Economic Convergence through Savings, Trade and Technology Flows: Lessons from Recent Research

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Introduction

In 1960, South Korea ranked almost on a par with Bangladesh in terms of gross domestic product (GDP) per capita: GDPs per capita in both countries were less than half the world's average. In 1990, South Korea's income per capita was 4.8 times that of Bangladesh and about one-third higher than the world's average; Bangladesh's income per capita, although 40 per cent higher than in 1960, had dropped to one-third of the international average. This was the result of Korea's economy growing at an average of 6.4 per cent annually during these three decades, while Bangladesh's economic growth was 1.2 per cent.

These are two specific examples, but they illustrate the importance of economic growth: differences in growth rates are decisive for prosperity and misery. 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 question analysed in this literature is whether the huge inequalities in income per capita between countries will tend to disappear or widen over time. Traditional growth economics in its simplest forms predicts convergence in per capita income levels through decreasing returns to physical and human capital. The recent literature has

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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 traditional theory. A large part of the literature predicts massive divergence, while other contributions discuss the conditions under which convergence may be an outcome. It is the aim of this article to review new and earlier literature on economic growth and discuss their implications for inequality between countries. The empirical literature will be reviewed, too, with a particular emphasis on the ability of poorer countries to catch up with richer ones.

The new and old literatures on economic growth have in common that technological change is regarded as the main driving force for growth. What distinguishes new from older theories, or endogenous from exogenous growth theories, however, is that the recent literature aims at explanations of technological change itself. This expansion of theorising widens the topic of study: growth economics is not only about how economies interact, given a certain pattern of technological change, but also about the various mechanisms 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 according to three different traditions. The first is a large set of studies based on cross-country growth regressions. In this literature growth rates in a set of countries, for one or 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 study of total factor productivity, the so-called growth-accounting tradition. This tradition relies more on stringent (and controversial) theoretical assumptions but has the potential to explain 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 third tradition is the study of the dynamics of income distribution between countries. Proponents of this tradition claim that neither cross-country growth regressions nor studies of total factor productivity reveal whether income inequalities between countries increase or decrease over time.

This article will first give an overview of some basic facts about world income distribution. Thereafter I will provide a guided tour of growth theory; the 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 to the subsequent discussion of empirical measures of convergence and the findings in existing studies. I conclude by summing up and presenting some thoughts on what has been learnt and what we need to learn more about.

1. Divergence and Convergence: Some Stylised Facts

There are very large differences in income per capita among countries in the world.[1] In 1990, the richest country in the world was 45 times richer than the poorest. This multiple had increased from 32 in the period from 1960. These are extreme cases, of course. An inequality measure that only expresses the highest as a multiple of the lowest conceals everything in between. Still, as will become clear, massive divergence in income levels is characteristic of capitalist economic development.

The topic here is convergence versus divergence in terms of per capita income internationally, not the developments in inequality between people within individual countries. Clearly, datasets of GDP per capita reveal nothing about internal inequality. Neither will this article look at the way in which population size influences inequality between people when use is made of per capita numbers.[2]

It should be noted that long-term development has necessarily been characterised by divergence. The richest countries in the world have been growing – though not entirely steadily – at a rate of over 1.5 per cent annually, at least since 1870, as Angus Maddison's long-term data show (Maddison, 1995). As argued by Lant Pritchett, this has only been possible because growth rates of developed economies have systematically been higher than those in poor countries. If growth rates in poor countries had been higher than in 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

