4. Technology, convergence and growth in the European Union

4.1. Introduction

Disparities of income per capita across regions and countries have been a matter of concern for the European Community since its inception\(^1\). The objective of reducing disparities across regions in the Community is laid down already in the preamble of the Treaty of Rome. In 1987, the Community received in the Single European Act an explicit competence for undertaking a regional policy aimed at reducing disparities. The Maastricht Treaty on European Union, moreover, in its Article 2, includes economic and social cohesion as a fundamental principle the Community seeks to respect. Moreover, Article 130a states that the Community shall aim at reducing disparities between the levels of development of the various regions.

There has been a renewed interest in the economic analysis of growth and convergence, which has been associated with both the objective of convergence across countries and regions becoming politically acceptable and with new developments in theories of economic growth. Theories of economic growth were, up to very recently, regarded as optimistic with respect to the distribution of income. They tended to suggest that the distribution of income would become more similar over time, so that poor countries converged to the income level of rich countries. In contrast, the literature on endogenous growth proposed that the gap between rich and poor countries would remain persistent over time, so that poor countries always remained poor and rich countries remained rich.

From an economic policy point of view, the issue of growth and convergence in Europe is indeed particularly interesting and relevant, for two reasons: first, regional convergence or divergence determines the usefulness of regional economic policies attempting to equalize the distribution of income [Sala-i-Martin, 1995]. Second, European monetary integration might contribute to convergence - or divergence - itself by increasing factor mobility or trade among participating countries. Economic integration may indeed have an effect on aggregate growth of GDP in the Community economy. To the extent that this is favourable, higher growth can be expected to improve welfare. There is, however, the fear that a full-fledged European Monetary Union (EMU) will widen the existing regional inequality in per capita income within the European Union (EU). Monetary integration, and its implicit obligation to assure convergence of nominal indicators such as inflation and interest rates, will entail
restrictions on macroeconomic policy that are more onerous for the less-prosperous countries of the Union [Begg and Mayes, 1993]. Together with unemployment problems, these concerns have already given rise to a doubling in real terms of European Community (EC) structural funds devoted to regional and social policy in the period 1988-1992 [Abraham and Von Rompuy, 1992]. These kind of arguments indeed lie at the heart of the real convergence debate in the context of European Monetary Union.

The present chapter deals with these issues within the framework of an empirical analysis of the relation between technological differences, convergence and growth across EU countries. Three main goals are associated with this chapter. For one, it aims to provide a review of empirical analyses and of the relevant theoretical background. In addition, the stability of the convergence processes across time and across countries is examined. Finally, we analyze the reason for the apparent instability of the growth and convergence process in Europe. Based on endogenous growth theories (and on technological catch-up approaches), a possible explanation is the presence of technological differences, which are tested for within a structural econometric framework. Thereby, the chapter contributes to analyze convergence of living standards in the EU member states, thus focusing on long-run aspects of real economic convergence.

We may first ask if technological differences, as for the high degree of integration and economic cooperation among EU countries, are really plausibly relevant for economic development in Europe. Several kind of theoretical and empirical considerations suggest that they might indeed be relevant, even in such an integrated area like the EU. Already on a national level, formal comparisons of productivity levels frequently uncover wide variation among finns in the same manufacturing industry. Even in a service industry such as retailing, finns like K-Mart and Wal-Mart use very different technologies to provide their service, with very different outcomes in terms of profitability and returns on equity [Romer, 1995]. These persistent differences are difficult to explain if the technology that each uses is a public good. Empirical evidence on the effect of innovation on output and productivity tends to support this skepticism. Here, a consensus has emerged that innovation has a significant effect on productivity at the level of the firm and industry [Cameron, 1996]. Griliches (1988), for example, suggests that the elasticity of output with respect to R&D is generally found to be much lower than the social rate of return to R&D. Recent work on the effect of geography on spillovers, moreover, indicates that technologically-intensive industries tend to be more localized than other industries, and that information flows locally more easily than at a distance [Jaffe et.al., 1993; Audretsch and Feldman, 1994].
Technological differences across economies are even more relevant than on the national level, in particular, if we think of technology in a broad sense, that is, representing resource endowment, climate and institutions, which supposedly vary across countries [Barro and Sala-i-Martin, 1995]. Technological differences would imply that convergence and growth processes differ across economies and would thereby contribute to explain the apparent instability of growth and convergence across time and across countries in Europe [e.g. Larch, 1994; Armstrong, 1995]. To test for the hypothesis of technological differences, I use cross-country data, which allows to apply a prolonged data set (1950 - 1992), and which enables to analyze the principal determinants of growth and convergence suggested by modern theories of economic growth.

The remainder of this chapter is organized as follows. In Section 2, the theoretical background is reviewed and the main implications for convergence are summarized. Three modern theories of economic growth are discussed in this section. Theories of technological catch-up argue that inefficient use of technology may lead to a process of convergence, depending on the degree of economic development in the economy. Neoclassical growth theories predict convergence due to decreasing returns to scale. Endogenous growth theories, in contrast, maintain that economic growth may be influenced by factors like market size, economies of scale and institutional structure, so that differences in living standards would possibly persist. Some controversy has also arisen with respect to the empirical assessment of convergence. A correct assessment of convergence is important, because whether convergence actually occurs across regions and countries may indeed shed some light on the relevance of new growth models. In view of this controversy, several empirical concepts of convergence have been developed recently, which are reviewed in Section 3. In addition, formal, mathematical concepts of convergence are contrasted with empirical convergence concepts. Section 4 provides a review of the empirical literature, concentrating first on papers dealing with the evolution of growth and convergence among world economies and then turning to empirical work using data from European regions. Section 5 analyzes the stability of the growth and convergence processes in Europe using descriptive statistical methods. The purpose of this analysis is to underline the argument that convergence has not been stable, neither across time nor across countries. In order to compare the performance of both measures, income per capita and labor productivity are used. In Section 6 a descriptive growth model is developed and used to derive a convergence regression equation. Section 7 contains an econometric analysis of technology, convergence and growth in the EU. The econometric model is based
on the stylized growth model developed above and concentrates on output per capita as measure for living standards. Section 8 summarizes the chapter, relates the empirical evidence to the European integration process, and provides conclusions.

4.2. Theoretical background

In this section, three modern theories of economic growth are reviewed and their implications for economic convergence are summarized. Theories of technological catch-up argue that inefficient use of technology may lead to a process of convergence, depending on the degree of economic development in the economy. Neoclassical growth theories predict convergence due to decreasing returns to scale. Endogenous growth theories, in contrast, maintain that economic growth may be influenced by factors like market size, economies of scale and institutional structure, so that differences in living standards would possibly persist.

4.2.1. Catching-up and falling behind

The notion of a catching-up effect can be traced back at least to Gerschenkron (1952) [cited in Hansson and Henrekson, 1994a,b], who maintained that, where a country's growth prospects are concerned, an advantage may lie in relative backwardness in terms of productivity\(^2\). The general idea of the catching-up hypothesis is that in terms of productivity backward countries will have an opportunity to embark on a catching-up process by imitating and borrowing superior production techniques from the more advanced economies cheaper and faster than the original discovery and testing. By imitating production techniques from the more advanced economies, the lagging ones may reduce the distance to their own technological frontier. The growth potential of lagging countries is not solely because of the possibility of replacing obsolete capital with best practice equipment. In addition, there is a chance to adopt advanced management practices, better marketing strategies etc. As a result, we ought to expect technologically less developed countries to experience faster productivity growth than the technologically leading ones. In the literature on the catching-up hypothesis, however, this possibility is not regarded as necessarily realisable. Another necessary condition for the catching-up factor to be operative is a sufficient degree of "social capability", as has been emphasized by Abramovitz (1986, p.388). Abramovitz distinguishes between potential and realized catching-
up. The former is due to the gap between the leader countries and the backward countries, which are thus able, through imitation, to increase productivity. Realized catching-up is the rate of exploitation of potential catching-up, which is caused by diffusion of knowledge, the rate of structural change, the accumulation of capital and the expansion of demand. He points out that a country has to have the "social capability" and "technological congruence" to catch up to the leader. Institutional commitments might also act as a constraint on convergence. However, once countries have reached a threshold level of development in terms of "social capability", the process of catching-up will be driven by interactions between leaders and followers via flows of capital, final goods and applied knowledge. Accordingly, the catching-up effect may be expected to be strongest in technologically backward but socially advanced countries. A major problem with the concept of social capability is its imprecision. Abramovitz (1986) enumerates a number of factors that are important determinants of a country's social capability: the level of education, the organisation of firms, openness to foreign competition, the ease by which new firms can be established, the power of vested interests in opposing change, the functioning of the labor market and the degree of competitiveness in domestic product markets. Stern (1991) has identified a number of other factors that are potentially important, notably managerial competence and the quality of infrastructures including features of the social infrastructure such as honesty, benevolence of bureaucracy, and how clearly property rights are defined.

In sum, two implications of these ideas emerge [Baumol et. al., 1989]: first, it means that those countries that lag somewhat behind the leaders, once they have reached a particular threshold level of development, can be expected systematically to move toward the level of achievement of the leaders. Second, the mechanism undermines itself automatically as follower countries gradually eliminate the difference between their own performance and that of the countries that were ahead of them.

4.2.2. The neoclassical approach

Neoclassical growth models have profoundly affected the way in which macroeconomists think of long-run interrelationships between economies. These models predict, based on the assumptions of decreasing returns to capital and free access by all countries to a common technology, on the one hand, that growth cannot be sustained permanently and, on the other hand, that countries converge to a steady state [De la Fuente, 1995a]. In the absence of technical progress,
decreasing returns imply that the marginal product of capital will fall with the accumulated capital stock, reducing both the incentive to save and the contribution of a given volume of investment to output growth. The same mechanism explains the convergence prediction: poorer countries will have a greater incentive to save and a higher rate of growth for a given rate of investment. It follows that if we have two identical economies in all respects, except of their initial capital stocks, the one with the lower capital stock will grow faster until the steady state output per capita levels of both countries have been equalized.

**Figure 4.1. : Absolute convergence**


This prediction will be reinforced by open-economy considerations, as labor flows and trade will both contribute to factor price equalization. Introducing technical progress does not change the qualitative results of the neoclassical model as long as one assumes that technology remains a public good such that economies do have access to common technical knowledge in the long-run³.

Suppose two countries that are characterized by equal consumption ratios, technology levels, labor force growth rates and capital depreciation rates [see Figure I]. Both countries are at a lower income level than in the steady state and will therefore experience a period of economic growth. Country P is poor and country R is rich, which means that the capital intensity and productivity are higher in the rich country than in the poor one, \( k_R > k_P \). Since the return of an additional unit of capital is negatively related to the stock of capital, the marginal
productivity of capital is higher in the poor country. This means that the capital intensity and production per capita grow faster there. This has been described as *absolute convergence* [Sala-i-Martin, 1990].

If the countries also differ in some other aspect, they will not move towards the same steady state [see Figure 2]. Assume, for example, that the poor country has a lower savings ratio, so that the steady state capital stock per capita is less in the poor country than it is in the rich country. In this example it is assumed that the rich country grows faster than the poor one so there is no convergence in the absolute sense. In contrast, each country is converging with a decreasing rate of growth in capital intensity and production per capita towards its own steady state, which means that the steady state production per capita, $y_1^*$, varies between countries. This has been described as *conditional convergence* [Sala-i-Martin, 1990; Mankiw et.al. 1992].

**Figure 4.2. : Conditional convergence**

![Figure 4.2. : Conditional convergence](image)


### 4.2.3. Endogenous growth

An important motivation for research on endogenous growth, noted by both Romer (1986) and Lucas (1988), is the apparent failure of traditional models to explain the persistence of income differences across countries. In these models, because of an assumed increasing marginal productivity of knowledge, both the growth rates and the per capita income level depend on the economy's initial
physical and/or human capital endowments, thus on history. The existence of a region of capital values over which the production function is convex leads to different long-run steady states for different initial conditions. Whereas early models are based on economies of scale as a mechanical instrument to obtain endogenous growth, Romer (1990) develops a model that relies on a combination of economies of scale and imperfect competition in which technological change arises when self-interested people have the opportunity to benefit from a monopoly rent. Technology is a non-rival input which is only partially excludable; its use by one firm explains knowledge spillovers and denies a constant returns to scale production function, since it is not necessary to replicate the non-rival inputs. The decentralized equilibrium is sub-optimal because of maximization of entrepreneurial benefits, which involve elements of imperfect competition. These endogenous growth models suggest, firstly, that social returns on R&D or education are larger than private returns. Thus, in the absence of a planner that closes the gap between social and private returns, a competitive equilibrium implies a sub-optimal accumulation of human capital and suggests a possible role for governments in subsidizing research, being effective in influencing the rate of growth of an economy in the long-run. Public intervention may thus in principle be used to coordinate domestic and international policies. Secondly, permanent differences in growth rates may arise as a result of differences across countries in economic policies, market size, or factor endowments. Thirdly, the existence of multiple long-run equilibria in the sense that the economies converge to different steady states (i.e. even for similar savings and population growth rates). The difference between these predictions and those of older models is not that significant, as has been emphasized by De la Fuente (1995b). In particular, neoclassical models suggest that income differences across countries will tend to disappear only under the assumption of identical economies except of the initial capital-labor ratio. In Solow's (1956) model, for example, long-run income levels are a function of investment rates and the rate of population growth, and may, therefore, differ across economies. Similarly, Abramovitz (1986) emphasizes social capability as condition for convergence. As has been emphasized by Barro and Sala-i-Martin (1992) and Mankiw et. al. (1992), and has been shown graphically before, traditional models only suggest convergence conditional on factors like investment rates, population growth rates or social capability, and are in this sense compatible with high and even rising international inequality. The lack of fundamental difference in their predictions makes it, however, difficult, if not impossible, to discriminate between the theories based on convergence.
In essence, the predictions of theoretical models concerning the prospects for income convergence across countries depend crucially on two assumptions [De la Fuente, 1995b]: the existence, or non-existence, of increasing returns to reproducible factors, including the stock of technological knowledge, and the degree to which useful knowledge is a public good across countries.

4.3. Convergence concepts

In this section, alternative convergence concepts are reviewed. First, I concentrate of formal, mathematical definitions of convergence and turn thereafter to empirical convergence concepts applied in the literature.

4.3.1. Definitions of convergence

Intuitively, convergence is given when the difference between two or more time series is reduced over time, or, more formally, becomes arbitrarily small as time elapses. For random series, such as most of economic variables, this can be extended by introducing the concept of stochastic convergence, according to which the expected value of the difference of two or more series should be constant, or, more strongly, zero [Bernard, 1991; Hall et.al, 1992]. Formally, we can express this by the relation:

\[ E_t \{ \lim_{t \to \infty} (X_t - \Psi Y_t) \} = \alpha \]

where \( X_t \) and \( Y_t \) are arbitrary time series. The probability that the two series differ by a specified amount \( \alpha \) is required to become arbitrarily small. However, if nonstationary time series are present, a drawback of this definition is that the two series may still behave quite differently even after convergence. An alternative, more restrictive definition of convergence is stated in terms of probability limits [Hall et.al., 1993]:

\[ p \lim_{t \to \infty} (X_t - \Psi Y_t) = \alpha \]

Two sufficient, but not necessary, conditions for this are

\[ \lim_{t \to \infty} E(X_t - \Psi Y_t) = 0 \]
and

\[(4.3b) \lim_{t \to \infty} \var(X_t - \Psi Y_t) = 0\]

This definition restricts asymptotically the ability of the series to move away from each other. Another definition that is sometimes appropriate, and on which some empirical work is focused, is conditional convergence. This would be useful as a predictive tool, i.e. when seeking an answer to the question whether, given existing information, future convergence is likely. The modified definition of convergence in probability is

\[(4.4a) \lim_{t \to \infty} E(X_t + z - \Psi Y_t + z - \alpha | \Omega) = 0\]

and

\[(4.4b) \lim_{t \to \infty} \var(X_t + z - \Psi Y_t + z - \alpha | \Omega) = 0\]

where $\Omega_t$ is the information set available at time $t$. Thus, most importantly, the formal definitions of convergence relate to the long-term reduction of differences of economic variables. In addition, they take into account of the randomness of time series.

