Factor Accumulation Story: Any Unfinished Business?

Michal Kejak
David Vavra

CERGE-EI

Charles University
Center for Economic Research and Graduate Education
Academy of Sciences of the Czech Republic
Economics Institute

WORKING PAPER SERIES (ISSN 1211-3298)
Electronic Version

220

Factor Accumulation Story: Any Unfinished Business?*

Michal Kejak[†] **and David Vavra**[‡]

This version 27 June 2003

Abstract

We construct a new measure of knowledge capital as an aggregate production factor in the sense of Lucas and employ it in a standard growth and variance accounting exercise. We base this new measure on the available data on educational attainment using the empirically confirmed relationship between the level of education and productivity growth. Decomposing the post war growth record we find that most of the growth in income per worker has been explicable in terms of factor accumulation. Overall, the scope for technology residual remained negligible, although there are important differences among various country groups. Unlike the results on growth accounting, explaining the variation in the average growth performance of the individual countries through the variation in the rates of growth of the production factors still leaves a substantial part of the variation unexplained. Yet, this part is significantly smaller than what other studies have ascribed to the variation of the technology residual. Lastly, we also demonstrate how the new measure of knowledge stock may be used to test theoretical predictions regarding the recent convergence experience in the EU periphery. The good fit of the theory can be interpreted as an indication that the theory provides a reasonable candidate explanation for total factor productivity growth.

Abstrakt

V této práci navrhujeme nový způsob měření znalostního kapitálu (knowledge capital) jako faktor agregátní produkce v Lucasově pojetí a ten pak užíváme ve standardních růstových a variančních dekompozicích. Tato nová míra je založena na dostupných datech o dosaženém vzdělání s použitím empiricky potvrzeného vztahu mezi úrovní vzdělání a růstem produktivity. Dekompozice údajů o poválečném růstu ukazuje, že většina růstu důchodu na pracovníka může být vysvětlena akumulací výrobních faktorů. Celkově rozsah technologického residua je zanedbatelný, ačkoli jsou zde významné rozdíly mezi různými skupinami zemí. Oproti výsledkům růstové dekompozice, dekompozice variancí v průměrných růstech jednotlivých zemí nechává stále podstatnou část variancí nevysvětlenu. Přesto je tato část významně menší než vykazují jiné studie. Dále také ukazujeme, jak může být toto měření znalostního kapitálu užito k testování teoretických predikcí týkajících se nedávné konvergenční zkušenosti v zemích tzv. periférie Evropské unie. Dobrá shoda s teorií muže být interpretována tak, že tato teorie by mohla poskytnout rozumné vysvětlení růstu celkové faktorové produktivity (total factor productivity).

*We are grateful to Max Gillman and Sjak Smulders for useful comments.

[†]CERGE-EI is a joint workplace of the Center for Economic Research and Graduate Education of Charles University and the Economics Institute of the Academy of Sciences of the Czech Republic, P.O. Box 882, Politických vězňů 7, 111 21 Praha 1, Czech Republic, Phone: +420-224-005-186, Fax: +420-224-227-143, E-mail: Michal.Kejak@cerge-ei.cz

[‡]Česká národní banka, Senovážná 3, 115 03 Praha 1, E-mail: david.vavra@cnb.cz

Keywords: human capital, endogenous growth, total factor productivity and growth accounting

JEL Classification: O00 and O47

1 Introduction and Motivation

Most of the empirical growth research fails to explain the long run growth performance of the world economy through factor accumulation. This is certainly the case of physical capital, but accounting for human capital does not significantly help, which seems to contradict a one strand of endogenous growth literature going back to Lucas (1988). The bulk of the world growth record is thus necessarily ascribed to factors behind persistent technology improvements, something that is commonly known as total factor productivity growth. All this growth accounting research, however, measures human capital by (variously amended) concepts of educational attainment (e.g. Hall and Jones, 1998, Temple, 2001) or enrolment ratios as the closest available proxies. We want to argue that there is no fundamental reason envisaged by growth theory to measure human capital in this way and that it is the inappropriate use of education data in measuring human capital that gives rise to the negligible role of human capital in empirical growth accounting.