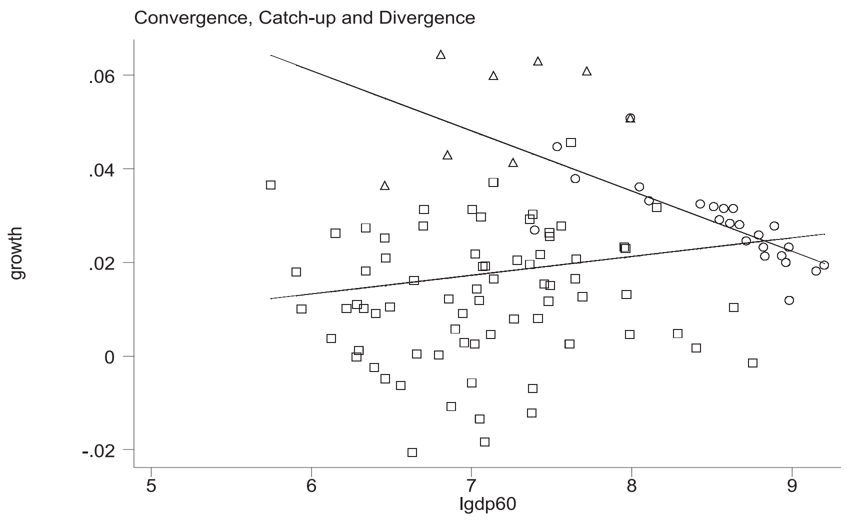
1 The data used in this article are taken from the Penn World Tables, Mark 5.6. The data are for GDP per capita in 1960 and 1990 for 104 countries. The GDP data refer to purchasing power parities at constant international prices and are therefore comparable over time and across countries. They have been used extensively in recent research, including many of the studies reviewed in this article. The data are available at http://pwt.econ.upenn.edu/

2 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.

run, capitalist development has been characterised by divergence. This is in line with the hypothesis of Simon Kuznets (1955) of an inverted U-shaped relationship between inequality and development. Development results in higher income. Development does not happen instantaneously for all members of a statistical population (in this case countries). Instead fractions of the population are relocated from a low-income distribution to a high-income distribution. If rich and poor countries populate the world, development will, at least partially, be characterised by countries relocating from the poor group to the rich group. Therefore, the relation between development and growth will be characterised by three elements: the nature of the low-income distribution, the nature of the high-income distribution and the consequence of relocation between the two. The last element will, at least initially, tend to increase income differences.

Recent studies of growth have tended to be occupied with short 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 (see, for example, Quah, 1993, or Barro, 1997). If there is any connection between growth and initial levels of income, it is positive. This is revealed in Figure 1, which 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.

Figure 1.



Source: The Penn World Tables, Mark 5.6.

2. Relative Economic Performance – Theoretical Perspectives

The figure does not support 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 positive. This is demonstrated by the positive sloping regression line included in the figure. The coefficient of initial income is not significant, however.

Three types of countries are shown in the figure. The triangles represent the East Asian tiger economies, which have had very high growth rates during the last three decades. The circles represent the OECD countries. Here, there seems to be a convincing impression of a negative relationship between growth and log of initial GDP. The included regression line for these countries is negatively sloping and highly significant (at a p-level below 1 per cent). This is in accordance with conditional convergence: inequality declines between countries that share important characteristics. The squares in the figure reprsent the rest of the countries in the world.

Growth theory for countries should therefore be able to explain (a) weak 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 (such as the OECD countries).

The development shown 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 (1995), 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).[3]

Growth theory and convergence: a selective review

The economic destinies of countries have long been of major interest to economists. I will review some main conclusions from both recent and older growth theories 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 their disposable

3 There is no consensus, however, as to whether the recent wave of globalisation has resulted in larger net capital flows compared with earlier periods. See Obstfeld (1998).

income on savings. Savings are translated into investments that result in increased capacity for production. Therefore, the relationship between savings and production and returns to capital are important determinants of long-term economic growth. This relationship constitutes one very important demarcation line in growth theory.

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 are constant (or decreasing) returns to scale, substitution possibilities between all factors of production and decreasing returns to all of them individually (see, for example, Solow, 1956). Constant returns to scale is the case when a doubling of the factors of production results in an exact doubling of production. The returns to individual factors of production refer to the increase in production of an increase in the use of that factor when other factors of production are held constant. Decreasing returns to capital is therefore the situation in which a certain increase in capital results in a larger increase in production when the use of capital is initially small. Constant returns to scale and decreasing returns to each factor of production make the model consistent with decentralised markets. In the neo-classical growth models technological change is assumed to be exogenous and equal to all production entities. 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 model, the engine of growth in the *short run* is capital accumulation. Through savings and investments, a country increases its production capacity. 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 with the same amount of factors of production.