### 4.3.2. Empirical concepts of convergence

The convergence hypothesis has recently been subject of growing research interest and has led to the development of a number of different empirical concepts. Several empirical concepts of convergence have received special attention recently. One concept, referred to as $\sigma$-convergence by Barro and Sala-i-Martin (1991, 1992), considers the cross-sectional dispersion in per capita earnings. $\sigma$-convergence occurs if the cross-sectional dispersion in per capita earnings, typically measured by either the standard deviation or the coefficient of variation, declines through time. It is, however, only a crude measure of dispersion, since the estimated variance of income across countries is influenced by shocks hitting the economy at any particular point in time. Hence, even if the economies were truly getting closer in the long-run, this statistic would have a lower bound by the variance of these shocks [Andrés et al.1995].

Another concept, used among others by Baumol (1986), DeLong (1988), Barro (1991) and Dowrick and Nguyen (1989), and referred to as absolute $\beta$-
convergence by Sala-i-Martin (1990), occurs when poor countries tend to grow faster than rich ones, such that poor countries catch up to rich ones in terms of the level of per capita output through time. The concept is generally implemented through a regression of the form

\[ \Delta y_t = \alpha + \beta y_0 + \nu \]

where \( \Delta y_t \) refers to an average growth rate. A negative coefficient of the initial level of per capita output is equated with convergence. In the long-run, expected per capita income is the same for all economies in the group, independently of its initial value. While this does not mean that inequality will disappear completely, for there will be random shocks with uneven effects on the different economies, such disturbances will only have transitory effects, implying that, in the long-run, we should observe a distribution in which the relative positions of the different countries change rapidly. Barro (1991), Barro and Sala-i-Martin (1992), and Mankiw et.al. (1992) emphasized, as noted before, that the neoclassical growth model implies only convergence after it has been controlled for differences in the economy's steady-states. They have called this concept conditional convergence, which is implemented through a regression of the form

\[ \Delta y_t = \alpha + \beta y_0 + \pi x_i + \nu \]

where the \( x_i \) refer to country-specific determinants of the steady state income per capita. Though the implementation of conditional convergence is similar to absolute \( \beta \)-convergence, its interpretation is fundamentally different. With conditional convergence, each country (may) converge to its own steady state, which could be very different from each other. Hence, a high degree of inequality among economies could persist, even in the long-run, and one could observe high persistence in the relative positions of the different economies. In other words, with conditional convergence, rich countries will tend to remain rich, and the poor will continue to lag behind.

The fourth concept is referred to as stochastic convergence [Carlino and Mills, 1993]. This line of empirical research, employed by Bernard (1991), Bernard and Durlauf (1995), and Jones (1995), relies on the time series properties of output series. Cross-country growth behavior is studied in the sense that convergence means that all per capita output discrepancies are transitory. Output in each country is realized to be subject to stochastic shocks, like technological or monetary disturbances, which render the level of output per
capita in each country nonstationary. Intuitively, cointegration is given if the
shocks affecting the individual countries have a common stochastic component,
so that the relative output series, $y_{it} - y_{jt}$, is stationary. In addition, economic
convergence requires that the difference between output in country $i$ and country
$j$, $y_{it} - y_{jt}$, becomes smaller over time. Formally, cointegration concepts assume
that the level of output per capita in each economy $i$ is integrated of order one,
thus, its growth rate follows a stationary stochastic process. Economic
convergence, in this interpretation, then implies that output differences between
countries $i$ and $j$, $y_{it} - y_{jt}$, obey a zero mean stationary stochastic process.

Recently, a method based on *income distribution dynamics* has become
increasingly popular in empirical research. As argued by Quah (1993 a,b),
analyzing an average or representative economy in a cross-section of economies
may give a misleading picture for the behavior of that entire cross-section. The
economic basis of the concept is that economies in an integrated world tend to be
increasingly interdependent units, which would make it necessary to drop the
neoclassical "representative economy" assumption [Quah, 1994b]. Therefore, he
proposes to study the probability distribution of transition over time. The
concept, in its discrete form, involves categorizing the sample of countries into
income classes and developing the law of motion for the probability distribution
of being in income class $i$ at time $t+k$ conditional on being in income class $j$ at
time $t$. Convergence can then be found in two ways: on the one hand,
convergence is given when the steady state probability distribution has a
unimodal shape. That is, intuitively, the probability for a country $i$ in the
distribution of ending up, in the long-run, at the mean income value should tend
to one. To calculate the long-run probability distribution requires that the
conditional probability is time invariant. Alternatively, by fixing the probability
vectors to be uniform and identical for every point in time, one can define a time-
variant grid (quantiles) and associated to that a sequence of fraction transition
probability matrices. The change in the grid describes the evolution of the cross-
section distribution for one period to the next one. Convergence is taking place
when the sequence of quantiles degenerates to the mean value of the distribution
[Andrés and Lamo, 1994].

### 4.4. Review of the empirical literature

In this section I discuss the empirical literature on growth and convergence\(^6\). I
will focus on a review without a critical evaluation, as it is the purpose of this
section to give an impression of the results obtained from similar analyses as the
subsequent one in the following sections. The section is structured based on the alternative empirical concepts of convergence discussed before. In sub-section one, I discuss some of the main contributions being motivated by the catching-up hypothesis. In sub-section two, empirical work using the concept of conditional convergence is reviewed. Sub-section three then contains empirical work on stochastic convergence, while sub-section four is related to empirical work on income distribution dynamics. In sub-section five I focus explicitly on empirical work using data from the EU.

4.4.1. Catching up and falling behind

The original empirical work on economic convergence is concerned about a negative relation between the average growth rate and its initial level and, thus, with unconditional convergence. Productivity growth rates are expected to be inversely related to their initial levels for three reasons: first, learning and imitating an existing technology should be easier than inventing and testing a new one. Second, countries with lower levels of industrialization may have greater returns relative to the most advanced economies in training labor and then reallocating it between agriculture and industry. Third, countries with lower levels of industrialization might have greater opportunities to exploit the possibilities of advanced scale-dependent technologies. An inverse relation between productivity growth rates and their initial levels is consistent with the neoclassical growth model, once you assume that all economies in the sample are structurally identical and differ only in their initial capital-labor ratios.

Abramovitz (1986) and Baumol (1986), using data compiled in Maddison (1982), support the convergence hypothesis for a set of sixteen presently industrialized countries over the time period 1870 - 1979. Abramovitz uses rank correlation coefficients and finds an inverse correlation between average productivity growth rates and their initial level, which confirms the potential to catch up for technologically backward countries. In addition, he finds that the estimated coefficient is higher, the longer the length of the sub-period under study, suggesting that the higher a country's productivity level in 1870, the more slowly that level grows in the following century. Baumol performs a regression of the average productivity growth rate and the initial level and obtains the following results:

$$\Delta \ln y_t = 5.25 - 0.75 \ln y_{1870} \quad R^2 = 0.88$$
He obtains a coefficient of determination, $R^2$, of 0.88, thus indicating that 88% of average growth is explained by the initial level. De Long (1988) criticizes the findings of Baumol on grounds of his results suffering from both sample selection bias and measurement error. That is to say, De Long argues that the results of Baumol do not provide conclusive information on convergence, because all countries are presently industrialized economies which have successfully performed during the 20th century. He argues that only a regression run on an ex-ante sample, a sample not of nations that have converged but of nations that seemed likely to converge, could tell whether growth since 1870 exhibits convergence. Based on this kind of reasoning, he then constructs and analyzes an alternative sample, excluding Japan and adding data for Argentina, Chile, East Germany, Ireland, New Zealand, Portugal and Spain, which represents more accurately a sample of ex-ante probable "winners". De Long performs a similar regression as Baumol, allowing, however, for measurement errors, and rejects convergence in the central case, when the variance of the unobservable measurement error equals the error term in the regression. He concludes that evidence in favor of convergence is no greater than evidence against it. Baumol and Wolff (1988), in reply to the comment by De Long, contribute to the discussion by examining additional data sets and by using additional methods for analyzing convergence. Firstly, the authors use a data set of 19 European countries over the period 1830 - 1919. The authors rank the countries in descending order of GNP per capita in 1870, successively construct samples consisting of the top 8, top 9, top 10,..., top 14 countries, and plot the corresponding time-series of the coefficients of variation. They find that only the top-8-country-sample support the convergence hypothesis, whereas all the other groups consisting of larger samples display a widening of income dispersion over time, thus indicating economic divergence. Secondly, Baumol and Wolff analyze post-World War II growth performance for 72 countries. Applying a similar ranking procedure as before, they find that per capita incomes among ex ante selected LDC's had diverged while the opposite had been true among initially industrialized countries. They supplement and confirm these initial results by formal nonlinear and piecewise linear regressions and conclude that there is evidence in favor of "convergence clubs". The richest 15 countries are described unambiguously by economic convergence, a result that holds also for larger sets of countries, once LDC's are excluded. However, for larger samples including LDC's cross-country differences are persistent, with little indication for convergence. Dowrick and Nguyen (1989), using the data set by Summers and Heston (1988), extensively tested the convergence hypothesis among 24 OECD countries...
countries in the post-World War II period. First, coefficients of variation and standard deviations of log output are calculated, supporting the convergence hypothesis as they both decline continuously from 1950 to 1985. Nonparametric tests show that the poorer half of the sample has grown faster than the richer over the entire period and over three sub periods (1950-60, 1960-1973, 1973-1985). Second, a regression analysis of average growth rates of output per capita on the initial real GDP per capita is performed, indicating a negative sign of the coefficient and reaching an $R^2$ of over 0.50. As in previous papers, the negative sign is interpreted as support for the convergence hypothesis, since countries with initially lower incomes tend to grow faster than initially rich countries. Dowrick and Gemmel (1991) extend the previous analysis to include 78 countries across the world. They analyze four alternative explanations for the existence of convergence clubs within a growth-accounting framework: technological spillovers, intersectoral disequilibrium in factor markets, sectoral differences in technical progress, and capital deepening. They find that, whereas agricultural productivity levels of poor countries relative to rich countries are catching-up, industrial productivity levels are diverging both within a group of poor countries and relative to the group of rich countries. The authors conclude that, for the industrial productivity sector, technological spillovers assist productivity growth in countries at a medium level of development, but are unavailable to the least developed countries. They interpret their results as being indicative for a structural poverty threshold in world development. Hansson and Henrekson (1994a,b) analyze technological catch-up within a disaggregated study for 14 OECD countries. They derive a testable model and find that after 1970 there is no catching up effect in the tradables sector, while catching up is found for industries in the nontradables sector.

These papers do not provide an unambiguous picture as to whether the world is described by economic convergence or divergence. However, they suggest three things: first, among the richest countries, a catch-up process is to be observed. Second, the world's poorest countries do not seem to catch up. Relative differences to the rich economies do persist, or possibly, they even increase over time. And third, they suggest what Baumol et.al.(1989) call "convergence clubs", that is, within a specific group of countries convergence is to be observed, whereas across groups income differences do persist.
4.4.2. Conditional convergence

As is the catching-up literature, the empirical work on conditional convergence is concerned with the relation between the average growth rate and its initial income. However, the interpretation is strikingly different. Whereas the literature on catching-up expects an inverse relation between the average growth rate and its initial level, because of factors like imitation and learning, returns from training, or opportunities of exploiting scale economies for backward countries, within the neoclassical framework, initial income per capita provides a measure of how far removed each country is from its specific steady state value.

The origin of the empirical literature on conditional convergence is the work by Romer (1987a). He uses a conditional convergence regression of the form as in (8) with the investment rate as conditioning variable. His results are presented in Table 1.

Romer finds a negative coefficient of initial income. There are two additional striking aspects of his results: first, he obtains a positive effect of the investment rate on the average growth rate in all regressions. Second, the capital's share coefficients are very high. In the third regression the capital share is estimated to be 74%.

<table>
<thead>
<tr>
<th>Table 4.1: Conditional convergence regression</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Table with data]</td>
</tr>
</tbody>
</table>

Source: Romer (1987a) [Table 4]

This stands in contrast to the predictions of the neoclassical growth model, according to which the estimate of \( a \) should be on the order of 0.25 to 0.33. These results have received special attention [Romer, 1994]. On the one hand, they indicate that the capital's factor share is higher than previously perceived to be and that diminishing returns to capital are setting in more slowly than previous estimates suggested. On the other hand, they may be interpreted in a way that convergence would have taken place if the investment rate had been held constant, or, more generally, if other variables had been held constant. Barro (1991) extends this latter line of reasoning, analyzing average growth rates for a set of 98 countries in the period 1960 - 1985. He tests whether the average...
growth rate across economies is inversely related to the initial level of per capita GDP, which he interprets, as usual, as indicator for economic convergence. At first, without additional explanatory variables he finds no significant relationship between the initial level of GDP per capita and its average growth rate. However, as in the work by Romer, Barro obtains an inverse relationship by adding additional explanatory variables in the regression. First, he adds school-enrollment observed at the beginning of the period, as a proxy for human capital, then he adds fertility and investment and obtains, in each case, an inverse relation between the average growth rate and its initial level.

Table 4.2.: Estimated rates of convergence. Regions in a country

<table>
<thead>
<tr>
<th>Author</th>
<th>Sample</th>
<th>Rate of convergence (in % p.a.)</th>
<th>Additional Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barro and Sala-i-Martin (1993)</td>
<td>47 Japanese prefectures 1930 - 1987</td>
<td>2.3</td>
<td>- regional dummies</td>
</tr>
<tr>
<td>Barro and Sala-i-Martin (1992)</td>
<td>48 U.S. States 1880 - 1988</td>
<td>1.8</td>
<td>- regional dummies</td>
</tr>
<tr>
<td>Coulombe and Lee (1993)</td>
<td>10 Provinces in Canada 1960 - 1991</td>
<td>1.05</td>
<td>no</td>
</tr>
<tr>
<td>Dolado et.al. (1995)</td>
<td>50 regions in Spain 1955 - 1989</td>
<td>1.81</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- savings rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- public investment</td>
</tr>
<tr>
<td>Herz and Röger (1995)</td>
<td>75 regions in West Germany 1955 - 1988</td>
<td>4.4</td>
<td>- schooling</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- regional dummies</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>variables</td>
</tr>
<tr>
<td>Keller (1995)</td>
<td>26 regions in Germany (East and West) 1955 - 1988</td>
<td>2.11</td>
<td>- fixed effects</td>
</tr>
</tbody>
</table>

Source: Own compilation.

