbf{X} + u$$

From the second of these equations, growth in total factor productivity is expressed as the difference between growth in total levels of GDP and a weighted average of factors of production (capital and labour in this simple stylised example). The last expression expresses the hypothesis that growth in total factor productivity is a linear function of possible explanatory variables.

Under the assumptions that factors are paid their marginal productivity, workers' share of production is equal to (1-α) and capital's share of production is equal to α. Therefore, growth in productivity will be equal to the difference between the growth rates in GDP and the reward to the factors of production times the growth rates in these. These are observable figures in many countries so they can be used to measure increase in total factor productivity. This is the growth-accounting procedure.

Studies of total factor productivity have revealed that growth in total factor productivity is substantial. In fact, several studies have demonstrated that productivity growth accounts for the major share of growth. Growth in total factor productivity has been denoted *a measure of our ignornance* (Abramowitz, 1956) because it is the share of growth that cannot be accounted for by growth in traditional factors of production. In recent research, however, it is just the productivity that is subject to research.

There are important limitations to growth accounting and studies of total factor productivity. This approach is based on assumptions of constant returns to scale in production and of perfect competition. Barro and Sala-I-Martin (1995) also points out that growth in capital and production might be the consequence of growth in total factor productivity. If so, the usual measures of total factor productivity underestimate the contribution from technological change and overestimate the contribution from capital accumulation.

4.2 Empirical results – an overview

4.2.1 Growth regressions

Growth regressions have been very popular in recent years. There are two traditions of growth regressions on data sets for global data. The first attempts to test the neo-classical growth model, often extended with human capital. These studies indicate that the *level* of GDP per capita can be well explained only by inclusion of investments and human capital (see e.g. Mankiw et al., 1992). However, these two variables do not succeed in explaining growth, i.e., changes in levels, very well.

The second approach to global data sets has been to include a large set of explanatory variables in regressions on growth. These exercises have been useful in at least two senses. First, they reveal possible explanations for growth. In growth regressions, investments, schooling (male, but not female!) and initial income are robust variables correlating with growth in many studies. Openness to trade is less robust, but most studies indicate an often strong, but not very significant effect. Second, they clarify the concept of convergence: By use of growth regressions on different samples of countries and with different explanatory variables, one may detect to what extent initial income robustly influences subsequent growth.

Growth regressions are not without problems. I will emphasise three of them. First, it is not clear what the direction of causation between the explanatory variables and growth is. Neither is it clear what variables to include in growth regressions. Levine and Renelt (1992) have constructed a test for the robustness of explanatory variables in growth regression. The essence in their test is that a variable should be significant of the same sign in regressions independently of inclusion of other different variables. Second, growth regressions of the type cited below very often presume that countries are independent observations. The most common regression methods are based on ordinary least squares regression and it is not taken into account how countries interact with each other. Third, growth regressions have limited explanatory power. One reason for this is that regressions on the largest samples possible provide researchers with a small set of available explanatory variables. We believe that investments in R&D are an important source of growth, but for many countries R&D-data are not available. Investments in human capital are therefore often approximated for instance by data on school enrolment.

Table 1 reports results from a set of nine often cited studies. It is seen that only three variables stand out as robust explanatory variables of growth. These are initial income, investments and international trade. Other variables are often not significant or their significance (and even their sign) depends on what other variables are included. Often variables seem to have non-linear effects. This is the case both of indexes of democracy and of inequality.

Table 1. Estimation results for growth in GDP per capita, global data, results from various studies

Variable	Reference	Effect	Robust/Fragile
1) initial income	MK, B, BS, I,	-*	R
2) investments	MK, B, BS, I,S	+*	R
3) human capital	MK, BS, I	+ (-)*	
4) trade	FR	+*	R
5) trade policy	S	+*	F
6) FDI	BLZ	-	
7) corruption	MK	-*	
8) democracy	B	±*	
10) health	B	+*	
11) inequality	B(1), PT	±*	
12) inflation	LR	-	F
13) regions	SM, B,	+* (East Asia,lat)	
14) rule of law	SM, B,	+*	
15) religion	SM	-*(Christianity)	

MK= Mankiw *et al*. (1992), B=Barro (1997), BS=Barro and Sala-I-Martin (1995), I=Islam (1995), FR=Frankel and Romer (1999), S=Sala-I-Martin (1997), BLZ=Blomström, Lipsey and Zejan (1996), PT=Persson and Tabellini (1994), B(1)=Barro (2000).