This may be illustrated in terms of the most simple neo-classical growth model. 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:

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

$$\frac{\dot{Y}}{Y} - \frac{\dot{L}}{L} = \frac{\dot{A}}{A} + \alpha \frac{\dot{K}}{K} - \alpha \frac{\dot{L}}{L} = \frac{\dot{A}}{A} + \alpha \left(\frac{sY}{K} - \frac{\dot{L}}{L} \right) = \frac{\dot{A}}{A} + \alpha \left(sA \left(\frac{L}{K} \right)^{1-\alpha} - \frac{\dot{L}}{L} \right)$$

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 in turn is will be increasing in the savings rate. As capital accumulates, however, the contribution from savings will decrease This is reflected in the term $(L/K)^{1-\alpha}$ which decreases with K. In the long run the second term in the last equation will equal zero. Therefore, in this model, technological change is the only potential source of growth in income per capita in the long run. Technological change is given by the growth rate of A.

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 per capita income. In the 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. Before all countries have achieved this level of income, poorer countries are predicted to grow faster than richer ones, as poorer countries have less capital-intensive economies and enjoy higher returns on their investments.

The above predictions are questionable. First, savings rates may vary. Second, that countries' macro-production functions are Cobb–Douglas, or that production is due to decreasing returns on capital at all, are both no more than assumptions.

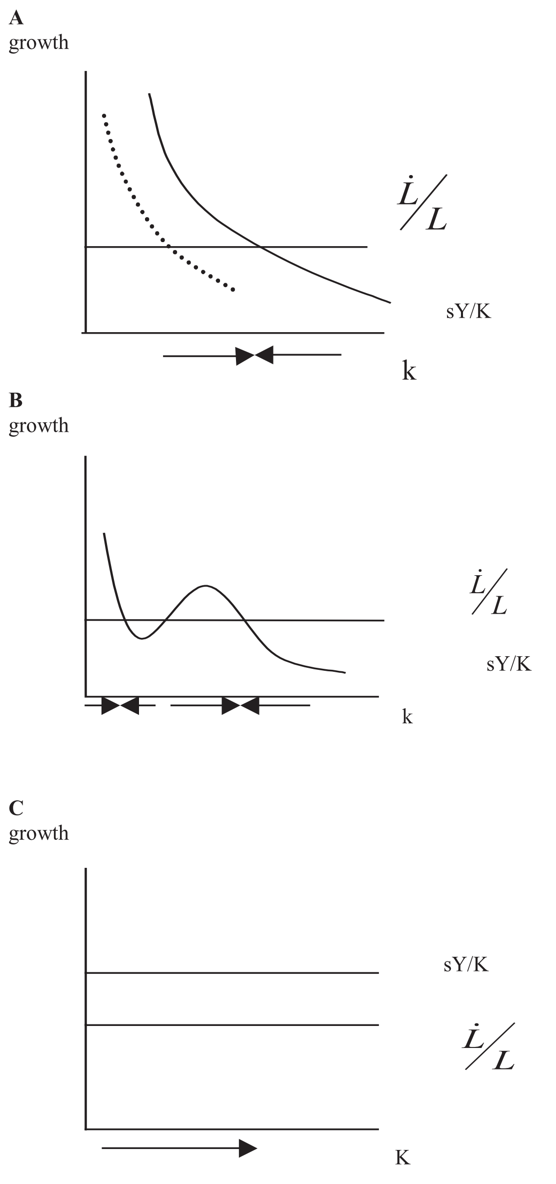
Figure 2 illustrates the critical role of these two assumptions. The vertical axes denote growth (in total income). The horizontal axes denote capital intensity in the economy (defined as capital per worker). In part A of the figure, the traditional neo-classical world is graphed. The downward sloping 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 are illustrated by the arrows below the graphs. The dotted line in panel A 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 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 is that as an economy grows structural changes may push it from phases of decreasing returns to phases of increasing returns. Thereafter, as the economy grows modern, it 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-term 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 production goes to zero. It is important that constant returns from savings normally result in divergence. Savings determine growth rates and there is nothing that ensures similar savings rates in different countries. As I will come back to, one important contribution from recent growth theory is that it explains how, in different ways, constant returns from savings, either in physical or in human capital, can be plausible.

The neo-classical growth model describes closed economies. If a country opens its doors to international trade, it experiences 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 those that are most capital-intensive (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.