Mankiw et. al. (1992) construct a human capital augmented version of the Solow model and test for convergence, using data for 98 countries over 1960 - 1985. Unconditional convergence, i.e. without conditioning on determinants of the steady state, is rejected. Then, by conditioning for the rates of investment or alternatively of saving, population growth and human capital, a significant
inverse relation between the average growth rate and the initial level - conditional convergence - is found. In contrast to other similar studies, however, the conditioning variables are derived from their augmented Solow-model. Barro and Sala-i-Martin (1992) analyze convergence across 48 U.S. States using both personal income data for the period 1840 - 1988 and gross state product data between 1963 and 1988. The authors use a regression of a form like equation (4), which they derive from a neoclassical growth model and which is estimated using nonlinear least squares. Initially, additional explanatory variables are excluded, so that the regression is an estimation of the average growth rate of the 48 states on their initial average level in 1840. They estimate the equation over sub-periods and over the whole period and obtain, in general, a significant inverse relation, thus convergence. However, tests for parameter stability of \( \beta \) indicate unstable coefficients, which lead the authors to include an additional explanatory variable, viz. a sectoral decomposition variable.

Table 4.3: Estimated rates of convergence. Multi-country analyses

<table>
<thead>
<tr>
<th>Author</th>
<th>Sample</th>
<th>Rate of convergence (in % p.a.)</th>
<th>Additional Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barro (1991)</td>
<td>98 countries</td>
<td>1.84</td>
<td>- enrollment rate</td>
</tr>
<tr>
<td></td>
<td>1960 - 1985</td>
<td></td>
<td>- fertility rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- investment rate</td>
</tr>
<tr>
<td>Islam (1995)</td>
<td>96 countries</td>
<td>3.75</td>
<td>- investment rate</td>
</tr>
<tr>
<td></td>
<td>1960 - 1985</td>
<td></td>
<td>- enrollment rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- fixed effects</td>
</tr>
<tr>
<td>Knight et.al. (1993)</td>
<td>98 countries</td>
<td>3.91</td>
<td>- investment rate</td>
</tr>
<tr>
<td></td>
<td>1960 - 1985</td>
<td></td>
<td>- enrollment rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- fixed effects</td>
</tr>
<tr>
<td>Mankiw et. al. (1992)</td>
<td>98 countries</td>
<td>1.37</td>
<td>- investment rate</td>
</tr>
<tr>
<td></td>
<td>1960 - 1985</td>
<td></td>
<td>- enrollment rate</td>
</tr>
<tr>
<td>Sala-i-Martin (1995)</td>
<td>110 countries</td>
<td>1.3</td>
<td>- enrollment rates</td>
</tr>
<tr>
<td></td>
<td>1960 - 1990</td>
<td></td>
<td>- savings rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- political variables</td>
</tr>
<tr>
<td>Wolf (1994)</td>
<td>98 countries</td>
<td>0.9</td>
<td>- investment rate</td>
</tr>
<tr>
<td></td>
<td>1960 - 1985</td>
<td></td>
<td>- labor growth rate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- mortality</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- revolutions &amp; coups</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- continent dummies</td>
</tr>
</tbody>
</table>

Source: Own compilation.
The authors argue that the unstable pattern of the $\beta$ coefficients across subperiods reflect aggregate disturbances that have differential effects on state incomes. Adding the sectoral decomposition variable, they are indeed able to accept the hypothesis of parameter stability across sub-periods. The authors obtain a coefficient $\beta = -2.49\%$ for the period 1840 - 1988 which suggests that the time needed to eliminate half of an initial gap between the states is about 35 years. Barro and Sala-i-Martin (1993) apply a similar framework to Japanese prefectures and obtain similar rates of convergence.

Subsequently, conditional convergence regressions have been applied by several authors for different data sets. Table 4.2. summarizes recent estimates of the convergence coefficient obtained by various other studies using data from regions within one country. Table 4.3. summarizes estimates using data from multi-country regressions. In these tables papers published after 1991 are summarized. In general, conditional convergence is found by empirical studies. Convergence rates for regions within a single country tend to be slightly higher, due probably to increased factor mobility on regional levels, than those obtained in cross-country studies.

4.4.3. Stochastic and local convergence

One way to interpret the implications of endogenous growth theories is in terms of multiple equilibria. Indeed, even if a set of control variables, meant to control for microeconomic heterogeneity, seems to support the convergence hypothesis, this may be in line with the existence of stable multiple equilibria in long-run output per capita. That is to say, differences in aggregate production functions and, correspondingly, technology may lead economies to converge to different steady states in output per capita. Durlauf and Johnson (1992) labeled this "local convergence", which, as they show, is consistent with several theories of endogenous growth and which stands in contrast to Solow-kind "global convergence", where all countries converge to the same steady state. They test the local convergence proposition for 98 countries over 1960 - 1985, the same data set that had been used by Mankiw et.al. (1992). First, based on the same convergence equation as in Mankiw et.al (1992), the authors use misspecification tests to test the hypothesis that the data can be described by a single production technology. They split the data set ad hoc into sub-groups, taking literacy rates and initial income levels as splitting criteria, and reject the null hypothesis of equal production technologies, which indicates local convergence. In a second step, the authors use regression trees, a nonparametric method, to split the overall
sample endogenously into sub-groups. They test for differences in technology and find evidence in favor of the local convergence proposition. In addition, the authors find that the speed of convergence in the sub-samples is faster than in the overall sample. They interpret their results as being in favor of Baumol's (1986) convergence clubs. Andrés and Boscá (1993) subsequently test the local convergence proposition for 24 OECD countries, using data from the OECD National Accounts for the period 1960 - 1991. The authors use an alternative sample-splitting method, which is directed towards revealing differences in initial conditions. They test sequentially, removing a priori reasonable countries at a time, for significant individual differences in the initial level of technology. They obtain three technological levels, which they label lagged, intermediate, and leading. They find that the rate of convergence in the sub-samples is greater than in the overall sample, with the rate of convergence among advanced economies being twice as large as that among the backwards ones. Tests for common technology point to the presence of two different technologies inside the OECD, thus confirming the local convergence proposition. Ben-David (1993, 1994, 1995) uses an alternative framework in his paper. He analyzes how the empirical convergence results change, on the one hand, with variations in the convergence group membership i.e. the relative wealth of the countries in the group and, on the other hand, with variations in the convergence group size. He analyzes data by Summers and Heston (1988) for 113 market economies between 1960 and 1985. Ben-David tests for convergence by pooling each country's annual discrepancy from the group average and estimating the following equation:

\[(4.7) \quad (y_{it} - y_t) = \phi (y_{i,t-1} - y_{t-1})\]

where \(y_{it}\) is country i's GDP per capita at time t and \(y_t\) is the group average at time t. The author interprets \(\phi\) as an indicator for economic convergence. A value of \(\phi\) below 1 is supposed to indicate convergence and a value greater than 1 economic divergence. He ranks the countries with respect to income per capita, divides the total sample into different groups, with the number of groups ranging between 1 and 8, and runs equation (7) for each group. He finds that the wealthiest countries converge upwards and poorest countries downwards, thus that rich countries are getting richer and poor countries poorer. He shows that this result is robust for variations in group size and for other partitions of the world. Bernard and Durlauf (1995) test convergence in a stochastic growth framework, using data from 15 industrialized countries over the period 1900 to 1987. The authors apply cointegration concepts, i.e. convergence requires that
the permanent components of output per capita are the same across countries. The authors tend to accept the hypothesis of no convergence. They conclude that per capita output differences appear to persist over time. Carlino and Mills (1993) study convergence of per capita income and per capita earnings in the regions of the U.S for the period 1929 - 1990, applying the stochastic convergence concept. After allowing for a break in 1946, they find evidence in favor of the neoclassical model's prediction of convergence. They find that shocks to per capita earnings are more persistent than shocks to per capita income, which leads the authors to conclude that the regional distribution of transfer payments tends to smooth the effects of deviations on relative regional per capita earnings and to reinforce trends in per capita income convergence. Crafts and Mills (1995) analyze stochastic growth in output per capita in 17 OECD countries from the late nineteenth century to 1989. They find that output per capita behavior in all countries is subject to structural breaks. The period 1951 to 1973 is argued to be an epoch of exceptionally rapid economic growth in Western Europe, due to catch-up and reconstruction.

4.4.4. Income distribution dynamics

Quah (1993 a,b) is directed towards focusing on the long-run distribution of incomes over time. The author analyzes the distribution of incomes across countries, using the Summers and Heston (1988) data set for 115 market economies. Quah discretizes the set of possible values of income relative to the world average at time t into intervals at $1/4$, $1/2$, 1, and 2 and estimates the probability that an economy at time t in one of these intervals remains or transits to another state. For the 23-year transition from 1962 to 1985, he obtains a probability of the richest countries to remain richest of 95%. In contrast, the probability of the poorest countries to remain poorest is 76%, both entries being by far the greatest in the transition matrix. His results suggest economic divergence, the world becomes partitioned into rich countries, whose share in total world income increase, and poor countries, whose share decrease further. Desdoigts (1994) extends the analysis of the world income distribution in various ways. First he confirms Quah's results of the distribution of income in the world becoming more unequal over time. He finds that, while the density estimate of income per capita and income per worker initially, in 1960, exhibits an unimodal structure, after 25 years, it exhibits a fourth or fifth modes structure. He interprets this evidence in terms of local convergence. In addition, applying non-parametric smoothing techniques, he analyzes the relation of income and various
variables of interest, viz. investment, public consumption, private consumption, and education. He finds that human capital accumulation functions as a main source of economic growth, in line with recent theoretical suggestions. The mean response of growth rates is strong for low investment shares, flattens, however, out among the highest shares of income devoted to investment. Quah (1994c) performs an analysis of the distribution of income for the US States, using data from 1948 - 1989. Here, intra-distributional mobility turns out to be high. Convergence is uniform towards a long-run distribution with only a single peak. Andrés and Lamo (1994) study cross-section growth dynamics of 24 OECD countries. Using raw data, i.e. income per capita relative to the mean value, they find polarization in the growth process. The results show a bimodal distribution of income per capita across OECD economies. In a second step, in order to make their analysis comparable to conventional parametric regressions, they examine the distributional dynamics of the residuals from a conditioning regression. The authors condition on accumulation rates of physical capital and population. At first, they impose a common technology restriction across countries on the conditioning regression. Most interestingly, and quite surprisingly, the estimated density functions of the residuals do still evolve into a bimodal distribution. There is little change in the results after conditioning on physical capital and population. The authors interpret these results as evidence against conditional convergence. The authors repeat the analysis, following Durlauf and Johnson (1992), by allowing for time-invariant and country-specific effects. Here the results show higher intra-distributional mobility; the estimated density function evolves into a uniform distribution. However, only after relaxing the main assumptions of conventional cross-section regressions, evidence in favor of convergence is found. This line of literature indicates not only that the distribution of income in the world becomes more unequal over time, but even within industrialized countries with similar economic structures income differences seem to persist. The results are in line with Baumol’s suggestion of existing convergence clubs.

Overall, the empirical evidence with respect to the evolution of the world distribution of income, or, in other words, with respect to convergence in the world economy, is mixed. However, there exists a broad consensus in the more recent literature suggesting an absence of convergence to a single steady state [Ben-David, 1994]. The absence of convergence to a single steady state may be explained either in the neoclassical tradition in terms of conditional convergence, that is, the rate of growth falls as the economy approaches its own long-run level, or in terms of local convergence and multiple equilibria.
4.4.5. Growth and convergence across Europe

In this sub-section I review contributions made within the context of growth and convergence using data from the European Union. Barro and Sala-i-Martin (1991) analyze 73 regions of 7 European countries, using data from 1950 - 1985. They start from the basic regression of the average growth rate on its initial level, dividing the total time period into sub-periods, and testing for parameter stability. As parameter stability is rejected using the basic regression, they continue to include regional dummies. The authors interpret regional dummies as proxies for country specific steady state values and for countrywide effects in the error term. They proceed by adding shares of agriculture and industry in total employment and find that the average growth rate is inversely related to the initial level, indicating convergence, with the coefficient $b$ being stable over all sub-periods. The value of $b$ for all sub-periods is around 2% per year. Subsequently, the authors turn to the behavior of the standard deviation of log output per capita over time ($\sigma$-convergence). They find that the dispersion of income has declined continuously, falling from 28% in 1950 to 18% in 1985. Neven and Gouyette (1995) apply three methods to analyze economic convergence in a sample of up to 142 European regions for the period 1975 - 1990. First, they analyze $\sigma$-convergence, the behavior of the standard deviation of log income per capita over time. They assess convergence for the total sample of regions and for sub-samples, namely North- and South-European regions. The results are weakly in favor of a reduction of income dispersion. Second, the authors turn to analyze unconditional and conditional convergence. They find that there is no evidence for convergence, when country effects are not controlled for. The authors proceed, following Barro and Sala-i-Martin (1991, 1992), by including a sectoral composition variable, which measures the extent to which output was distributed in the initial period in growing sectors, and human capital. Testing for parameter stability over sub-periods, the authors find that the process of convergence is not stable, and that it slows down in the later part of the 1980s. Third, they use a markov chains approach to analyze the distribution of income over time in Europe. They find evidence in favor of a limited poverty trap; poorest and richest countries do not seem to modify their relative standing over time. The authors conclude that southern regions seem to catch up in the early 1980s but stagnate thereafter, while northern regions first stagnate and then converge towards the steady state. Pagano (1995) analyzes convergence of member states of the EC using cross-country data for the period 1950 to 1988. Using a cross-section approach he finds that since 1950 there has been Total Factor Productivity (TFP)
catching-up. However, he finds that the process was far from being stable, as the rate of convergence reached its peak during the 1960's but dropped virtually to zero during the 1980's. He continued using the stochastic convergence framework and strongly rejects the hypothesis of convergence in this dynamic framework. Grahl and Simms (1994) analyze regional data of the EC for the period from 1960 to 1990. While they find evidence in favor of conditional and unconditional convergence for the whole period, they note that in the second half of the three decades, thus from 1975 to 1990, the convergence coefficients are always less than half their value for the period 1960 - 1975. Thus, the convergence process has slowed down in recent years. Thomas (1995) examines 12 countries and 166 regions of Europe over the period 1975 - 1991. First, following Barro and Sala-i-Martin (1991, 1992), he tests for unconditional and conditional convergence. The author finds both unconditional and conditional convergence both on country and regional level. Conditioning on country-dummies and club-dummies, for example, he obtains a rate of convergence of 2.5% on regional level for 1981 - 1991. Subsequently, the author looks at the behavior of coefficients of variation of output per capita over time, which confirms his convergence findings. The variation of output per capita both across countries and regions in Europe falls within the 80s. Armstrong (1995) tests for conditional convergence using data of 85 regions in 12 European countries (1950-1990). He finds that EU regions exhibit a clear pattern of convergence. The rate of convergence, however, has slowed down in the past 20 years. Whereas between 1950 and 1970 the rate of convergence is about 2%, being in line with the results by Barro and Sala-i-Martin (1991), for the period 1970 to 1990 a rate of convergence of only 1% per year is found. Button and Pentecoast (1995) analyze the impact of the membership in the Exchange Rate Mechanism (ERM) on convergence, using data from 51 regions in 9 countries. They find that membership assisted GDP convergence in the 1980's. Larch (1994) studies cross-section growth dynamics of 107 regions in 9 European countries over the period 1970 - 1990. He estimates transition probabilities, grouping the spectrum of relative output per capita levels into three and five states. In both cases, he finds that the probability to retain in the initial position is high. Whereas intra-distributional mobility is high for middle-income countries, both towards the upper and lower end of the distribution, the probability for high income countries to descent is relatively low. The author tests and finds that the transition behavior has changed in the 80s compared to the 70s. In the 70s the low output regions moved comparatively fast, attaining a better possibility to improve in relative output terms. The very rich regions, on the other hand, moved slowly maintaining
their position for an extended period of time. In the 1980s transitions occur less frequently, especially at the lower end of the distribution, leading to a higher degree of persistence. Higher persistence, however, implies that the position of the rich countries is enforced and that the poor countries tended to be stuck in their positions.