4.2.2 Studies of total factor productivity

Empirical studies of factor productivity abstract away from the convergence debate. In studies like these, a hypothesis that is often tested is the predicted potential for lagging countries, sectors or firms to catch up in terms of productivity by use of knowledge developed elsewhere. In order to study the effects of innovation and knowledge flows or spillovers, as modelled in endogenous growth models, many researchers have chosen to focus on smaller data set for which more variables are available. Such variables are data on R&D, patents and most important for our subjects: variables reflecting diffusion of technology. I will distinguish between findings of embodied and disembodied technology flows, since there are different interpretations of these two types of flows of technology.

Evidence on embodied technology flows

As discussed above, technology flows potentially have many forms. One is technology flows embodied in goods. Buyers benefit from the knowledge that is used to develop a good, both if the good is used as a factor in production and if it is used for consumption. A set of studies has revealed important effects of embodied technology flows for growth in factor productivity.

A) Coe and Helpman (1995) hypothesise that growth in productivity is a positive function of own R&D and a function of other countries' R&D. They assume that others' R&D is imported through imports of capital goods. They therefore regress productivity growth in the OECD countries on own R&D and a weighted sum of other countries' R&D where the weights are the shares of imports from those countries to the country in question. The results are striking: Coe and Helpman find that most productivity growth results from foreign R&D and not from national R&D. The import of foreign R&D has larger influence on smaller countries than on large ones. A later study is that of Frantzen (2001), who extended Coe and Helpman's analysis to a longer period.

B) Coe, Helpman and Hoffmeister (1997) extend the above study to a group of developing countries. In this study, there is found evidence that foreign R&D stocks and imports of capital goods from other countries explain growth in total factor productivity more than does for instance schooling. Furthermore, the effect of foreign R&D seems to be larger the more open the economy is.

C) Lichtenberg and van Pottelsberghe de la Potterie (1996) aim at extending the analysis by Coe and Helpman to flows of international foreign direct investments. Their findings do no lend support to important technology flows from the investing country to the recipient country. Their findings suggest the opposite; the investing country benefits from R&D in the host country.

D) This lends support to the findings in Eaton and Kortum (2001), who find negative effects of an estimated price index of trade capital goods for importing countries.

E) Similar results are found in Maurseth (2002) in which a theoretical price index of capital goods is constructed. The price index is constructed according to an assumption that geographical distance is an important barrier to trade. Maurseth furthermore demonstrates that the constructed price index levels of GDP give a well-founded theoretical basis for the empirical regularity that market potential seems to explain differences in cross-country GDP per capita levels.

Disembodied knowledge flows

A) In models of technology gaps, the main hypothesis is that a technology gap between a follower country and the leading country potentially favours growth. Fagerberg (1987) demonstrates that, for a sample of 25 countries, including the OECD countries, growth is well explained as a positive function of each country's number of patents (as a measure of innovation), a negative function of the technology level (measured as own GDP per capita) and investments. The negative coefficient of initial level of GDP is interpreted as a technology gap to the technology leader in the sample (the US). It should be noted that this study does not differ from growth regressions except for the inclusion of patents as technology. The interpretation of the result differs, however.

B) In the same vein, Griffith, Redding and Van Reenen (2000) estimate productivity in industries in a country as a function of the lag between productivity of the industry in this country and the productivity of the same industry in the country in which the industry has the highest productivity. They find clear evidence of convergence in productivity levels between countries.

B) Eaton and Kortum (1996) analyse international patenting. They hypothesise that if an invention is patented in a country (particular in other countries than the one in which it was invented), it signals a transfer of technology. They estimate the determinants of international patenting and find, among other things, that distance reduces knowledge diffusion. They find positive and significant effects of international knowledge flows and in the same vein as Coe and Helpman (1995): foreign innovation is more important than national innovation in smaller countries. Eaton and Kortum analyse growth in labour productivity, however.