Unlike the standard practice, we don't think educational attainment is directly applicable as a proxy for human capital as one's skill level, essentially because the two are distinct concepts, although they are related. We demonstrate that, if one adopts an extended measurement of human capital that is related to education in a more complex way, which is supported by some empirical growth literature, then the newly constructed measure plays a much more significant role in explaining the post-war world growth record. This remarkable result is achieved under very simplistic assumptions, and seems to be robust to the few parameters used. The good fit of the theory can be interpreted as an indication that the theory provides a reasonable candidate explanation for total factor productivity growth. Although the role of residual in accounting for growth is greatly diminished, its variation still remains an important factor explaining the differences in growth performance of countries over time. For a margin of our parametrization, however, the variability of the residual among OECD countries falls to zero.

The paper is structured in the following way. In the first section we briefly summarize the current confusion surrounding the theoretical concept of human capital and its empirical measurement. This helps us lay intuitive foundations for an alternative use of education in measuring human capital. This simple alternative is introduced in the second section and a new measure of human capital is constructed. In order to avoid further confusion we refer to this alternative measure as knowledge capital rather than human capital. The standard growth and variance accounting decomposition is performed next for a large set of countries. There we show that the role of total factor productivity in accounting for growth is greatly diminished (for OECD countries, for instance, it is almost negligible), so the chief engine behind world growth rests with factor accumulation. A simple sensitivity analysis checks for the robustness of our results. In the fourth section we take a more focused position and examine how the new way of knowledge capital measurement can help the endogenous growth theory account for the convergence record of few peripheral countries of Europe. The final section summarizes our basic findings.

1.1 Human Capital vs Educational Attainment

Ever since the Lucas (1988) landmark contribution, researchers have been puzzled by the way human capital can contribute to our understanding of long run growth phenomena. This puzzle comes from empirical results (Benhabib and Spiegel, 1994, Easterly and Levine, 2001) which in the majority reject human capital as an important factor behind the productivity *level*, but tend to support the notion of education as a carrier of productivity *growth*(Romer, 1990). All these studies, however, employ various educational data in place of the theoretical concept of human capital, and as such, they are only indicative about the relationship between education and productivity. Because human capital, unlike physical capital, is not directly observable, central to understanding this puzzle is the issue of the measurement of human capital, and in particular the role played in its measurement by educational attainment.

Traditionally, human capital has been measured using data on educational attainment as a direct proxy. Indeed, Aghion and Howitt (1998) in their insightful review on endogenous growth confirms this by writing:

> The educational achievement of a society, usually referred to as the 'human capital stock', plays an important role in economic growth, but the precise mechanism is unclear. (page 354)

The interchange between education and human capital is indeed widespread. For instance, Krueger and Lindahl (2001) in their recent contribution relate micro evidence on returns to investment in one's education to the concept of human capital of an endogenous growth model. They interpret the observation that a change in the amount of schooling has no effect on aggregate productivity as an indication against the human capital as a neoclassical factor of production in the sense of Lucas. Yet, a precise motivation for the use of education in the place of human capital for the purposes of growth theory has remained unclear in their work and elsewhere. In principle, the measurement should always be firmly based in the theory which it is designed to test. The endogenous growth theory, in the words of Lucas (inspired by Rosen, 1976), speaks about one's human capital as 'his general skill level' that improves his productivity.

Somebody with twice as much human capital should be twice as much productive. The literature is, nevertheless, silent about the exact way through which this skill level affects production and the theory thus permits various possibilities. Certainly, there is undoubtedly a positive relationship between the educational attainment and a skill level, but, as we assert later, it is not necessarily a linear one. Or should the productivity of an individual with twice as many years of schooling be twice as high? In any case, though, there is no intuitive indication that education is the appropriate empirical counterpart for human capital as the production factor used in aggregate macroeconomic growth models.