Table 4.4. summarizes regression results obtained for data for the European Union being based on the concept of conditional convergence.

**Table 4.4.: Estimated rates of convergence. Regions in EU**

<table>
<thead>
<tr>
<th>Author</th>
<th>Sample</th>
<th>Rate of convergence (in % p.a.)</th>
<th>Additional Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barro and Sala-i Martin (1991)</td>
<td>73 regions in 7 countries</td>
<td>1.78</td>
<td>- country dummies - structural variable</td>
</tr>
<tr>
<td>Button and Pentecoast (1995)</td>
<td>51 regions in 9 countries</td>
<td>1.7</td>
<td>- ERM dummy - structural variable - country dummies</td>
</tr>
<tr>
<td>Grahl and Simms (1994)</td>
<td>51 regions 1960 - 1990</td>
<td>2.52</td>
<td>- country dummies</td>
</tr>
<tr>
<td>Thomas (1995)</td>
<td>166 regions in 12 countries 1981 - 1991</td>
<td>2.5</td>
<td>- country dummies - club dummies</td>
</tr>
</tbody>
</table>

Source: Own compilation.

As can be seen, the rates of convergence are within a similar range as with other data sets, although the speed is slightly higher than in multi-country regressions using world economic data. In sum, empirical studies for Europe tend to support the convergence hypothesis. At the same time, however, the existing evidence indicates that the convergence process has not been stable, neither across time nor across countries. In recent years, convergence seems to have slowed down and may have become reversed.
4.5. On stability of growth and convergence in the European Union

In this section, descriptive statistical methods are used to analyze the convergence process. The purpose of this analysis is to underline the argument that convergence has not been stable, neither across time nor across countries. In doing so, as for the controversy on the right measure of convergence, a number of alternative concepts are applied. In order to compare the performance of both measures, income per capita and labor productivity are used. The main data source is the Penn World Table 5.6., an updated version of Summers and Heston (1991). Output per capita data [RGDPCH] and Investment rates [I] cover the period 1950 - 1992 while output per worker data cover the period 1950 to 1990. Data used as proxy for human capital accumulation comes from the World Tables and the World Development Report, various issues. Secondary and tertiary school enrollment rates are available for the period 1960 to 1991, in general with a five-year frequency. Azariadis and Drazen (1990) provide data on literacy rates and output-to-literacy ratios, which are their proxies for human capital accumulation, for 1940 and 1960. Data for 10 EU-countries are provided in their Table II. Assuming that enrollment rates behave proportionally to output-to-literacy ratios, I constructed enrollment rates for 1950 and 1955 for those countries. For the remaining countries, the values assigned to the missing observations is the average of the values for adjacent years or, if this is not possible, that of the closest available year.

4.5.1. Stylized facts

In Table 5 basic information on growth rates in per capita (per worker) output is presented. The average growth rate of GDP per capita (per worker) between 1950 and 1990 was 3.18 (3.16) for the European Union. The rate of growth has slowed down considerably in recent years. Whereas the average growth rate of GDP per capita (per worker) was 4.02 (4.29) during the period 1950 - 1973, it was only 2.06 (1.63) during the 1973 - 1990 period, thus being reduced by about 50%. The steady economic growth in terms of GDP per capita (per worker) is based, on the one hand, on low population growth (0.57% p.a.) and, on the other one, on high investment rates. Interestingly, the average investment rate has remained basically unchanged in both sub-periods. Average growth has been far from homogeneous. Differences in accumulation rates explain part but not the whole of the heterogeneity in average growth. Some countries' relative success can be explained by relatively high savings rates; this
Table 4.5: Stylized facts on growth and convergence in the European Union

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>3.67</td>
<td>3.79</td>
<td>0.27</td>
<td>4.72</td>
<td>5.40</td>
<td>2.24</td>
<td>1.61</td>
<td>25.90</td>
<td>23.45</td>
<td>25.76</td>
<td>66.78</td>
<td>15.19</td>
</tr>
<tr>
<td>Belgium</td>
<td>2.73</td>
<td>2.66</td>
<td>0.36</td>
<td>3.31</td>
<td>3.56</td>
<td>1.96</td>
<td>1.45</td>
<td>22.50</td>
<td>24.05</td>
<td>22.39</td>
<td>74.31</td>
<td>11.62</td>
</tr>
<tr>
<td>Denmark</td>
<td>2.43</td>
<td>2.09</td>
<td>0.46</td>
<td>3.05</td>
<td>2.96</td>
<td>1.59</td>
<td>0.91</td>
<td>24.20</td>
<td>25.18</td>
<td>23.85</td>
<td>79.32</td>
<td>18.43</td>
</tr>
<tr>
<td>Finland</td>
<td>3.47</td>
<td>3.41</td>
<td>0.55</td>
<td>4.24</td>
<td>4.39</td>
<td>2.43</td>
<td>2.07</td>
<td>33.32</td>
<td>35.23</td>
<td>33.22</td>
<td>84.78</td>
<td>13.86</td>
</tr>
<tr>
<td>France</td>
<td>3.09</td>
<td>3.10</td>
<td>0.77</td>
<td>4.07</td>
<td>4.38</td>
<td>1.76</td>
<td>1.38</td>
<td>26.77</td>
<td>25.50</td>
<td>26.56</td>
<td>67.89</td>
<td>15.85</td>
</tr>
<tr>
<td>Germany</td>
<td>3.58</td>
<td>3.48</td>
<td>0.59</td>
<td>4.80</td>
<td>5.14</td>
<td>1.94</td>
<td>1.23</td>
<td>25.86</td>
<td>30.16</td>
<td>25.58</td>
<td>59.08</td>
<td>15.22</td>
</tr>
<tr>
<td>Greece</td>
<td>3.92</td>
<td>4.09</td>
<td>0.73</td>
<td>5.68</td>
<td>5.93</td>
<td>1.54</td>
<td>1.60</td>
<td>23.61</td>
<td>22.32</td>
<td>23.21</td>
<td>60.72</td>
<td>13.01</td>
</tr>
<tr>
<td>Italy</td>
<td>3.06</td>
<td>3.34</td>
<td>0.41</td>
<td>3.12</td>
<td>3.71</td>
<td>2.97</td>
<td>2.85</td>
<td>25.68</td>
<td>21.37</td>
<td>25.53</td>
<td>65.05</td>
<td>14.67</td>
</tr>
<tr>
<td>Ireland</td>
<td>3.79</td>
<td>3.97</td>
<td>0.52</td>
<td>4.80</td>
<td>5.30</td>
<td>2.42</td>
<td>2.18</td>
<td>25.53</td>
<td>30.23</td>
<td>25.36</td>
<td>53.50</td>
<td>13.19</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>2.28</td>
<td>2.46</td>
<td>0.64</td>
<td>2.35</td>
<td>3.03</td>
<td>2.19</td>
<td>1.69</td>
<td>26.86</td>
<td>36.37</td>
<td>26.52</td>
<td>50.11</td>
<td>10.04</td>
</tr>
<tr>
<td>Netherlands</td>
<td>2.64</td>
<td>2.52</td>
<td>0.98</td>
<td>3.47</td>
<td>3.78</td>
<td>1.52</td>
<td>0.80</td>
<td>22.57</td>
<td>25.95</td>
<td>22.33</td>
<td>72.85</td>
<td>14.03</td>
</tr>
<tr>
<td>Portugal</td>
<td>4.56</td>
<td>4.34</td>
<td>0.40</td>
<td>5.68</td>
<td>5.73</td>
<td>3.04</td>
<td>2.46</td>
<td>22.17</td>
<td>21.40</td>
<td>21.83</td>
<td>46.44</td>
<td>14.94</td>
</tr>
<tr>
<td>Spain</td>
<td>4.03</td>
<td>4.16</td>
<td>0.84</td>
<td>5.60</td>
<td>5.99</td>
<td>1.90</td>
<td>1.69</td>
<td>25.23</td>
<td>23.14</td>
<td>25.08</td>
<td>57.30</td>
<td>10.32</td>
</tr>
<tr>
<td>Sweden</td>
<td>2.33</td>
<td>1.91</td>
<td>0.50</td>
<td>2.92</td>
<td>2.57</td>
<td>1.54</td>
<td>1.00</td>
<td>22.12</td>
<td>23.75</td>
<td>21.98</td>
<td>69.35</td>
<td>20.05</td>
</tr>
<tr>
<td>UK</td>
<td>2.24</td>
<td>2.08</td>
<td>0.32</td>
<td>2.51</td>
<td>2.48</td>
<td>1.88</td>
<td>1.53</td>
<td>17.76</td>
<td>16.71</td>
<td>17.72</td>
<td>70.82</td>
<td>19.68</td>
</tr>
<tr>
<td>EU-15</td>
<td>3.18</td>
<td>3.16</td>
<td>0.57</td>
<td>4.02</td>
<td>4.29</td>
<td>2.06</td>
<td>1.63</td>
<td>25.26</td>
<td>26.11</td>
<td>25.07</td>
<td>65.22</td>
<td>14.67</td>
</tr>
</tbody>
</table>

Source: Own calculations.
is the case for Finland (3.47 and 33.32) among the fast growers and the United Kingdom (2.24 and 17.76) among the slow growers. Variations in enrollment rates are even sharper and at first glance its correlation with growth rates is less clear; Denmark, for example, with a very high enrollment rate has grown less than countries with much less human capital investment (Portugal or Italy).

4.5.2. The stability of relative output

Following Blanchard and Katz (1992), Ben-David (1994), and Neven and Gouyette (1995), I characterize the stochastic behavior of GDP per capita (per worker) in country i relative to the EU average.

Table 4.6.: Estimates of relative output per capita (per worker)

<table>
<thead>
<tr>
<th>Coefficient</th>
<th>Output per worker</th>
<th>Output per capita</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AR(1)</td>
<td>AR(2)</td>
</tr>
<tr>
<td>$\gamma_1$</td>
<td>0.974</td>
<td>1.199</td>
</tr>
<tr>
<td>$\gamma_2$</td>
<td>-0.218</td>
<td>-0.216</td>
</tr>
<tr>
<td>Unit root test</td>
<td>-7.549**b)</td>
<td>-5.4**</td>
</tr>
<tr>
<td>Impulse responses</td>
<td>t = 1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.974</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.948</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.924</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>0.900</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.789</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>0.607</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>0.467</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>0.213</td>
</tr>
</tbody>
</table>

a) * indicates significance at 5 per cent level; ** indicates significance at 1 per cent level. Critical values -2.12 and -3.19, respectively, taken from Quah (1994b) for (N,T) = (25,50)

b) * indicates significance at 5 per cent level; ** indicates significance at 1 per cent level. Critical values -2.14 and -3.13, taken from Quah (1994b) for (N,T) = (25,25)

c) The regression results are based on the regressions:

AR(1): $y_t = \gamma_1 y_{t-1} + \epsilon_t$

AR(2): $y_t = \gamma_1 y_{t-1} + \gamma_2 y_{t-2} + \epsilon_t$

where $y_t$ denotes GDP per capita (per worker) in country i relative to the EU average.

d) The unit-root test involves the null hypothesis that ($\gamma_1 - 1$) equals zero. The values for ($\gamma - 1$) are obtained from a regression in differenced form.

Source: Own calculations.
Pooling the data, I apply an autoregressive model and test for stationarity of relative output. The number of lags in the regressions is assumed to be either one or two. The results of the unit-root tests and the corresponding impulse response values are given in Table 6. The estimates suggest that relative output per capita (per worker) in the EU are characterized by mean reversion, so that they return to their mean after a shock, but they do so only at a slow rate. In the EU, relative output per worker is observed to adjust more quickly than output per capita. Whereas, after 30 years, 54 per cent of a shock to relative output per worker has been absorbed, the corresponding percentage of relative output per capita is only 47%. These patterns can be compared to those observed in the US and in disaggregated regional data of Europe. Blanchard and Katz (1992) report that 43 per cent of the shock is absorbed after 10 years and about 80 per cent after 20 years. Neven and Gouyette (1995), analyzing 107 EC-Nuts II regions, find that after 30 years, only 25 per cent of a shock has been absorbed. Thus, whereas the process of mean reversion across European countries seems to be much slower than across regions of the United States, it is faster than on the regional level in Europe.

**4.5.3. σ-convergence**

![Fig. 4.3.: Sigma-convergence of output per capita and labor productivity](image)

Source: Own calculations.
σ-convergence considers the cross-sectional dispersion in per capita earnings [Barro and Sala-i-Martin 1991, 1992].

σ-convergence occurs if the cross-sectional dispersion in per capita earnings, typically measured by either the standard deviation or the coefficient of variation, declines through time. The evolution of the standard deviation of (the log of) output per capita and productivity in the EU is displayed in Figure 3. σ-convergence in the EU in terms of output per capita has been less remarkable than in terms of labor productivity. This is due to relatively slower convergence in the demographic structure and in participation rates than in terms of employment. This point can be seen differently, and more clearly, by looking at employment rates.

The employment rate is defined as employment over population, hence its variance reflects the impact of both participation and unemployment rates. In Figure 4, the evolution over time of the employment rate in the EU is displayed. This statistic displays a smooth and rising trend until the beginning of the 1980’s and a sharp increase thereafter.

![Figure 4.4: Sigma-convergence of employment rate](image)

Source: Own calculations.
This divergence in terms of the employment rate stands in contrast to the behavior of the dispersion of both output per capita and labor productivity. Figures 3 and 4 together indicate that productivity growth in Europe has converged over the post World-War II period, probably due to increased integration of goods and financial markets. However, the lagging countries have managed to close the gap with the more advanced ones in productivity terms only at the cost of low employment rates, thus output gains have been achieved with very low employment creation. In Figure 5 σ-convergence of output per worker in the EU is displayed, this time together with the implicit σ-convergence that one would expect if the β-coefficient was stable along the sample period. The implicit σ-convergence, which is derived by adding log(y_{it-1}) on both sides of equation (4.5), computing the variance, and using the condition that the covariance between u_t and log(y_{it-1}) is zero, is computed using the following difference equation:

\[ \sigma^2_t = e^{-2\beta} \sigma^2_{t-1} + \sigma^2_u. \]  

Assuming that the variance of the disturbance, \( \sigma^2_{ut} \), is constant over time, \( \sigma^2_{ut} = \sigma^2_u \), which implies homoskedasticity of residuals, the solution of the difference equation (8) is given by

\[ \sigma^2_t = \frac{\sigma^2_u}{1-e^{-2\beta}} + \left[ \frac{\sigma^2_0 - \sigma^2_u}{1-e^{-2\beta}} \right] e^{-2\beta}. \]  

Substituting the actual values of \( \sigma^2 \) in 1990 and 1950, \( \sigma^2_u \) is approximated by

\[ \sigma^2_u = (\sigma^2_{90} - \sigma^2_{50} e^{-80\beta})(1-e^{-2\beta})(1-e^{-80\beta})^{-1}. \]

Empirical σ-convergence is less smooth than predicted by the theoretical concept of implicit σ-convergence. Since 1974, empirically, σ-convergence is above implicit σ-convergence, thus the theoretical σ-convergence permanently underpredicts income dispersion in the EU. Indeed, the figure suggests that convergence in the EU has virtually stopped in the mid 1970's and partly been reversed since then. Two explanations seem plausible: first, the variance of shocks affecting the economies might have increased, the economies thus having increasingly been subject to large asymmetric shocks. Second, the β-coefficient has not been stable all along the observation period.
Figure 4.5: Implicit and empirical sigma-convergence

Source: Own calculations.