Figure 2. Savings and growth



Financial integration is predicted to result in fast convergence, however. If capital moves to wherever returns are the highest, poor and capital-deficient countries will receive inflows of capital. In fact, convergence is predicted to be instantaneous in the case of complete capital mobility.[4]

Escaping decreasing returns

The hypothesis of convergence in income per capita levels is the result of the assumption of decreasing returns to accumulatable factors of production (capital above). In the long run, growth is dependent on exogenous productivity growth. Endogenous growth theories attempt to explain technological progress as an inherent part of economic mechanisms. They 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 and development result in new knowledge that is used to produce new or 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 economic terms. Knowledge can be used without being exhausted. Thus, it is a so-called *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 imply that there are externalities connected with the production of knowledge.

4 Barro *et al.* (1995) discuss capital mobility in neo-classical 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.

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

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

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

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

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 the spillover parameter δ add up to one. Therefore there are constant returns to capital at the social level. If the amount of capital is doubled production is doubled as well. This is expressed in the second set of equations. In these equations, total production is expressed as the sum of individual firms' production. The constant social returns to capital will yield endogenous growth in the long run, as illustrated in the third set of equations. 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. In this context the savings rate is decisive, not only for the level of income per capita but also for its long-term growth rate.

Complete versus incomplete 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 from those of the neo-classical model. 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 endogenous growth theory is that the growth rate is explained rather than being assumed. The explained growth rate will be common to all countries and technology is still a global public good.

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-term growth rates.

Lucas (1988) and Young (1991) provide 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 concentrate their production in sectors where 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 introduces the possibility of diverging economic development.

In the simplest models of endogenous growth, spillovers are thought of as an automatic effect of production or investments. In other 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. From these blueprints particular varieties are then produced and sold in a context of monopolistic competition to consumers. It is assumed that investments in R&D will occur until expected profits equal costs. In these models 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. These models do not predict convergence. Growth will be an increasing function of the workforce employed in R&D and of aggregated knowledge. There will be dynamic effects of economic integration in two different ways. First, through trade an economy gains access to a larger flow of new varieties. This generates increased 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-I-Martin (1995, Ch. 7) take into account uncertainty of technological change. Instead of modelling research as a deterministic process, they think of it as a stochastic process.

The R&D models formalise older ideas of Joseph Schumpeter[5] on *creative destruction.* The idea is that new innovations are destructive for previous innovations since they render them obsolete. The computer industry is a good example of this process. An interesting extension by Howitt (2000) is a model in which researchers' efficiency depends on an existing international knowledge base. In Howitt's model some countries do not undertake R&D. The model demonstrates how a country's position on the world income ladder may depend on the resources and subsidies it devotes to R&D. In some situations some countries will not invest at all, in which case there is no growth.

Technology gaps

Also inspired by Schumpeter is a less formal and more heterogeneous tradition of studies of technological change and economic growth. Such approaches stress the ability of countries that are not at the technological forefront to adapt and imitate new technologies. 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

5 Schumpeter (1934) and (1944).

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 not only bring outdated blueprints, but are also a source of new 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. Later on in the product cycle, production is relocated to other countries. This may be the effect of two independent factors. First, as the advanced country keeps on innovating, efficiency and wages increase. Therefore productions of some goods become unprofitable. The relocation of the Western European textile industry to low-wage countries is an example of this mechanism. Second, as a technology grows old, it becomes well known. The technology changes nature from a semi-private to a public good. As a consequence of these conditions, other countries further down on the productivity ladder take over production of the older goods. Krugman (1979) formalises the diffusion effect; in a later study (Krugman, 1986) he analyses the crowding out effect. Barro and Sala-I-Martin (1997) present a model in which technology gaps and diffusion of technology to poor countries are combined with endogenous innovation in the leading country. An interesting implication in these models is that increased productivity at the forefront is always of benefit to both rich and poor countries. Diffusion of knowledge, however, benefits poorer countries but not necessarily richer ones. Global intellectual property rights, imposed on all countries through the WTO's Trade-Related Intellectual Property Rights agreement (TRIPS), are an example of how global politics have traded off these considerations.[6]

6 The TRIPS agreement obliges all member countries in the WTO to establish a standardised patent institution. In principle, all patentable innovations can be patented in all countries. Maskus (2000) discusses the consequences of the TRIPS agreement. Helpman (1993) extends the technology gap model of Krugman (1986) with a discussion of intellectual property rights and their implications for the ability of poor countries to catch up.