In truth, such an assumption has a serious implication for the interpretation of the growth performance of developed countries, one which our intuition cannot support. In these countries we observe the levels of average educational attainment to hardly move at all over time. Interpreting the educational attainment strictly as a stock of human capital in the sense of Lucas would mean that average skill level in those countries stays approximately constant! Because in Lucas (1988) the accumulation of human capital is the only source of perpetual growth, there is no room left for eventual total factor productivity improvements and the countries with constant average skill levels could grow only along transition paths. The observation of positive long term growth rates in the developed countries therefore contradicts the use of education in the place of human capital as envisaged by the literature following Lucas.

The boldness of the traditional way of using education as a proxy for human capital has also been recognized by others. For instance Hall and Jones (1988), based on the survey of Mincerian wage regressions by Psacharopoulos (1994), suggest years of education should be related to the measure of human capital using an exponential relationship tested in those regressions. Wage regressions are definitely a helpful tool to evaluate the effect of educational attainment on one's marginal productivity proxied by wages. As such, though, they say nothing more than there *is* a relationship between one's education (years of schooling) and one's skill level (i.e., one's stock of human capital), perhaps even an exponential one. These regressions are too stylized, though, to be a reliable source of the exact specification of the appropriate aggregate macroeconomic relationship. Hence, too strict adherence to specification of these wage regressions, in our view, explains why Hall and Jones's concept of human capital measurement has not succeeded in assigning a greater role to human capital accumulation. We return to this point in greater detail in the next section.

On an intuitive level, it seems difficult to even imagine education as a proxy for a person's skill level, i.e. stock of human capital. We think of this skill level as a knowledge base that consists of pools of ideas and little inventions that the person has acquired over the years through a conscious process of knowledge accumulation. Education (either formal or informal) undoubtedly plays a crucial role in this process, because it reflects the ability to build upon and expand the existing base of knowledge. In order not to confuse the matter further, we will refrain from using the term 'human capital' altogether in the remaining part of the main text, simply because the reader might confuse it with education. In its stead we will employ the term 'knowledge capital' which is nonetheless directly related to the concept of human capital in Lucas (1988) and Uzawa (1965). We hold that both these concepts can jointly be understood as the skill level composed of ideas and inventions increasing average productivity.

This interpretation of education is fully in line with the empirical results of the strand of literature initiated originally by Nelson and Phelps (1966). There the positive relationship between education and productivity growth is interpreted such that better education improves the ability to adopt and implement new technologies and ideas, both of domestic and foreign origins. Temple (2001) in his extensive survey of literature on the growth effects of education speaks about 'skills acquired through education.' The distinctive feature of these two concepts is that while a simple allocation of time to the 'production' of ideas and inventions improves productivity (by expanding the available pool of knowledge), better education has no such direct consequences. This distinction is crucial for any empirical work on level or growth accounting, because unless a direct measure of knowledge (or human) capital is available, one cannot employ measures of education attainment directly in place of production factors.

This is also the reason why we think most research studies failed to find significant impacts of human capital (or knowledge) accumulation on the growth performance of countries when they employed educational attainment as a factor of production (see for instance, Temple, 2001, Hall and Jones, 1998). For example, an early test provided by Romer (1990) demonstrated that it is the level of literacy that affects growth in income, rather than its change. This has traditionally been interpreted as a case against the human capital as a factor whose accumulation leads to perpetual growth a la Lucas (Krueger and Lindahl, 2001).

In their influential empirical contribution, Benhabib and Spiegel (1994), inspired by the earlier work of Nelson and Phelps (1966), recognize this by arguing that "the role of human capital is indeed one of facilitating adoption of technology from abroad and creation of appropriate domestic technologies rather than entering on its own as factors of production." In their empirical treatment, though, 'human capital' is simply a measure of school attainment, so the concepts of education and human capital become equivalent. We consider it a gross simplification that leads to their (in our view false) conclusion that it is the *stock* of human capital, rather than its *growth*, which affects the growth of per capita income[1]. This is certainly not the case of productivity enhancing stock of human capital (or knowledge as we like to call it) as in Lucas and that we have in mind here. Nevertheless the conclusions of Benhabib and Spiegel and Romer (1990) become directly supportive for ours, once we strictly interpret their concept of 'human capital' as educational attainment, which it effectively is.