4.5.4. Income distribution dynamics

$\sigma$-convergence is, however, only a crude measure of dispersion, since the estimated variance of income across countries is influenced by shocks hitting the economy at any particular point in time. Hence, even if the economies were truly getting closer in the long-run, this statistic would have a lower bound by the variance of these shocks [Andrés et al., 1995]. As argued by Quah (1993a,b), analyzing an average or representative economy in a cross-section of economies may give a misleading picture for the behavior of that entire cross-section. Therefore, he proposes to study the probability distribution of the evolution of income over time. We will make use of some descriptive techniques proposed by this author. The purpose is to obtain more detailed information as to which countries converge and which do not. We define the grid in such a way that the set of quantiles determines the sequence of cross-section distributions. The change in the grid describes the evolution of the cross-section distribution from one period to the next one. Convergence in this context is taking place if the
Figure 4.6: Income distribution in the European Union

a) Fractiles GDP per worker

b) Fractiles GDP per capita

Source: Own calculations
Figure 4.7:
a) Ranking of output per capita

Fig. 4.7:
b) Ranking of output per worker

Source: Own calculations.
sequence of quantiles degenerates to the mean. Figures 6 a) and b) show the sequence of fractiles of income per capita and labor productivity relative to the average value in the EU. The 25 per cent of countries with lowest productivity of labor in 1950 fell in a range of 0.35 to 0.72 of the EU average. The upper limit of this interval rose steadily until 1975 and has stayed around 0.95 times the average since then. The evolution of the lower limit was similar, so that the range remained about the same over the whole time period. The second and third quantile tend to concentrate around the mean. The 25 per cent of countries with highest productivity fell in a range of 1.33 to 1.69 of EU average. The lower limit evolved until 1.11, the upper limit until 1.38 times the average, where again it is to be noted that this is about the same as in the mid 70's. Indeed, the upper limit has been increasing slightly since the mid 70's. The behavior of income per capita over time is similar, though the degeneration process towards the mean is clearly less pronounced. As with labor productivity, since the mid 70's, the convergence process seems to be stagnating.

Figures 7 a) and b) provide additional information on the evolution of the income distribution in Europe. It ranks the countries according to the relative income per capita (labor productivity) in the first year of the sample and shows the evolution of the ranking over time. Each line represents, for a single year (1950, 1973, 1990), the relative income of the EU countries ordered by their initial ranking. By construction, the larger the income differences, the steeper the lines are. Income per capita differentials among middle income countries and high-income countries have been reduced slightly over recent years, as the slope remains about the same. However, differences between, on the one hand, rich and middle income countries, and a group of poor economies on the other one, notably Portugal, Greece, Spain and Ireland, have widened over the post World-War II period, as the slope in this range becomes steeper over time. While the ranking of productivity evolves similarly, the changes in ranking are realized to be much more pronounced than changes in income per capita.

At this stage, I may review the main impressions obtained from the descriptive statistical analysis. First, the adjustment process of goods markets across regions in Europe is slower than across countries. This is in line with other empirical evidence concerning goods- or labor market-adjustment in the EU and implies that lagging economic regions in the EU have greater difficulties to cope with region-specific structural adjustment problems than countries with country-specific ones. Second, economic convergence of output per worker in the EU over the post World-War II period is confirmed. Convergence is found by applying σ-convergence. The summed deviation from the mean across EU countries has
decreased over time. However, first, ς-convergence is seen to be empirically less smooth than theoretically predicted and, second, the process of convergence seems to have been reversed since 1974. Third, while income differentials have been reduced among middle- and high-income economies, differentials to a group of poor economies remain persistent. Thus, while on average European economies seem to converge, this process is far from common to all economies. The descriptive analysis in this section, thus, confirms the impression obtained from other empirical studies that the EU is characterized empirically by economic convergence. However, the process of convergence has not been stable, neither across time nor across countries.

4.6. A stylized growth model

In this section, a stylized growth model is developed that conveniently incorporates the alternative theoretical approaches presented in section two of this chapter. The model will be used as the theoretical basis for the subsequent econometric analysis. The model is in the neoclassical tradition of Solow (1956) and, more recently, Barro and Sala-i-Martin (1992) and Mankiw et.al. (1992). The formulation of the production function follows Ethier (1982) and Romer (1987). The treatment of the technological gap is based originally on Nelson and Phelps (1966) and follows De la Fuente (1995a,b) and Hansson and Henrekson (1994a). The aggregate production function is assumed to be given by

\[ Y = AK^{a+\mu}N^{1-a} \]

where \( Y \) is GDP, \( K \) is the capital stock and \( N \) is total employment. \( \mu \) denotes an externality and describes the substitutability between different intermediate capital goods. Taking logs of equation (1) and differentiating with respect to time, we obtain the rate of growth of aggregate GDP, \( g_Y \), as the weighted sum of three components, reflecting, respectively, the rate of technical progress \( g_A \), the accumulation of reproducible factors \( g_K \), and population growth \( g_N \).  

\[ g_Y = g_A + agx + \beta gN \]

In order to describe economic growth in the economy, we need to specify the determinants of the three growth rates, \( g_A \), \( g_K \) and \( g_N \). The rate of population
growth, is exogenous. Let \( g_N \) equal \( n \). Let's turn to the second factor, the rate of growth of the capital stock, which is given by

\[
g_K = AK^{\alpha + \mu} N^{1 - \alpha} - C - \delta
\]

Let \( k = K/AN \) and \( y = Y/AN \) denote the capital-labor ratio and production in efficiency units, respectively. The growth rate of the stock of capital per efficiency unit of labor, \( g_k \), is the difference between the growth rate of the aggregate stock of capital and the sum of the rates of technical progress and population growth.

\[
g_t = g_K - g_t - n = sk^{\alpha + \mu - 1} - (n + g_A + \delta)
\]

The rate of savings \( s \) is assumed to be constant. \( n \) and \( \delta \) denote the population growth rate and the depreciation rate, respectively. The average product of capital taking into account of the externality. The rate of factor accumulation, \( g_k \), is given by the difference between the average product of capital and the rate of consumption, which amounts, for a constant consumption rate, to equal the investment rate, and the effective depreciation rate \( (n + g_A + \delta) \). The time path of capital depends crucially on its factor share \( \alpha + \mu \). If \( \alpha + \mu \) is less than one, then the marginal product of capital, and hence the rate of return on investment, falls with the accumulated capital stock, reducing the incentive to save and the contribution of a given volume of investment to output growth. The system then returns to the steady state level of capital, which is given by

\[
k^* = \frac{1}{1 - \alpha - \mu} \ln A_0 + \frac{1}{1 - \alpha - \mu} \ln s - \frac{1}{1 - \alpha - \mu} \ln(n + \delta + g_t)
\]

In contrast, if \( \alpha + \mu \) equals one, so that returns to reproducible factor inputs are constant, the rate of return on investment remains constant and the incentive to save is not reduced with an increasing capital stock. Initial deviations from the steady state are persistent and remain constant. If \( \alpha + \mu \) is greater than one, since the return on investment is an increasing function of the stock of capital per efficiency unit of labor, the rate of accumulation of \( g \) increases with \( k \). Thus, \( k \) grows when it is larger than \( k^* \) and falls when it is smaller, moving farther and farther away from the steady state. Finally, we specify the determinants of the rate of technical progress, \( g_A \). Here we partly endogenize technical progress by assuming that it depends at any time \( t \) on the opportunity to exploit existing
technological differences, which in turn is associated with the social capability of the economy. As discussed before, the general idea is that backward countries will have an opportunity to embark on a catching-up process by imitating and borrowing superior production techniques from the more advanced economies cheaper and faster than the original discovery and testing. The difference between potential technological spillover and the actual spillover may be captured by assuming that in every period the relative change in the technological level is proportional to the technological gap \( b \). The technological gap \( b \) is measured by the log difference between a "technological frontier" denoted by \( X \) and the country's own technological index, \( A \):

\[
(4.16) \quad g_t = \Phi(s) \frac{X - A}{A} = \Phi(s)(\ln X - \ln A) = \Phi(s)b \quad 0 \leq \Phi \leq 1
\]

\( s \) denotes the social capability. \( \Phi(s) \) measures the speed of diffusion of new technologies and is assumed to be positively related to the social capability of the country, i.e., \( \Phi'(s) > 0 \). Assuming that \( X \) grows at the constant rate \( g_X \) and solving the resultant differential equation, we obtain the time path of the technology index \( A \):

\[
(4.17) \quad A_t = \left( A_0 - \frac{\Phi(s)}{\Phi(s) + g_X} \right) e^{-\Phi t} + \frac{\Phi(s)}{\Phi(s) + g_X} e^{g_X t}
\]

The second term on the right hand side denotes the evolution of \( A \) in the steady state \( (A^*) \), while the first term captures the part of the evolution that is attributable to the out-of-steady-state effect. The steady state technological gap is given by

\[
(4.18) \quad b^* = \frac{g_X}{\Phi(s)}
\]

It follows that increased social capability reduces the steady state technological gap in a country. Two cases, displayed in Figure 8 illustrate the diffusion mechanism inherent in equations (16) to (18). For one, consider two countries with different social capabilities, \( s_H \) and \( s_L \), but with the same initial technological gap. In this case the country with the higher level of social capability will have a faster rate of productivity growth. Eventually, the steady state growth rate \( g_X \) is reached in both countries, and the technological gaps
converge to the steady state values corresponding to the respective levels of social capability. Put differently, conditional on different initial levels of social capability, countries move to the same steady state technological gap. Alternatively, consider two countries with the same social capability level, but with initially differing technological gaps b₁ and b₂. The country with the larger technological gap will grow faster than the country with the smaller gap, but both countries eventually converge to the same equilibrium gap b*. The differences in productivity growth rates thus remain temporary, dependent on the technological distance prevailing in the economy.

In sum, the model provides a formal synthesis of the three alternative theoretical approaches discussed in section two. The model incorporates two convergence mechanisms, the neoclassical convergence one due to decreasing returns to scale to reproducible factors, and a technological diffusion convergence one due to differences across countries to the respective steady state technological gaps. The model predicts, under plausible assumptions, what Barro and Sala-i-Martin (1991,1992) labeled *conditional convergence*. There is convergence in the sense that each country approaches its long-run equilibrium in which its income per capita remains constant over time at a level determined by its investment effort [De la Fuente, 1995a]. During the transition process, growth rates may differ across countries. Growth rates may differ due to differences in initial capital intensities. In addition, they may vary due to technological differences.

*Figure 4.8.: Evolution of technological gap*

Source: Own calculations.
4.7. Econometric analysis

In this section a structural econometric model is estimated applying the concept of conditional convergence. The econometric analysis allows to obtain a deeper view of the causes of economic convergence. The econometric model is based on the stylized growth model developed above and concentrates on output per capita as a measure for living standards.

4.7.1. Model specification

The neoclassical growth model suggests that economies are converging to a common rate of technical change. The conditional convergence equation that has been applied by, for instance, by Mankiw et al. (1992), and that has been used frequently in subsequent empirical research on convergence, is of the following form (all values in logs):

\[
\ln y_t - \ln y_0 = (1 - e^{-\lambda}) \ln y_0 + \frac{\alpha + \mu}{1 - \alpha - \mu} (1 - e^{-\mu}) s_k * \\
+ (1 - e^{-\lambda}) \ln A_0 - \frac{\alpha + \mu}{1 - \alpha - \mu} (1 - e^{-\mu}) (n + g + \delta) + A^* e^{\delta t} + \nu
\]

(4.19)

with \( \lambda = (1 - \alpha - \mu) (n + g + \delta) \).

According to equation (19), the growth rate of income per capita is a function of the determinants of the ultimate steady state and the initial level of income. Mankiw et al. (1992) approximate equation (19) with a regression of the form

\[
\Delta y_t = \text{const.} + \beta_1 y_{t-1} + \pi_1 \left( \frac{I}{Y} \right) t + \pi_2 (n + 0.05) + \nu
\]

\[
\Delta y_t = \ln y_t - \ln y_0 = \frac{(1 - e^{-\lambda}) y_0}{(1 - e^{-\lambda}) A_0 + g(t_2 - e^{-\lambda} t_1)}
\]

\[
\pi_1 = \frac{\alpha + \mu}{1 - \alpha - \mu} (1 - e^{-\mu})
\]

\[
\pi_2 = \frac{\alpha + \mu}{1 - \alpha - \mu} (1 - e^{-\mu})
\]

\[
I/Y = s^* k
\]

Christian Schmidt - 9783631750056
Downloaded from PubFactory at 08/09/2019 04:37:47AM via free access
Mankiw et al. (1992) hold differences in the countries' steady states constant by the country-specific savings rates of reproducible capital, and by the average growth rate of working-age population. Their approximation relies on the assumption of equal initial levels of technology across economies. Since the technology parameter $A_0$ is defined in a broad sense, which includes resource endowments, institutions etc., it is not convincing that these factors should not vary across economies. In addition, the rate of technical change is assumed to be equal across economies. As Keller (1995) points out, in order to evaluate neoclassical and endogenous growth models, it is important to allow for technological differences in rates of technical change as they, presumably, in models with endogenous technical change, vary across economies. From equation (19), solving for $\ln y_t$ yields

$$\ln y_t = e^{-\mu} \ln y_0 + \frac{\alpha + \mu}{1 - \alpha - \mu} (1 - e^{-\mu}) s_t \ast (1 - e^{-\mu}) \ln A_0$$

(4.20)

$$- \frac{\alpha + \mu}{1 - \alpha - \mu} (1 - e^{-\mu})(n + g_t + \delta) + A \ast e^{g_t} + \nu_t$$

Here, equation (20) is approximated as follows:

(4.21) $$\Delta y_t = \chi + \beta_1 y_{t-1} + \pi_1 \left(\frac{l}{y_t}\right) + \pi_2 (n + 0.05) + \mu + \varphi + \nu_t$$

where

- $y_t = \ln(y_t)$
- $y_{t-1} = \ln(y_0)$
- $\beta_1 = e^{-\lambda t}$
- $\pi_1 = + \frac{\alpha + \mu}{1 - \alpha - \mu} (1 - e^{-\mu})$
- $\pi_2 = - \frac{\alpha + \mu}{1 - \alpha - \mu} (1 - e^{-\mu})$
- $(l/Y)_t = s^*k$
- $\chi + \mu I = f(A_0)$
- $\varphi_t = f(g_t)$

The Appendix contains a formal derivation of this equation from the model specified before. Note a few things about this specification: first, following Islam (1995), initial levels of technology may vary across economies ($\mu = \mu_I$). $\mu_I$ refers to an economy-specific random shock which is constant over time. It measures the initial levels of technology $A_0$ in the economies. Differences in initial levels
of technology may lead to a technological catch-up process, which this specification thus incorporates implicitly. Second, $\varphi_t$ is a time-specific random shock common to all economies. It is supposed to capture time-specific technological shocks, which presumably affect the economies similarly. Third, the equation conditions for differences in savings rates of reproducible capital, and for country-specific population growth rates. Physical capital's savings rate, $s^*k$, is proxied by the average share of real investment in real GDP. Fourth, as in Mankiw et al. (1992), $(g+\delta)$ is assumed to be equal to 0.05 and to be the same for all countries and all years.