In Fagerberg (1988) 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 of the resources devoted to increasing the country's absorptive capacity. Fagerberg demonstrates that the outcome of economic development might be both convergence and divergence. He proposes that a country's income level will depend on its own R&D, diffusion of knowledge from abroad and the country's capacity to exploit foreign knowledge. 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 taken to be knowledge in the leading economy in the world. In this set-up, therefore, growth will depend on a country's initial income (which indicates the technology gap), its absorptive capacity and possibly some other variables. The empirical implications of this model are very similar to the 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. He explicitly allows for the existence of underdevelopment traps. In the case of countries that are way behind the technological leader, their ability to make use of technology flows is limited. Other countries, further up the productivity ladder, have higher absorptive capacity and are able to keep the technology gap constant or reduce it. Thus, Verspagen's model predicts a world in which there is a club of very poor countries and another club of converging wealthy countries.

Summing up

Recent growth theory is to a less extent than traditional theory based on assumptions of decreasing returns on physical or human capital. Leaving behind 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. Moreover, when there is international trade, convergence depends on the extent to which prices of goods imported from technological leaders tend to fall over time as technology progresses.

3. Empirical Evidence

Measurement and methodology

In the empirical literature several measures of convergence have been proposed. The first has already been 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:

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

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. The regression equation above therefore expresses the hypothesis that growth depends in the (log of) initial income and a set of other variables. 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 other explanatory variables are also included in the regression. The literature is not conclusive on what variables to include. Often included are variables reflecting openness to trade, the population's educational level and the level of investments. Levine and Renelt (1992) and Barro (1997) provide critical reviews of what conditioning variables to include in cross-country growth regressions. Dobson *et al.* (2001) argue that the rate of convergence obtained in such regressions depends on what conditioning variables are included. In the following subsection, 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 the neo-classical hypothesis of convergence, the endogenous growth hypothesis with international technology diffusion and the 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 (the log 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-divergence can co-exist with β-convergence but not the other way around. The relation between β-convergence and σ-convergence may be derived from the above equation. Rewriting it and setting T=1, a equation of log(y_{it}) is obtained. This equation is a so-called difference equation in which the level in one period depends on the level in the previous period. The term u remains in the equation and is assumed to be 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:

$$\sigma^2_{yt} = (1+\beta)^2\sigma^2_{yt-1} + \sigma^2_u$$

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:

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

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

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). This is similar to the expressions above. The last of these expresses the hypothesis that growth in total factor productivity is a linear function of possible explanatory variables.

Normally it is assumed that factors of production are paid their marginal productivity. This means that capital and workers are employed until the value of the extra production that results equals the cost of hiring them. In this case workers' share of production is equal to (1-α) and capital's share of production is equal to a. 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. In many countries both investments and wages are observable. Given the above assumptions, total factor productivity can be estimated. Growth in factor productivity is used as a dependent variable in this kind of study. 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 ignorance* (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 very often 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 point 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.

Empirical results – an overview

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, for example, 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.[7] Resource abundance is negatively related to growth, at least in countries with institutions of low quality (Sachs and Warner, 1995b and Mehlum *et al.*, 2002).[8] Political instability is detected as important for economic growth, although it is hard to determine whether this reflects the impact of social unrest, insecure property rights or lack of other institutional qualities. Openness to trade is a less robust explanatory variable, but several studies indicate a strong, but not very significant effect. Rodriguez and Rodrik (1999) present evidence of the opposite: they find no significant relationship between trade policy and economic growth. Second, growth regressions clarify the concept of convergence: by use of such 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 of their test is that a variable should be statistically significant and of the same sign in regressions independently of the inclusion of other different variables. This implies that investment will be a robust explanatory variable if regressions give a positive and significant result independently of whether other variables, like schooling, trade policy etc. are included. Second, growth regressions of the type cited below very often presume that countries can be observed independently. 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.

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7 The finding that female schooling is associated with low growth rates has spurred debate and further studies. There is now agreement that it should not to be interpreted as a causal effect, but it represents a puzzle in the data. See Klasen (2002).

8 It is found in several studies that a high share of exports of natural resources in a country's GDP is negatively correlated with economic growth. Two main explanations have been put forward. The first is Dutch decease, which implies that other productive activities are crowded out. The second is that resource abundance stimulates rent-seeking activities.