To sum up, we interpret education in line with Benhabib and Spiegel as the capacity to absorb new ideas and creatively build upon the existing (productivity improving) knowledge stock in generating new ones. As a consequence, it is the level of education (measured, for instance, by average attainment) that matters for flows of productivity improving inventions, and hence for the growth of knowledge stock as one's skill level. In other words, a person's skill level grows faster at higher attained levels of education. This also implies that one cannot use measures of school attainment directly in place of knowledge capital as a factor of production in empirical growth accounting exercises.

2 Measuring Knowledge Capital

We restrict our attention on the theory that explains the productivity (or total factor productivity) growth through the embodied forms of knowledge and try to calibrate a measure of knowledge consistent with the theory. The engine of knowledge driven perpetual growth lies in the mechanism through which knowledge is accumulated. Following Lucas, a sufficiently general form of learning technology generating new knowledge could look like:

$$\frac{\dot{h}_t}{h_t} = B(1-u), \tag{1}$$

where h denotes the stock of knowledge as a factor of production and u refers to the proportion of non-leisure time allocated by an average individual to work (as opposed to learning). The productivity parameter B can be in the simplest setting conceived as a constant, as in Lucas (1988). Alternatively, though, it may contain a complex mechanism of the learning technology, such as a catching up process with S-shaped externalities, as in Kejak (2003). In fact, the latter is the formulation that we champion later when discussing the EU periphery convergence.

[1] Krueger and Lindahl (2001) modify their approach and find strong relationship between the productivity growth and both the level of education and its rate of change. However, because they use the initial level of education, their specification can also be understood as the relationship between the average level of education over time and income growth.

In any case, though, the formulation in (1) does not help much in constructing a stock of knowledge capital, unless one has a reliable measure of the time share devoted to work[2], which is unlikely to be the case for the majority of countries. Instead, we may rely on more easily available data on education attainment, which is the standard strategy in the literature. As outlined above, we have to beware, though, the crude practice of confounding knowledge with education. Rather, the construction of a measure of knowledge capital from the available data on school attainment has to build on the earlier assertion that the ability mastered through education facilitates the rate of knowledge accumulation. To keep matters clear and void of too many additional complications we choose as elementary of a specification as one can invent, and examine its implications on the measure of knowledge stock:

$$\frac{\dot{h}_t}{h_t} = \gamma \log E_t, \tag{2}$$

where E denotes the ability to accumulate knowledge mastered through education proxied by educational attainment, and γ is the scale parameter[3]. The logarithm implies a falling marginal impact of an additional unit of education on the rate of knowledge accumulation and concurs with the specification of Benhabib and Spiegel. Although this functional form echoes Nelson and Phelps (1966), it is presumably not contradicting (1): the number of years spent in education can be understood as an indicator of one's time allocated to learning, perhaps expressed relative to one's life expectancy[4].

Solving the differential equation in (2) for the stock of knowledge we find that

$$\log h_t = \log h_s + \gamma \int_s^t \log E_\tau d\tau. \tag{3}$$

As regards the relationship between education and productivity (skill level), this specification implies that i) an additional year of average schooling has a diminishing impact on the average productivity and ii) this marginal impact is falling over time. Both these implications seem to be born out by the micro evidence on the determinants of wage earnings. In the already-mentioned study, Hall and Jones (1998), relying on a survey by Psacharopoulos (1994), work with marginal returns to education fals from 13.4 % for the first four years of education to 6.8 % for the countries with attainment beyond 8 years. In addition, the same survey study reports that the semi-elasticity of earnings has fallen by 2 percentage

[2]Data on annual working hours which are available for a larger set of countries can be problematic, because they also comprise of hours of on-job learning.