This specification is a more general version of the model estimated by Mankiw et al. (1992). In contrast to their approach, and based on the theoretical model developed before, technological differences are allowed for [Islam, 1995; Keller, 1994, 1995]. Initial levels of technology may vary across economies, thereby allowing for differences in employed technologies. I deviate from the model presented above in that "social capability" is not attempted to measure, being taken exogenously.

4.7.2. Econometric methodology

Equation (21) is a dynamic panel regression model. Panel data econometric methods are thus applied. Panel data analysis has several advantages [Keller, 1995]: first, by breaking up the period of observation into subperiods, the number of data points is increased. More data improves the fit of the estimation, as measured by the coefficient of determination, $R^2$. In addition, statistical inference is facilitated in a panel context. If $N$ is the size of the cross-section, and $T$ the number of time periods the cross-section is observed, then switching from cross-sectional to panel analysis increases the number of degrees of freedom from $N$ to $NT$. Secondly, a panel approach exploits the time dimension of the data in a way cross-sectional analysis does not, as the latter does preclude any analysis into the time dimension of the convergence phenomenon. Thirdly, and most importantly, panel data analysis controls for economy-specific effects which, if present and not orthogonal to the other regressors, will bias the estimated coefficients. This bias is the standard omission-of-variable bias: if there is unobserved heterogeneity across economies, failing to control for this will bias the coefficients of the remaining variables according to their "true" correlation with the unobserved heterogeneity. Following Islam (1995) and Keller (1995), the individual effects are thought of as deterministic. In contrast, treating the individual effects as random would imply an assumption that the exogenous
regressors be uncorrelated with the fixed effects. This, however, would not be suitable in the present case, because it is against the argument of the economic model, as the individual-specific effects capture technological differences, which are correlated with the exogenous variables. In the present case, the Least Squares Dummy Variable (LSDV) may be applied. This amounts to introducing a dummy for each economy, and subperiod, and estimate the equation by OLS. As has been shown by Anderson and Hsiao (1982) and Hsiao (1986), the estimator of $\beta$ is inconsistent when asymptotics are considered in the direction of $N \to \infty$. However, in the direction of $T \to \infty$, the LSDV estimator is consistent and asymptotically equivalent to the Maximum Likelihood Estimator [Amemiya, 1967]. A consistent estimate of $\beta$ can be obtained by using instrumental-variable methods. The instrumental-variable method proposed by Anderson and Hsiao (1982) involves estimating equation (8) in differenced form, with the fixed effects being swept out. Therefore, I proceed by estimating equation (8) using the LSDV-estimator in order to obtain the fixed effects. Indeed, Islam (1992) applied Monte-Carlo methods and showed that the LSDV-estimator performs very well in comparison to other estimators.

4.7.3. Estimation results

The observation period spans 42 years from 1950 to 1992 using data from 15 countries. The whole period is divided into eight sub-periods, thus seven sub-periods over a length of five years and one over seven years. At first, the observations are treated as if they were 120 independent draws from a given population. That is, regressions abstract from the fact that every 15th observation comes from the same region, and that every 8th observation belongs to the same subperiod. I then add, sequentially, country-specific and time-specific effects to allow for a less restrictive version of the econometric model, which takes into account of differences across economies and across time.

The results from estimating equation (21) are given in Table 7. In the upper part of the table results from unrestricted regressions are displayed. In the lower part of the table, results from restricted regressions, imposing the (neoclassical) restriction that the coefficients of the investment and population growth rates are equal in magnitude but opposite in sign ($\pi_1 = -\pi_2$), are given.

The first column gives the results from estimating equation (21) with pooled ordinary least squares [regression (1)]. The signs of the coefficients are as to be expected from economic theory. Physical capital's investment rate has a positive and significant effect on output per capita. The coefficient of the rate of
Table 4.7: Regression results from estimating equation (21)

<table>
<thead>
<tr>
<th></th>
<th>$\hat{y}_{OLS}$ (1)</th>
<th>$\hat{y}_{LSDV}$ (2)</th>
<th>$\hat{y}_{LSDV}$ (3)</th>
<th>$\hat{y}_{LSDV}$ (4)</th>
<th>$\hat{y}_{LSDV}$ (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>constant</td>
<td>0.7047 (0.1870)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\ln (y)_{t-1}$</td>
<td>0.9085 (0.0125)</td>
<td>0.9269 (0.0119)</td>
<td>0.8780 (0.0171)</td>
<td>0.9271 (0.0186)</td>
<td>0.6774 (0.0442)</td>
</tr>
<tr>
<td>$\ln (GDP)_{t}$</td>
<td>0.0767 (0.0345)</td>
<td>0.2309 (0.0478)</td>
<td>0.1184 (0.0537)</td>
<td>-0.0234 (0.0525)</td>
<td>-0.0168 (0.0533)</td>
</tr>
<tr>
<td>$\ln (n + g + \delta)_{t}$</td>
<td>0.0057 (1.677)</td>
<td>0.8745 (1.9767)</td>
<td>-1.4025 (1.9418)</td>
<td>0.6703 (1.5279)</td>
<td>2.5546 (1.5332)</td>
</tr>
<tr>
<td>Implied $\lambda$</td>
<td>0.01827 0.0144</td>
<td>0.02478 0.0144</td>
<td>0.0548</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$R^2$ adj.</td>
<td>0.98 0.98 0.98</td>
<td>0.96 0.98</td>
<td>1.56 1.78 1.68</td>
<td>1.80 1.80</td>
<td>0.054</td>
</tr>
<tr>
<td>Durbin - Watson</td>
<td>1.56 1.78 1.68</td>
<td>1.86 1.75</td>
<td>0.065 0.067 0.062</td>
<td>0.056 0.055</td>
<td></td>
</tr>
</tbody>
</table>

**Restricted Regression**

<table>
<thead>
<tr>
<th></th>
<th>$\hat{y}_{OLS}$ (1)</th>
<th>$\hat{y}_{LSDV}$ (2)</th>
<th>$\hat{y}_{LSDV}$ (3)</th>
<th>$\hat{y}_{LSDV}$ (4)</th>
<th>$\hat{y}_{LSDV}$ (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>constant</td>
<td>0.7089 (0.1661)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\ln (y)_{t-1}$</td>
<td>0.9083 (0.0122)</td>
<td>0.9267 (0.0119)</td>
<td>0.8811 (0.0164)</td>
<td>0.7761 (0.0184)</td>
<td>0.6789 (0.0442)</td>
</tr>
<tr>
<td>$\ln (GDP)_{t}$</td>
<td>0.0772 (0.0331)</td>
<td>0.2507 (0.0326)</td>
<td>0.1045 (0.0494)</td>
<td>-0.0220 (0.0510)</td>
<td>0.0027 (0.0520)</td>
</tr>
<tr>
<td>$\ln (n + g + \delta)_{t}$</td>
<td>0.01832 0.0145</td>
<td>0.0241 0.0482</td>
<td>0.0737</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implied $\lambda$</td>
<td>0.98 0.98 0.98</td>
<td>0.98 0.98</td>
<td>1.56 1.77 1.69</td>
<td>1.86 1.75</td>
<td>0.054</td>
</tr>
<tr>
<td>$R^2$ adjusted</td>
<td>0.98 0.98 0.98</td>
<td>0.98 0.98</td>
<td>1.56 1.77 1.69</td>
<td>1.86 1.75</td>
<td>0.054</td>
</tr>
<tr>
<td>Durbin-Watson</td>
<td>1.56 1.77 1.69</td>
<td>1.86 1.75</td>
<td>0.064 0.067 0.062</td>
<td>0.056 0.055</td>
<td></td>
</tr>
</tbody>
</table>

**Wald test for neoclassical restriction : p-value**

|                  | 0.96 0.64 0.50 | 0.08 0.09 |

**Test for relative fixed effects and neoclassical restriction : p-value**

|                  | 0.57 0.02 |

**Individual Fixed Effects Included**

|                  | No | Yes | Yes | Yes | Yes |

**Time Fixed effects included**

|                  | No | No | No | Yes | Yes |

**LR-tests for significance of fixed effects**

| $H_0$: No individual fixed effects $\chi^2(15)$ : p-value | 0.0013 |
| $H_0$: No time fixed effects $\chi^2(8)$ : p-value | 0.013 0.0001 |

Standard errors in parentheses. P-value refers to marginal significance level.
Heteroskedasticity-consistent errors are used. [White 1980].

Source: Own calculations.
population growth remains insignificant. The coefficient of the log of output per capita in the previous sub-period is 0.9, which implies a rate of convergence of 1.82 per cent p.a.\textsuperscript{24} The value is within the range of estimates obtained by other authors using cross-section regression analysis with regional European data. Barro and Sala-i-Martin (1991), for example, obtained a corresponding speed of 1.78 per cent p.a., while Armstrong (1995) reports rates between 1 and 2 per cent p.a. The estimated coefficients from restricted regressions are similar as before. The restriction is accepted, with a probability of 96\% that the restriction is correctly imposed. The second and third column [regressions 2 and 3] contain the results from estimating equation (21) with individual-specific fixed effects, thus allowing for differences in initial states of technology. A dummy for each economy is included, which effectively introduces a constant term for each country. In the second column [regression 2] the fixed effects are restricted to sum to zero, thus expressing initial technology relative to an EU-average. The rate of convergence drops to 1.44 per cent p.a. in the unrestricted and to 1.45 per cent p.a. in the restricted regression. In the third column [regression 3] the fixed effects are expressed in absolute terms. The rate of convergence now increases to 2.47 per cent p.a., thus by inclusion of individual-specific fixed effects the rate of convergence is enhanced. As before, the neoclassical restriction (i.e. opposite signs of coefficients of population growth and investment rates) is accepted. It remains to test for the significance of the fixed effects, thus for the significance of differences in initial levels of technology. The corresponding Likelihood Ratio (LR)-test rejects the hypothesis of no fixed effects at the 1\% significance level. The fourth and fifth column [regressions 4 and 5] display the results from estimating equation (21) with both individual- and time-specific effects. In the fifth column the fixed effects are again expressed in absolute terms. The rate of convergence is now 5.48 per cent p.a.. Thus, conditioning on time-specific shocks does contribute to a more than double of the rate of convergence indicating that time-specific factors, like the oil-crises, are very relevant for differences across economies. The LR-test for significance of time-specific effects confirms that they are statistically significant for convergence and growth in the EU.

Next I turn to the issue of human capital. Human capital has been assigned several roles in the literature on economic growth [Hansson and Henrekson, 1994a]. First, it is seen as a separate factor of production, e.g., Mankiw et.al. (1992). Second, it is a source of innovative activity, and therefore an important input in the production of basic knowledge [Romer, 1990]. Third, a larger stock of human capital makes it easier for a country to absorb the new products or
of human capital makes it easier for a country to absorb the new products or ideas that have been discovered elsewhere, and hence the catching-up potential may be exploited (Nelson and Phelps, 1966; Easterlin, 1981; Abramovitz, 1986).

Fourth, there may be an external effect of human capital, i.e. human capital embodied in a worker may raise the productivity of colleagues [Lucas, 1988].

The regression equation including human capital then becomes

$$\Delta y_t = \chi + \beta_1 y_{t-1} + \pi_1(\sqrt{y_t}) + \pi_2(n + 0.05) + \pi_3 \ln(s) + \mu + \phi + \nu$$

The savings rate of human capital is approximated by the tertiary school enrollment rate. For the present sample of EU economies the use of the tertiary school enrollment rate seems to more appropriate than secondary school enrollment rates, as the latter show relatively little variation across the countries.

Table 8 contains the results from estimating equation (22). In the upper part of the table results from unrestricted regression estimates are given, while in the lower part of the table restricted estimates, imposing the neoclassical restriction that the coefficients on the investment rate, the human capital accumulation rate and the population growth rate sum to zero, are provided.

In the first column the results from pooled regression estimates are displayed [regression 6). The value of the coefficient of lagged output per capita is 0.9, which is similar as before in the pooled regression without human capital. Indeed, the coefficient of human capital accumulation turns out to be insignificant. Imposing the neoclassical restriction, which is accepted, does not affect the estimated coefficients. Next economy-specific fixed effects are included [regressions 7 and 8). The coefficient of lagged output per capita drops to 0.75, thus the rate of convergence rises to 5.72 per cent p.a.. The value of the coefficient of human capital accumulation now rises and becomes clearly significant. One interpretation for this finding may be that the initial level of technology is correlated with the rate of human capital accumulation, as proposed by some endogenous growth models [Lucas 1988]. The LR-test indicates that the individual-specific fixed effects are statistically significant. Finally, in regressions 9 and 10, the full two-way fixed effects structure is included. The coefficient of human capital becomes insignificant, which may suggest the partial correlation between human capital and output per capita is time-sensitive. A possible interpretation, noted by Andrés et.al. (1995), is that the human capital influence upon output takes time to show up, and hence it might be the case that changes in the tertiary school enrollment rate are weakly correlated with current output per capita. The rate of convergence becomes 7.62 per cent p.a., thus by
Table 4.8.: Regression results from estimating equation (22)

<table>
<thead>
<tr>
<th>Regressors / Estimators</th>
<th>$y_{\text{est}}$ (6)</th>
<th>$y_{\text{est}}$ (7)</th>
<th>$y_{\text{est}}$ (8)</th>
<th>$y_{\text{est}}$ (9)</th>
<th>$y_{\text{est}}$ (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>constant</td>
<td>0.7278</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>$\ln (y)_{t-1}$</td>
<td>0.9055 (0.0156)</td>
<td>0.8827 (0.0149)</td>
<td>0.7507 (0.0312)</td>
<td>-0.0174 (0.043)</td>
<td></td>
</tr>
<tr>
<td>$\ln (1 / \text{GDP})_{t}$</td>
<td>0.0724 (0.0456)</td>
<td>0.2802 (0.0450)</td>
<td>0.0523 (0.0654)</td>
<td>0.0180 (0.0209)</td>
<td></td>
</tr>
<tr>
<td>$\ln (s_{k})_{t}$</td>
<td>0.0035 (0.0122)</td>
<td>0.0469 (0.0127)</td>
<td>0.0897 (0.0155)</td>
<td>0.0180 (0.0209)</td>
<td></td>
</tr>
<tr>
<td>$\ln (n + g + \delta)_{t}$</td>
<td>0.1350 (1.7960)</td>
<td>2.4583 (2.1768)</td>
<td>1.3972 (2.1880)</td>
<td>2.8522 (1.6222)</td>
<td></td>
</tr>
<tr>
<td>Implied $\lambda$</td>
<td>0.0189</td>
<td>0.0237</td>
<td>0.0546</td>
<td>0.0762</td>
<td></td>
</tr>
<tr>
<td>$R^2$ adj.</td>
<td>0.98</td>
<td>0.97</td>
<td>0.98</td>
<td>0.98</td>
<td></td>
</tr>
<tr>
<td>Durbin - Watson</td>
<td>1.56</td>
<td>1.80</td>
<td>1.94</td>
<td>1.81</td>
<td></td>
</tr>
<tr>
<td>s.e.e.</td>
<td>0.0654</td>
<td>0.0737</td>
<td>0.0572</td>
<td>0.0551</td>
<td></td>
</tr>
</tbody>
</table>

Restricted Regression

| constant                | 0.7318 (0.2147)       | -                     | -                     | -                     |
| $\ln (y)_{t-1}$         | 0.9054 (0.0156)       | 0.8886 (0.0142)       | 0.7515 (0.0312)       | 0.7460 (0.0266)       |
| $\ln (1 / \text{GDP})_{t}$-$\ln (n + g + \delta)_{t}$ | 0.07524 (0.0390)     | 0.3206 (0.0325)       | 0.0703 (0.0603)       | -0.0105 (0.0519)      |
| $\ln (s_{k})_{t}$      | 0.0032 (0.0120)       | 0.0382 (0.0108)       | 0.0857 (0.0145)       | 0.0267 (0.0185)       |
| Implied $\lambda$      | 0.0189                | 0.0224                | 0.0544                | 0.0558                |
| $R^2$ adj.              | 0.98                  | 0.97                  | 0.98                  | 0.98                  |
| Durbin-Watson           | 1.56                  | 1.75                  | 1.89                  | 1.86                  |
| s.e.e.                  | 0.0650                | 0.0740                | 0.0572                | 0.057                |

Test for neoclassical restriction: p-value

| 0.905 | 0.47 | 0.098 | 0.077 |

Test for rel. Fixed. Eff. And neoclassical rest. : p-value

| 0.0001 | 0.022 | -     |

Individual Fixed Effects Included

| No | Yes | Yes | Yes | Yes |

Time Fixed effects included

| No | No | No | Yes | Yes |

LR - tests for significance of fixed effects

| $H_0$: No individual fixed effects $\chi^2(15)$ : p-value | 0.0001 |
| $H_0$: No time fixed effects $\chi^2(8)$ : p-value | 0.0001 |

Standard errors in parantheses. P-value refers to marginal significance level. Heteroskedasticity-consistent errors are used. [White 1980].