C) Keller (2002) estimates total factor productivity as a function of own and others' R&D in 14 countries, but for a large set of industries. He finds that the effects of others' R&D on a sector's productivity decrease rapidly with geographical distance and that language differences matter negatively.

D) Verspagen (1997) estimates total factor productivity in different industries and uses patent citations as the weights for technology diffusion from one sector to another. Also in Verspagen's analyses, there seems to be important effects of technology diffusion. The same result is found in Maurseth (2001) for a disaggregated set of Western European regions.

To sum up: studies of total factor productivity suggest that the productivity in industries and countries depends to a large degree on technology flows from other sources than their own invention.

4.2.3 σ-convergence and other types of distribution dynamics.

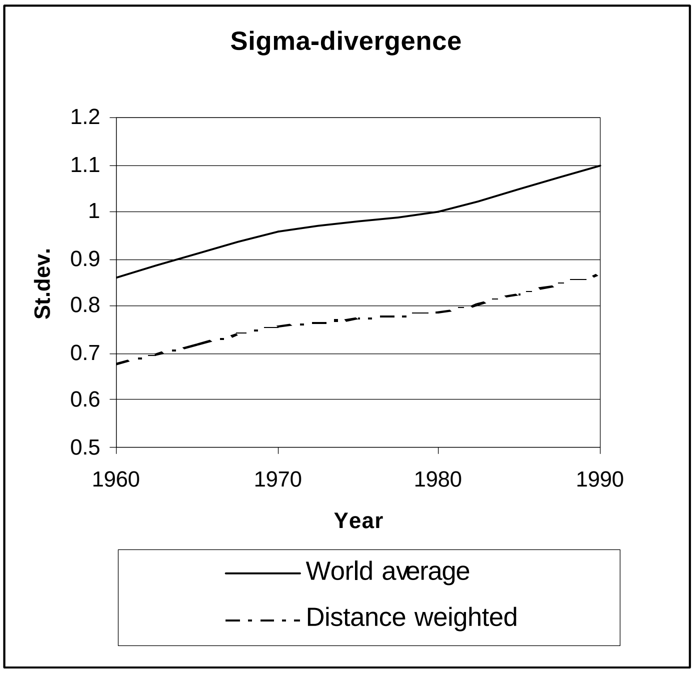
As mentioned above, a strict test of convergence is σ-convergence. σ-convergence denotes reduced standard deviation in the cross-country income distribution over time. As such the measure is extremely simple. There have been only a few studies that incorporate explanatory variables in analyses of σ-convergence. One of these is Ben-David (1996) and Ben-David and Kimhy (2001). Ben-David acknowledges the problems of including trade in growth regressions. He therefore analyses σ-convergence among trading partners. In particular, Ben-David finds that pairs of countries that trade intensively with each other show less dispersion in their income than other countries. Similarly, he finds that pairs of countries that increase their trade relations, experience reduced dispersion in their income per capita, i.e., there is more rapid convergence between countries that increase their trade relations. A related finding is presented in Figure 3. That figure shows the dispersion in income per capita among countries standardised to world average and in income per capita standardised to a distance-weighted world average. In analyses of geography in general (and for economic growth in particular), the hypothesis is that some variable x in entity i influences some variable y in entity j as a decreasing function of the distance from i to j, d_{ij}. Therefore, a distance weights matrix was constructed according to:

$$w_{ij} = \frac{1/d_{ij}}{\sum_{j=1}^{n} 1/d_{ij}}$$

The resulting weight matrix postulates that the influence of any variable between two countries decreases with the inverse of the distance between them. The weights are standardised so that they sum to one for each country. This makes it easier to construct weighted averages of variables for countries.