[3]The particular choice in (2) was also motivated by the desire to compare our approach to the growth accounting exercise of Benhabib and Spiegel (1994).

[4]Rosen (1976) himself specified the learning production function as concave in the fraction of knowledge devoted to learning, relaxing the linearity of (1).

points over a 12 year period. Although we do not want to draw too far-reaching conclusions from this micro evidence, we interpret it as not contradicting the specification in (3).

The functional specification (3) forms the basis of our measure of knowledge capital. We proxy the ability acquired through education, E, by data on the average school attainment in the population aged 25 and more which come from Barro and Lee (2000) and goes as far back as 1950. Because of the five year paucity of the attainment data, however, we approximate the integral in (3) for any year T for which the data are available as[5]:

$$h_t = h_{t-\Delta t} e^{\gamma \frac{\log E_{t-\Delta t} + \log E_t}{2} \Delta t}, \tag{4}$$

where $\Delta t = 5$. Note that this specification is entirely consistent with the 'ad hoc' specification used by Benhabib and Spiegel in testing whether the level of education (which they refer to as 'human capital') impacts growth. They use the average of the log of attainment to proxy the percentage change in the human capital as the factor of production.

The computation of the knowledge stock from (4) requires an assignment of the initial level of knowledge stock. This is somewhat arbitrarily constructed for the year 1950 on the assumption that the average attainment in 1850 in all countries was exactly 0.1. This simplification is however unimportant for our exercise, for we are concerned with the growth of knowledge and productivity only after 1950.

The last obstacle on our route to employ (4) in a measure of the knowledge stock is the calibration of the free parameter γ. We resort to the underlying theory to provide us with guidance. In an endogenous growth model that would be consistent with the above specification of (1) the productivity would grow on a BGP at the same rate as would the rate of knowledge accumulation (see Lucas, 1988, for the basic argument, and Kejak, 2003 for the same result in a more complicated setting). Hence, if we had an estimate of such a BGP productivity growth rate for a country, we could use its educational attainment and the formula in (2) to obtain an estimate of the appropriate γ as $\gamma = \frac{g^{BGP}}{\log E^{BGP}}$, where g is the income per worker growth and the superscript BGP denotes a value on a balanced growth path. Obviously, in reality it is difficult to find examples of such countries and periods which we could declare with reasonable certainty as periods of BGPs. Additionally, in our calibration of γ we should also account for two alternative theoretical views of the world's growth performance (Klenow et al., 1997): that countries tend to converge to parallel long run BGPs, or follow paths of varying balanced growth rates. We therefore follow two routes. First, we give a calibration for a common balanced rate of growth based on the average

[5]We could even use numeric approximation of the integral function, but consider it an unnecessary complication.

performance of OECD countries and try to establish a reasonable range for the parameter. Secondly, we use every country's growth performance as a basis for calibrating country specific γ, thus entertaining the possibility of varying balanced rates of growth.

To begin with, we put our benchmark common BGP rate of productivity growth at 2.9 % per year, which corresponds to the OECD average in 1950-90. This assumption, combined with the OECD average educational attainment in 1990 of about 9.6 years gives a benchmark value of $\gamma = 0.013$. Obviously, both assumptions leading to this point calibration may be relaxed and perturbed in various ways. In order to address the issue of the sensitivity of our results we try to establish a reasonable range for this parameter based on the available sample. When searching for a permissible lower bound, we find that the US experience defies our benchmark calibration in many respects. First, many authors actually consider the US as the prime example of an economy that has long been close to its BGP[6]. Second, the US productivity has in fact grown only 1.5 % per year over the 1950-1990 period. This assumption would have clearly revised our calibration of γ downwards. The second possible source of upward bias in the benchmark calibration of γ is the educational attainment: the US is currently at about 12 years, well ahead most of the other OECD countries. These assumptions provide an alternative calibration of $\gamma = \frac{0.015}{\log(12)} = 0.006$, which we treat as a lowest reasonable value for the parameter.