Source: Own calculations.
taking into account of time-specific shocks the speed of convergence is increased. Time-specific effects are significant, as indicated by the LR-test. The neoclassical restriction is, as before, accepted.

In sum, while, on the one hand, the results tend to accept the restrictions suggested by the neoclassical growth model, differences, on the other hand, in initial states of technology are found to play an important role for the post-World War II growth experience in the EU. Thus, the process of convergence is influenced by differences in technology levels. By taking into account of these differences, the rates of convergence are increased. In other words, with respect to the hypotheses formulated above, the estimation results are essentially in line with a model of decreasing returns to scale and opportunities for technological catch-up.

4.7.4. Economic interpretation

In this section I attempt to deepen the economic interpretation of the estimation results discussed in the previous section and to derive some of their economic implications.
Figure 9 displays the estimated economy-specific fixed effects obtained from regression 10, which included the full two-way fixed effects structure. The coefficients are presented relative to their average values. Apart from the strongly negative deviation of the initial level of technology in Denmark, for which I do not find a plausible explanation, the estimated values seem reasonable. The estimated levels of technology are clearly below the average in Greece, Ireland and Portugal, and deviate positively, in particular, in Italy and Belgium from the average.

In Table 9 the correlation coefficients between the estimated fixed effects and the levels of GDP per capita in different years are given. Since $A_0$ is part of the production function, it should be correlated with per capita income at different points of time. As expected, the correlation is strongly positive, indicating that a higher initial level of technology implies a higher living standard in the future. Interestingly, the correlation seems to become stronger, the longer the period to the observed income per capita is.

**Table 4.9. Analysis of estimated fixed effects. Correlation coefficients**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fixed effect (3)</th>
<th>Fixed effect (5)</th>
<th>Fixed effect (8)</th>
<th>Fixed effect (10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln $y_{50}$</td>
<td>0.39</td>
<td>0.25</td>
<td>0.28</td>
<td>0.25</td>
</tr>
<tr>
<td>ln $y_{60}$</td>
<td>0.49</td>
<td>0.35</td>
<td>0.34</td>
<td>0.35</td>
</tr>
<tr>
<td>ln $y_{73}$</td>
<td>0.47</td>
<td>0.43</td>
<td>0.39</td>
<td>0.42</td>
</tr>
<tr>
<td>ln $y_{91}$</td>
<td>0.57</td>
<td>0.46</td>
<td>0.42</td>
<td>0.45</td>
</tr>
<tr>
<td>$\Delta \ln y(91-50)$</td>
<td>-0.19</td>
<td>-0.05</td>
<td>-0.13</td>
<td>-0.05</td>
</tr>
<tr>
<td>$\Delta \ln y(73-50)$</td>
<td>-0.22</td>
<td>-0.01</td>
<td>-0.11</td>
<td>-0.01</td>
</tr>
<tr>
<td>$s_k$ Tertiary enrollment rate (average)</td>
<td>0.23</td>
<td>0.28</td>
<td>0.29</td>
<td>0.28</td>
</tr>
<tr>
<td>$s_k$ Secondary enrollment rate (average)</td>
<td>0.02</td>
<td>-0.08</td>
<td>0.09</td>
<td>-0.07</td>
</tr>
<tr>
<td>ln ($L/Y$)(90-50)</td>
<td>0.05</td>
<td>0.11</td>
<td>0.24</td>
<td>0.12</td>
</tr>
<tr>
<td>ln $n(90-50)$</td>
<td>-0.06</td>
<td>0.18</td>
<td>0.03</td>
<td>0.17</td>
</tr>
<tr>
<td>ln ($G/Y$)(90-50)</td>
<td>-0.12</td>
<td>-0.31</td>
<td>-0.26</td>
<td>-0.32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fixed effect (3)</th>
<th>Fixed effect (5)</th>
<th>Fixed effect (8)</th>
<th>Fixed effect (10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln $y_{50}$</td>
<td>0.39</td>
<td>0.25</td>
<td>0.28</td>
<td>0.25</td>
</tr>
<tr>
<td>ln $y_{60}$</td>
<td>0.49</td>
<td>0.35</td>
<td>0.34</td>
<td>0.35</td>
</tr>
<tr>
<td>ln $y_{73}$</td>
<td>0.47</td>
<td>0.43</td>
<td>0.39</td>
<td>0.42</td>
</tr>
<tr>
<td>ln $y_{91}$</td>
<td>0.57</td>
<td>0.46</td>
<td>0.42</td>
<td>0.45</td>
</tr>
<tr>
<td>$\Delta \ln y(91-50)$</td>
<td>-0.19</td>
<td>-0.05</td>
<td>-0.13</td>
<td>-0.05</td>
</tr>
<tr>
<td>$\Delta \ln y(73-50)$</td>
<td>-0.22</td>
<td>-0.01</td>
<td>-0.11</td>
<td>-0.01</td>
</tr>
<tr>
<td>$s_k$ Tertiary enrollment rate (average)</td>
<td>0.23</td>
<td>0.28</td>
<td>0.29</td>
<td>0.28</td>
</tr>
<tr>
<td>$s_k$ Secondary enrollment rate (average)</td>
<td>0.02</td>
<td>-0.08</td>
<td>0.09</td>
<td>-0.07</td>
</tr>
<tr>
<td>ln ($L/Y$)(90-50)</td>
<td>0.05</td>
<td>0.11</td>
<td>0.24</td>
<td>0.12</td>
</tr>
<tr>
<td>ln $n(90-50)$</td>
<td>-0.06</td>
<td>0.18</td>
<td>0.03</td>
<td>0.17</td>
</tr>
<tr>
<td>ln ($G/Y$)(90-50)</td>
<td>-0.12</td>
<td>-0.31</td>
<td>-0.26</td>
<td>-0.32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fixed effect (3)</th>
<th>Fixed effect (5)</th>
<th>Fixed effect (8)</th>
<th>Fixed effect (10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln $y_{50}$</td>
<td>0.39</td>
<td>0.25</td>
<td>0.28</td>
<td>0.25</td>
</tr>
<tr>
<td>ln $y_{60}$</td>
<td>0.49</td>
<td>0.35</td>
<td>0.34</td>
<td>0.35</td>
</tr>
<tr>
<td>ln $y_{73}$</td>
<td>0.47</td>
<td>0.43</td>
<td>0.39</td>
<td>0.42</td>
</tr>
<tr>
<td>ln $y_{91}$</td>
<td>0.57</td>
<td>0.46</td>
<td>0.42</td>
<td>0.45</td>
</tr>
<tr>
<td>$\Delta \ln y(91-50)$</td>
<td>-0.19</td>
<td>-0.05</td>
<td>-0.13</td>
<td>-0.05</td>
</tr>
<tr>
<td>$\Delta \ln y(73-50)$</td>
<td>-0.22</td>
<td>-0.01</td>
<td>-0.11</td>
<td>-0.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fixed effect (3)</th>
<th>Fixed effect (5)</th>
<th>Fixed effect (8)</th>
<th>Fixed effect (10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln $y_{50}$</td>
<td>0.39</td>
<td>0.25</td>
<td>0.28</td>
<td>0.25</td>
</tr>
<tr>
<td>ln $y_{60}$</td>
<td>0.49</td>
<td>0.35</td>
<td>0.34</td>
<td>0.35</td>
</tr>
<tr>
<td>ln $y_{73}$</td>
<td>0.47</td>
<td>0.43</td>
<td>0.39</td>
<td>0.42</td>
</tr>
<tr>
<td>ln $y_{91}$</td>
<td>0.57</td>
<td>0.46</td>
<td>0.42</td>
<td>0.45</td>
</tr>
<tr>
<td>$\Delta \ln y(91-50)$</td>
<td>-0.19</td>
<td>-0.05</td>
<td>-0.13</td>
<td>-0.05</td>
</tr>
<tr>
<td>$\Delta \ln y(73-50)$</td>
<td>-0.22</td>
<td>-0.01</td>
<td>-0.11</td>
<td>-0.01</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Fixed effect (3)</th>
<th>Fixed effect (5)</th>
<th>Fixed effect (8)</th>
<th>Fixed effect (10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln $y_{50}$</td>
<td>0.39</td>
<td>0.25</td>
<td>0.28</td>
<td>0.25</td>
</tr>
<tr>
<td>ln $y_{60}$</td>
<td>0.49</td>
<td>0.35</td>
<td>0.34</td>
<td>0.35</td>
</tr>
<tr>
<td>ln $y_{73}$</td>
<td>0.47</td>
<td>0.43</td>
<td>0.39</td>
<td>0.42</td>
</tr>
<tr>
<td>ln $y_{91}$</td>
<td>0.57</td>
<td>0.46</td>
<td>0.42</td>
<td>0.45</td>
</tr>
<tr>
<td>$\Delta \ln y(91-50)$</td>
<td>-0.19</td>
<td>-0.05</td>
<td>-0.13</td>
<td>-0.05</td>
</tr>
<tr>
<td>$\Delta \ln y(73-50)$</td>
<td>-0.22</td>
<td>-0.01</td>
<td>-0.11</td>
<td>-0.01</td>
</tr>
</tbody>
</table>

Source: Own calculations.
Turning to the relation between the initial level of technology and the subsequent rate of growth, one needs to think first about what to expect from economic theory. With no technological diffusion, a technologically leading economy always has a higher rate of productivity growth. The distance between the technological leader and its follower grows without bound. This would be the case in endogenous growth models, where differences in initial levels of technology are allowed for and which remain persistently different.

With technological diffusion, on the other hand, the initial technological gap between two economies is reduced over time and the rate of productivity growth is equalized. Though I do not have a measure for the rate of productivity growth, the rate of growth of GDP per capita may serve as a proxy. In addition, Table 9 contains the correlation coefficients between the rate of growth and the estimated initial levels of technology are given, which turn out be negative. Thus a higher initial level of technology is associated with a relatively lower subsequent growth rate. This result confirms the impression of the estimation results in the sense that initially, in terms of technology, backward economies tended to catch-up to technologically advanced ones.

An interesting question relates to the determinants of technological differences. According to endogenous growth theories, factors like market size, economic policies, or factor endowments may affect technology and growth. To obtain an impression, I calculate correlation coefficients between several explanatory variables and the estimated technology parameters. In addition to the variables used in the regressions (physical and human capital, population growth rates), I put the initial levels of technology in relation to the size of the government (G/Y), which may be thought of as proxy for institutional differences. The results are displayed in the lower part of Table 9. Tertiary school enrollment rates show the strongest positive partial correlation with the estimated fixed effects. While both investment rates and population growth rates are positively correlated, the relation to the size of the government is negative. Barro (1991) and Landau (1983, 1986) report negative coefficients in cross-sectional analyses between the average growth rate and the size of the government, which is in line with the negative correlation coefficients. The results here, suggest, interpreted with all necessary caution, that the mechanism may work through the effect on technological parameters. More research, however, on the determinants of technological differences is needed to obtain more reliable empirical evidence.
4.8. Concluding remarks

This chapter contains an empirical analysis on growth and convergence in the European Union. The chapter starts from a discussion of the relevant theoretical background. Three modern theories of economic growth are discussed. Theories of technological catch-up argue that inefficient use of technology may lead to a process of convergence, depending on the degree of economic development in the economy. Neoclassical growth theories predict convergence due to decreasing returns to scale. Endogenous growth theories, in contrast, maintain that economic growth may be influenced by factors like market size, economies of scale and institutional structure, so that differences in living standards would possibly persist. It is argued that the predictions of theoretical models concerning the prospects for income convergence across countries depend crucially on two assumptions: the existence, or non-existence, of increasing returns to reproducible factors, including the stock of technological knowledge, and the degree to which useful knowledge is a public good across countries.

As for the controversy on the right measure of convergence, theoretical and empirical concepts of convergence are reviewed. First, σ-convergence considers the cross-sectional dispersion in per capita earnings. σ-convergence occurs if the cross-sectional dispersion in per capita earnings, typically measured by either the standard deviation or the coefficient of variation, declines through time. Second, absolute β-convergence occurs when poor countries tend to grow faster than rich ones, such that poor countries catch up to rich ones in terms of the level of per capita output through time. Third, conditional convergence refers to convergence after it has been controlled for differences in the economy's steady states. With conditional convergence, each country may converge to its own steady state, which could be very different from each other. Hence, a high degree of inequality among economies could persist, even in the long-run, and one could observe high persistence in the relative positions of the different economies. Finally, a concept that analyses the evolution of the distribution of income over time has been applied. The economic basis of the concept is that economies in an integrated world tend to be increasingly interdependent units, which would make it necessary to drop the "representative economy" assumption inherent in neoclassical approaches.

The empirical evidence with respect to convergence in the world economy is mixed. However, there exists a broad consensus in the more recent literature suggesting an absence of convergence to a single steady state. The absence of convergence to a single steady state may be explained either in the neoclassical...
tradition in terms of conditional convergence, that is, the rate of growth falls as
the economy approaches its own long-run level, or in terms of local convergence
and multiple equilibria. Empirical studies for Europe tend to support the
convergence hypothesis.

The chapter continues with an analysis of the stability of growth and
convergence processes in Europe, using descriptive statistical techniques and
alternative methods to measure convergence. The results obtained may be
summarized as follows: first, the adjustment process of goods markets in Europe,
on a regional level, is slower than across countries. This is in line with other
empirical evidence concerning goods- or labor market-adjustment in the EU and
implies that lagging economic regions in the EU have greater difficulties to cope
with region-specific structural adjustment problems than countries with country-
specific ones. Second, economic convergence of output per worker in the EU over
the post World-War II period is confirmed. Convergence is found by applying \( \sigma \)-
convergence. The summed deviation from the mean across EU countries has
decreased over time. However, first, \( \sigma \)-convergence is seen to be empirically less
smooth than theoretically predicted and, second, the process of convergence
seems to have been reversed since 1974. Third, while income differentials have
been reduced among middle- and high-income economies, differentials to a
group of poor economies remain persistent. Thus, while on average European
economies seem to converge, this process no common to all economies. The
descriptive analysis in this section, thus, confirms the impression obtained from
other empirical studies that the EU is characterized empirically by economic
convergence. However, the process of convergence has not been stable, neither
across time nor across countries.