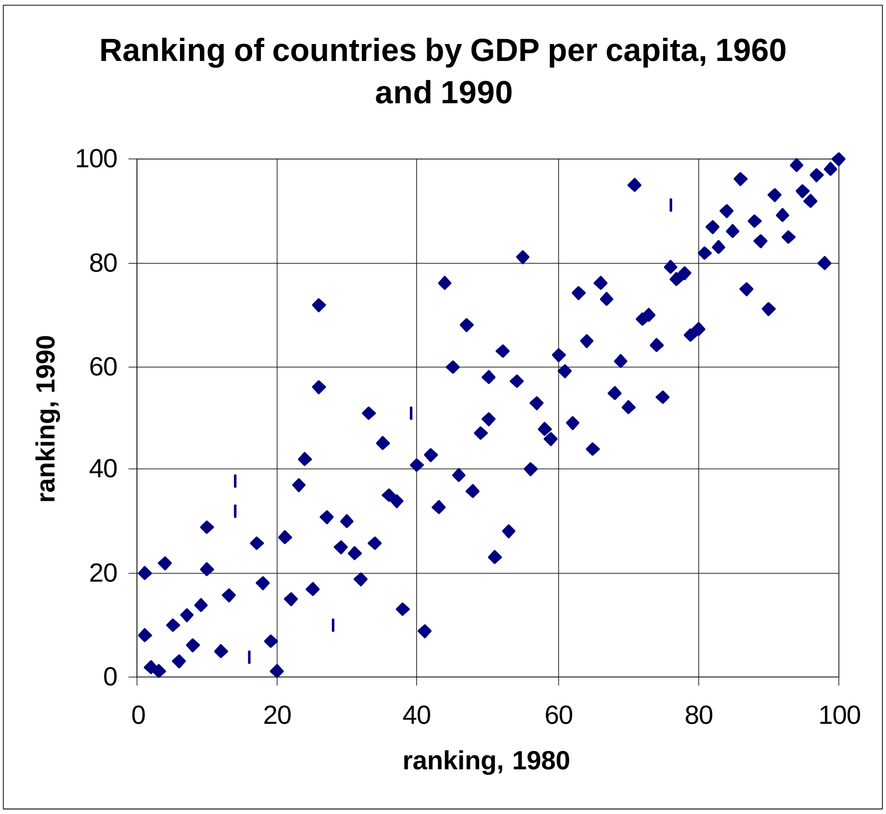
The figure reveals that dispersion is less between neighbours, but Figure 3 reveals σ-*divergence* in both the overall distribution and the distance-normalised distribution.

Figure 3



Quah (1993 and 1996) argues that both β-convergence and σ-convergence are crude measures of convergence. For instance, both β-convergence and σ-convergence can be consistent with Baumol's notion of convergence clubs, in which there are clubs of countries converging towards common levels of GDP per capita (Baumol, 1986). Quah proposes to report transition probabilities from discretised percentiles of the distribution of income over time. Thus, growth clubs would be characterised by more entries into certain discrete percentiles of the population than exits from the same percentiles. The essence in Quah's proposal is demonstrated in Figure 4. That figure graphs the ranking of 104 countries in the world economy in 1960 and 1990. Quah's transition probabilities correspond to countries jumping from one of the graphed squares to another. Quah characterises the cross-country income distribution as stable if countries remain within those squares and unstable if they jump out of their squares. Figure 4 demonstrates that the income distribution across countries in the world was more stable for rich countries than for the other countries. This reflects the clear convergence among the rich OECD countries.

Figure 4



5. Summary and conclusion

Whether countries will tend to converge in income per capita is an important question for students of economic growth. While convergence was an inherent prediction in the traditional neo-classical growth model because of decreasing returns to capita, in recent theories convergence is predicted to depend on diffusion of knowledge. Diffusion of knowledge takes many forms and is often distinguished as embodied in traded goods and disembodied flows of knowledge.

Recent empirical research lends support to the neo-classical hypothesis of conditional convergence: When other relevant factors are accounted for, there is convergence in GDP per capita. It is not clear from growth regressions what to conclude from this. One interpretation is that this supports decreasing returns to capital. Another is that low levels of initial incomes indicate a large potential for catch-up through assimilation of technology.

Studies of smaller data sets demonstrate a potentially large influence of such technology diffusion. Of the channels for knowledge spillovers, trade between countries has been identified as important. It is not clear from recent studies whether trade-induced spillovers dominate in importance over the disembodied spillovers analysed in the first generations of endogenous growth models.

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