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

Variable	*Reference*	*Effeect*	*Robust/Fragile*
(1) initial income	Ba, MK, B, BS, I, SW(1), M	-*	R
(2) investments	Ba, MK, B, BS, I,S	+*	R
(3) human capital	Ba, MK, BS, I	+ (-)*	
(4) trade	FR	+*	R
(5) trade policy	S, SW (1), RR	+(..)*	F
(6) foreign direct investments	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)	
(16) size of public sector	Ba, BS	-*	
(17) resources	SW, M	-(±)*	
(18) political stability	SW	+*	

Note: + and – denote positive and negative influence, respectively. ± denotes a non-linear influence. +() denotes that studies have conflicting results. * denotes whether the effects are statistically significant. Ba=Barro (1991), 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), SW (1)= Sachs and Warner (1995a), SW=Sachs and Warner (1995b), RR=Rodriguez and Rodrik (1999), M=Mehlum *et al.* (2002).

Table 1 reports results from some important 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 for indexes of democracy and for inequality.

Studies of total factor productivity. In empirical studies of factor productivity convergence is not the issue. The focus is on productivity and its determinants. 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 sets for which more variables are available. Such variables are data on R&D, patents and, most important for our subjects, those reflecting the diffusion of technology. I will distinguish between findings of embodied and disembodied technology flows since their interpretations differ.

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 depends positively on a country's own R&D and 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 each country's 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 greater 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, evidence is found 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 not lend support to the view that 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. This is an important finding since many proponents of foreign direct investments (FDI) argue that inward FDI are an important source of technology. In fact, several studies indicate that this is not the case.

(D) Another extension of Coe and Helpman is the study by Eaton and Kortum (2001). They hypothesise that imports of capital goods depend on these goods' prices. They estimate a price index of trade capital goods for importing countries and find that countries that face high prices of imported capital goods experience lower productivity and income per capita.

(E) Similar results are found in Maurseth (2003) 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. Therefore, the price index of capital will be higher in peripheral countries. This gives an explanation for the empirical regularity that high-income countries are located near large markets. Similarly these results indicate that growth rates between countries will be geographically clustered. Negative growth in one country infects neighbouring countries and positive growth is likewise transmitted to neighbours.

(F) These results are in line with Easterly and Levine (1998) who explicitly estimate contagion effects in economic growth. They find that countries are affected by the growth destiny of their neighbours. For the world economy, the nature of these findings contribute to explanations of why clusters of countries get rich and other clusters remain poor.

There is also another set of studies that focuses on disembodied technology flows. These denote flows of technology that occurs without economic transactions as prerequisites. Examples of such technology flows are exchange of knowledge in academic reseach, industrial espionage and reverse engineering.

(A) In models of technology gaps, the main hypothesis is that a technology gap between a poor country and the leading country potentially favours growth in the poor country. 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 the country's own GDP per capita) and investments. The negative coefficient of initial level of GDP is interpreted as a technology gap between the country in question and 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 an indicator of technology. The interpretations of the result differ, 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 with the highest productivity in that industry. They find clear evidence of convergence in productivity levels between countries.

(C) Eaton and Kortum (1996) analyse international patenting. They hypothesise that if an invention is patented in a country (particularly when it is not where the invention originated), 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 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.

(D) Keller (2002) estimates total factor productivity as a function of a country's own R&D and that of others, 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 linguistic borders.

(E) Verspagen (1997) estimates total factor productivity in different industries and uses patent citations as the weights for technology diffusion from one sector to another. erspagen's analysis, there also seem 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 rather than from their own inventions.