The subsequent econometric analysis of the relation between technological
differences, convergence, and growth suggests that over the post World-War II
period European economies have been converging in terms of output per capita
in a conditional sense. Other things equal, poor countries in Europe tend to grow
faster than richer ones. Conditional on equal investment, enrollment rates and
technologies, economies in Europe do seem to converge to the same level of
income per capita. The finding of conditional convergence, however, does imply
that at present economies living standards in Europe diverge. In other words,
since investment rates, enrollment rates, and employed technologies differ across
EU countries, economies converge, dependent on these determinants, to
individual levels of output per capita. It follows that poor economies, like
Portugal, Greece, Spain and Ireland, presumably converge to a lower steady state
level of income per capita, which implies persistent differences in income per capita.

Technological differences are found to be an important factor for our understanding of growth and convergence in the European Union. The empirical evidence seems to support a model with technological diffusion, in which technologically lagging economies manage to catch-up to technological leaders by innovating and imitating at a lower cost. The exhaustion of catch-up opportunities, associated with initial technical backwardness, in addition, may be a factor that helps to explain the slowdown of growth and convergence in more recent years.

The estimation results tend to suggest that living standards in Europe are unlikely to equalize over time, as there will remain a group of about four countries that converges to a relatively lower steady state. If we think of the responsibility of policymakers to reduce disparities in Europe, based on Article 130a of the Maastricht Treaty, the estimates indicate that extended fiscal transfers may be needed to secure this policy goal. However, at the same time it needs to be emphasized that cohesion does not require that incomes or social conditions should be equalized. Nevertheless, if gaps are too large, it is plain clear that it will be difficult for the Community to be cohesive. Therefore, plausible targets for reductions in disparities, which pass the test of being politically acceptable, would be helpful.

Appendix to Chapter 4

1. Derivation of convergence equation

In this appendix the convergence regression equation, which is given in the main text as equation (21), is derived. The derivation is based on the stylized growth model presented in the main text. An alternative derivation may be found in De la Fuente (1995a). A derivation of the convergence equation from the neoclassical growth model is, for instance, in Barro and Sala-i-Martin (1995a). We start from the dynamic equation describing the evolution of the capital stock per efficiency unit.

\[ g_t = s k^{\alpha \mu - 1} - (n + g_t + \delta) \]
where $s$ is the constant savings rate in the economy. The rate of technical progress, $g_A$, is given by

$$g_A = \Phi(s)((X - A) / A) = \Phi(s)(\ln X - \ln A) = \Phi(s)b$$

where $b = \ln X - \ln A$ denotes the technological gap between the actual technology level in economy $i$ and its technological frontier. We assume that the technological frontier $X$ grows at a constant exogenous rate, $g_X$, which is identical across countries. The rate of change of the technological gap, $g_b$, is then given by the difference of the growth rate of the best-practice technology and the rate of technical progress.

$$g_b = g_X - g_A = g_X - \Phi(s)b$$

Equations (2) and (3) are both linear, first-order differential equations describing the dynamic behavior of the rate of technical progress and the technological gap, respectively. By solving equation (2), we obtain the time path of the technology index.

$$A_t = [A_0 - \Phi(s) / (\Phi(s) + g_x)] e^{-\Phi(s)t} + [\Phi(s) / (\Phi(s) + g_x)] e^{gd}$$

The second term on the right hand side denotes the evolution of $A$ in the steady state ($A^*$, the particular solution), while the first term captures the part of the evolution that is attributable to the out-of-steady-state effect (complementary solution). From equation (3), we obtain the time path of the technological gap.

$$b_t = [b_0 - \frac{g_X}{\Phi(s)}] e^{-\Phi(s)t}$$

Asymptotically, the technological gap converges to a steady state value, $b^* = \frac{g_X}{\Phi(s)}$, which depends negatively on the speed of technological diffusion and on the social capability of the economy. From equation (1), we obtain the steady state value of the stock of capital per efficiency unit.

$$k^* = \frac{1}{1 - \alpha - \mu} \ln A_0 + \frac{1}{1 - \alpha - \mu} \ln s - \frac{1}{1 - \alpha - \mu} \ln(n + \delta + g_x)$$
Substituting (2) into (1), and dividing by \( k \), we obtain

\[
(A.7) \quad g_k = sk^\alpha \mu^{\alpha - 1} - (n + \Phi(s)b + \delta)
\]

We may rewrite equation (7) as follows.

\[
(A.8) \quad \ln g_k = se^{k^\alpha \mu^{\alpha - 1}} - (n + \Phi(s)b + \delta)
\]

Evaluating the partial derivatives of equation (8) at the steady state, we get

\[
(A.9) \quad F_k = -(1 - \alpha - \mu) \cdot (n + g_k + \delta) = -\lambda \quad F_b = -\Phi(s)
\]

Equation (8) can thus be approximated by the log-linear equation

\[
(A.10) \quad g_k = -(k - k^*) - \Phi(s)(b - b^*)
\]

From equation (10), and using (5), we obtain the time path for the capital stock per efficiency unit.

\[
(A.11) \quad k_t = k^* + e^{-\lambda t}(k_0 - k^*) + e^{-\Phi(s)\mu t}(b_0 - b^*)
\]

We may rewrite equation (11) as in

\[
(A.12) \quad k_t = (1 - e^{-\lambda t})k^* + e^{-\lambda t}k_0 + e^{-\Phi(s)\mu t}(b_0 - b^*)
\]

The time path of (the log of) output per capita is given by

\[
(A.13) \quad y_t = A + (\alpha + \mu)k_t
\]

Substituting equation (12) into equation (13), we obtain

\[
(A.14) \quad y_t = A + (\alpha + \mu)(1 - e^{-\lambda t})k^* + e^{-\lambda t}k_0 + e^{-\Phi(s)\mu t}(b_0 - b^*)
\]

We may rewrite equation (14), using (13), as follows:

\[
(A.15) \quad y_t = A + (\alpha + \mu)(1 - e^{-\lambda t})k^* + e^{-\lambda t}(y_0 - A_0) + (\alpha + \mu)e^{-\Phi(s)\mu t}(b_0 - b^*)
\]
Substituting equation (4), the expression for the time path of the technology index, into equation (15) we see that

\[ y_t = (A_0 - A^*) e^{-\Phi(s) t} + A^* e^{s t} \left( \alpha + \mu \right) \left( 1 - e^{-\delta t} \right) k^* + e^{-\delta t} y_0 - e^{-\delta t} A_0 + \left( \alpha + \mu \right) e^{-\Phi(s) t} \left( b_0 - b^* \right) \]

(A.16)

Substituting the expression for the steady state capital stock into equation (16), and rearranging, we arrive at

\[ y_t = A_0 (e^{-\Phi(s) t} - e^{-\delta t}) + \left( \alpha + \mu \right) e^{-\Phi(s) t} b_0 + A^* e^{s t} \]

\[-e^{-\Phi(s) t} [b^* (\alpha + \mu) + A^*] + e^{-\delta t} y_0 + \left( 1 - e^{-\delta t} \right) \frac{\alpha + \mu}{1 - \alpha - \mu} s k^* \]

\[-\left( 1 - e^{-\delta t} \right) \frac{\alpha + \mu}{1 - \alpha - \mu} (n + g_s + \delta) \]

(A.17)

We subtract \( y_0 \) on both sides, to obtain

\[ y_t - y_0 = A_0 (e^{-\Phi(s) t} - e^{-\delta t}) + \left( \alpha + \mu \right) e^{-\Phi(s) t} b_0 + A^* e^{s t} \]

\[-e^{-\Phi(s) t} [b^* (\alpha + \mu) + A^*] - \left( 1 - e^{-\delta t} \right) y_0 + \left( 1 - e^{-\delta t} \right) \frac{\alpha + \mu}{1 - \alpha - \mu} s k^* \]

\[-\left( 1 - e^{-\delta t} \right) \frac{\alpha + \mu}{1 - \alpha - \mu} (n + g_s + \delta) \]

(A.18)

We may rewrite equation (17) and (18), by rearranging, as

\[ y_t = (e^{-\Phi(s) t} - e^{-\delta t}) A_0 + \left( \alpha + \mu \right) e^{-\Phi(s) t} b_0 - e^{-\Phi(s) t} b^* [\left( \alpha + \mu \right) + A^*] \]

\[ + A^* e^{s t} + e^{-\delta t} y_0 + \frac{\alpha + \mu}{1 - \alpha - \mu} (1 - e^{-\delta t}) s k^* - \frac{\alpha + \mu}{1 - \alpha - \mu} \left( 1 - e^{-\delta t} \right) (n + g_s + \delta) \]

(A.19)

The regression equation (21) of the main text, which is repeated here for convenience, may then be given the following interpretation:

\[ y_t = \chi + \beta y_{t-1} + \pi_1 \left( \ln Y \right) + \pi_2 \left( n + 0.05 \right) + \mu_i + \phi_t + \varepsilon_t \]

where \( y_t = \ln y_t \)

\[ \beta = e^{-\delta t} \]
\[\chi = e^{-\Phi(s)}[b^*(\alpha + \mu) + A^*]\]
\[Y_{t-1} = \ln y_0\]
\[\pi_1 = \frac{\alpha + \mu}{1 - \alpha - \mu}(1 - e^{-\lambda})\]
\[\frac{1}{Y} = \frac{s_k}{s}\]
\[\pi_2 = -\frac{\alpha + \mu}{1 - \alpha - \mu}(1 - e^{-\lambda})\]
\[n + 0.05 = n + g_s + \delta\]
\[\mu_i = (e^{-\Phi(s)} - e^{-\lambda}) \ln A_0 + (\alpha + \mu)e^{-\Phi(s)}b_0\]
\[\phi_t = f(g_t)\]

This provides an alternative interpretation of the convergence equation, while the regression equation remains unchanged.

2. Dynamic stability

The dynamic stability of the model depends on the asymptotic behaviour of the technological gap and the capital stock. In other words, the stability of the model is based on equations (1) and (3). The partial derivatives, evaluated at the steady state, are given by

\[(A.20)\]

\[F = \begin{bmatrix}
-(1 - \alpha - \mu)(n + g_s + \delta) & -\Phi(s) \\
0 & -\Phi(s)
\end{bmatrix}\]

The Trace of (19) is given by

\[\text{TR}(A) = -(1 - \alpha - \mu)(n + g_s + \delta) - \Phi(s)\]

The Determinant of A is given by

\[\text{D}(A) = [-(1 - \alpha - \mu)(n + g_s + \delta)] \cdot (-\Phi(s))\]

We distinguish 3 cases.

I. \((1 - \alpha - \mu) > 0 ; \Phi > 0\)
   \[\Rightarrow \text{D}(A) > 0 ; \text{TR}(A) < 0\]
   \[\Leftrightarrow \text{stable node}\]
This is the case with decreasing returns to scale and a stable evolution towards the steady state technological gap. The model is stable.

II. \((1-\alpha-\mu) < 0 ; \Phi > 0\)
\[ \Rightarrow \ TR(A) \leq 0 ; D(A) < 0 \]
\[ \Leftrightarrow \text{saddle path stable} \]

With increasing returns to scale and technological catch-up, there exists a unique stable path towards the steady state.

III. \((1-\alpha-\mu) < 0 ; \Phi < 0\)
\[ \Rightarrow \ TR(A) > 0 ; D(A) > 0 \]

With increasing returns to scale and technological divergence, the model is unstable. Thus, we may conclude that the stability of the dynamic system depends on the interaction between the technological catch-up process and the neoclassical convergence mechanism.

Endnotes

1 An abbreviated version of this chapter in *International Advances in Economic Research*.
2 This section draws heavily on Hansson and Henrekson (1994a).
3 See also Barro and Sala-i-Martin (1995a,b) and Betis et.al. (1993) for alternative theoretical models of technological diffusion and growth. Eaton and Kortum (1995) provide simulation results for a multi-country model of technological innovation. Based on plausible assumptions about technology gaps that existed among five leading research economies, they can explain growth experiences quite successfully.
6 For other recent surveys, see Desdoigts (1994) and De la Fuente (1995b).
7 Baumol et. al. (1989) contains additional empirical analyses (moving averages, Gini-coefficients) using the same data set as in Baumol and Wolff (1988), which confirm the above stated result.
8 The authors divide the sample of countries into three groups: The poor country group includes 29 countries, which are almost entirely African. The middle-income group includes 27 countries and the rich-country group 22 countries, being mainly OECD countries.
9 Empirical studies usually report several regressions based on different conditioning sets. Here, from each study the results from one regression are reported, usually based on the
largest number of conditioning variables used in the study. For a survey on earlier empirical evidence, see Levine and Renelt (1991). Levine and Renelt (1992) provide a sensitivity analysis of different variables and show that the results are very sensitive to the choice of variables.

10 The countries are: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, Netherlands, Norway, Sweden, UK, USA.

11 Club dummies are two dummies: one "lower club dummy", which refers to the poorest 25 regions in 1981 and one "upper club dummy", which refers to the richest 25 regions in 1981.

12 The countries included are: Belgium, Denmark, Finland, Greece, Ireland, Netherlands, Portugal, Spain, Sweden, United Kingdom.

13 The slowdown of growth and productivity in the past 20 years is a well-documented phenomenon for all OECD countries. See, for recent analyses, Ben-David (1995), Crafts and Mills (1995), Siebert (1992).

14 This point has been emphasized for the OECD countries by Andrés et al. (1995). See Decressin and Fatás (1994) for related empirical evidence on labor market adjustment in the EU economies.

15 The concept of implicit σ-convergence has been used by Andrés et al. (1995). The graph for output per capita looks similar; it is not included here.

16 See Barro and Sala-i-Martin (1995a), Chapter 11.

17 See, for example, Dolado et al. (1994).

18 Here, as in the rest of the chapter, I use the notation x' = dx/dt for the derivative of x with respect to time. The growth rate of x is denoted by g_x = x' / x.

19 See, e.g., Chiang (1984, pp.470) for solving first-order linear differential equations.

20 In Figure 4.8, the time paths of the technology index, based on equation (4.17), are displayed. The equilibrium rate of technical progress, g_t, is assumed to be zero. The other values used are:

(a) s_H : A_t = 0.9^{0.04t} + 0.05
       s_L : A_t = 0.9^{0.04t} + 0.03
(b) b_1 : A_t = 0.9^{0.04t} + 0.05
       b_2 : A_t = 0.9^{0.01t} + 0.05

21 See the Appendix for an analysis of the stability properties of the model.

22 The third alternative estimator would be Chamberlin's minimum-distance estimator. See, for example, Chamberlin (1984).

23 Different specifications of the econometric model were applied. In particular, estimating equation (20) in differenced form did not change the results.

24 β = e^{-λτ}, where τ equals the average subperiod length in years. Thus, λ = - ln(β) / τ with τ = 5.25.

25 The estimates for the fixed effects obtained from other regressions are similar.

26 De la Fuente (1995a,b) provides a formal model for the subsequent argument.

27 This is in line with results obtained from De la Fuente (1995) and Dowrick and Nguyen (1989). Islam (1995) obtained, for a large sample of economies, which includes developing countries, a positive correlation between the estimated technology levels and the subsequent average growth rate.

28 See Begg and Mayes (1993) for a similar argument.