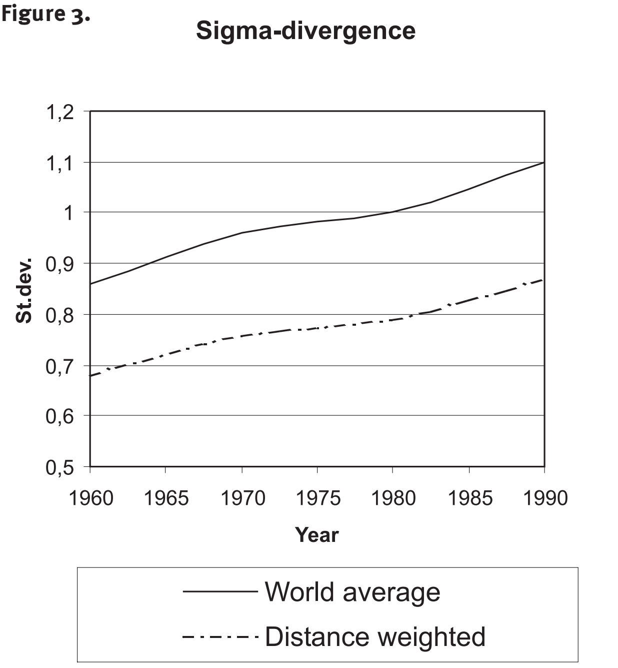
σ-convergence and other types of distribution dynamics. As mentioned above, a strict test of convergence is σ-convergence. σ-convergence denotes reduced standard deviation in the cross-country income distribution over time. As such the measure is extremely simple. There have been only a few studies that incorporate explanatory variables in analyses of σ-convergence. Two of these are 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, he 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. A related finding is presented in Figure 3. The 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:

$$\mathrm{w}_{\mathrm{ij}} = \frac{1/d_{ij}}{\sum_{j=1}^{n} 1/d_{ij}}$$

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 add up 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 that s-*divergence* occurs in both the overall distribution and the distance-normalised distribution.

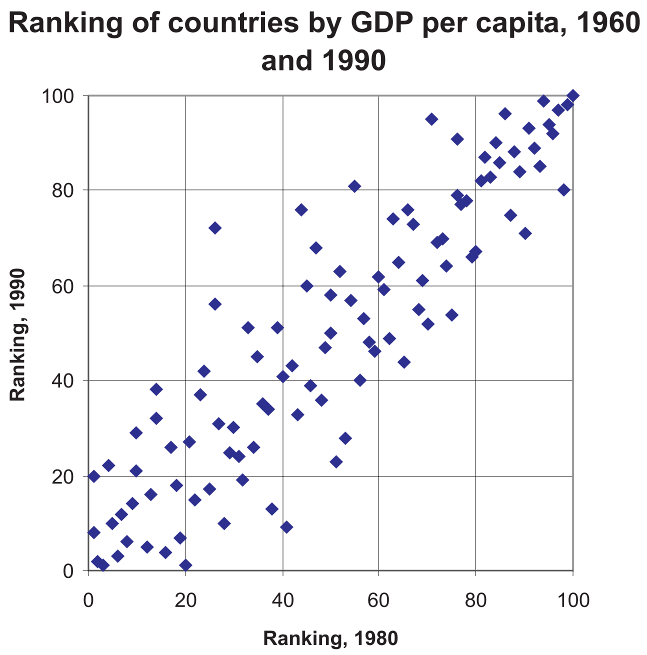
Figure 3.



Quah (1993 and 1996) argues that both β-convergence and σ-convergence are crude measures of convergence. For instance, both 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 percentiles of the distribution of income over time. Thus, growth clubs would be characterised by more entries into certain percentiles of the population than exits from the same percentiles. The essence of his proposal is demonstrated in Figure 4, which 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. He characterises the cross-country income distribution as stable if countries remain within those squares and unstable if they jump out of their squares.[9] Figure 4 demonstrates that the

9 An objection to this approach is that countries at the lower and higher parts of the income distribution can only 'jump' in one direction. Still, comparing the ranking of countries at different points in time gives an impression of stability versus instability.

Figure 4.



income distribution across countries in the world was more stable for rich countries than for others. This reflects the clear convergence among the rich OECD countries.

4. 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 capital, in recent theories convergence is predicted to depend on diffusion of knowledge. Diffusion of knowledge takes many forms and is often distinguished as being 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 the hypothesis of decreasing returns to capital. Another is that low levels of initial income indicate a large potential for catch-up through assimilation of technology. It is important that conditional convergence is not equivalent with a collapsing or narrowing income distribution. In fact, differences between rich and poor countries have increased. Growth regressions have revealed important potential sources of growth, however. These are investments in human and physical capital, institutional quality and openness to trade.

Studies of smaller datasets demonstrate a potentially large influence of 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.

While growth economics has revealed a set of important mechanisms related to economic growth, it has not resulted in a toolbox for growth-promoting policies. In particular for very poor countries, there are many remaining questions. The effects of institutional quality, governance and geography on economic growth seem to be major issues for future research.

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