As for the upper bound[7], we think that the main margin to perturb is the level of BGP educational attainment, for the benchmark productivity growth of 2.9 is fairly high and its variation among the various sets of countries is not dramatic. On the other hand, the educational attainment varies considerably; for instance the countries' average in 1990 was only 4.1 years, well below the OECD average. Hence, we base our upper bound of γ on the average performance of all the countries in our sample (referred to as a 'world'[8]) in terms of average productivity growth (2.4) and educational attainment (4.1) to give

[6]We note in passing that the US does not seem to be the perfect fit to our requirements, for its average educational attainment is growing over time. For instance, since 1950 it has augmented from about 9 to more than 13 by the year 2000. Part of this growth in educational attainment may be tempered, though, by an adjustment for growth in life expectancy. This has grown by more than 10% between 1950 and 1990, and thus the ratio of educational attainment to life expectancy has risen by only 20% over this period. As we have suggested earlier, it should perhaps be this ratio which should be used in (2) in place of E, because it is a better approximation of the share of the non-leisure time an average person wishes to spend accumulating knowledge.

As a more general caveat, in any case, there is no guarantee that the US BGP is also applicable to other countries at all. In fact, the individual country growth experiences are so diverse that the new growth literature favors the idea of different BGP or, at least, quasi-balanced growth paths. We take up exactly this point later when we analyze the convergence experience in the EU periphery.

[7]However, because it is clear from (4) that our measure of knowledge stock is going to assign a much larger role in growth accounting to knowledge accumulation than other studies, the upper bound is perhaps of less importance for the significance of our conclusions.

[8]For the purpose of this article, we refer to 'world' as the group of 96 countries examined in the Appendix.

$\gamma = \frac{0.015}{\log(13)} = 0.017$.

As alternative sources of calibration we could have also used empirical results from several macro studies on the cross-country growth regressions. For instance, the cited work of Benhabib and Spiegel empirically tests specifications close to ours. When adjusting their coefficients of elasticity between the level of schooling and income by the number of years, we observe that the average of the significant specifications is about 0.007, which is close to the lower bound, but within the chosen parameter range. Krueger and Lindahl (2001) perform similar tests and the (already adjusted) coefficient on the log of initial level of schooling explaining growth in GDP is 0.01, which is close to our benchmark parameterizations. We chose to do a more ad hoc calibration on purpose, for the results of these regression have recently come under criticism for possible misspecification in Topel (1999).

Next, we allow for the eventuality that countries are actually close to their (very different) BGPs, although we do not champion this interpretation of the world's growth. This hypothesis requires a country specific γ. To this end, we take each country's average productivity growth and level of educational attainment in 1990 as proxies for the BGP values. In doing so, we do not only neglect the possibility of transitional convergence paths, but also episodes of productivity catch-up that we think did take place in many countries of our sample. A more elaborate approach would therefore call for time varying γ_t allowing for the existence of quasi BGPs. Indeed, this is the approach we take later when we focus on the growth record in the EU periphery. Here, however, we are driven by the desire to keep the matter simple. We hope that the comparison of outcomes across these different parametrization will give a reasonable picture of the robustness of our main conclusions.

The resulting estimates of the knowledge capital stock, expressed in index form, for individual countries in our data set can be found in the various tables of the Appendix. The index is set to unity at the initial period for which the Barro and Lee data set contains a figure on educational attainment. As a summary, given the exponential nature of the function in (4) it is perhaps not surprising that the measure of knowledge stock exhibits a rapid growth across all country groups. According to the formula (4), the low value of γ leads to correspondingly lower estimates of knowledge capital stock at any point of time, and, as we shall see later, this estimate may in fact be lower than the index of educational attainment as a conventional proxy for knowledge capital. The upper bound of γ, on the other hand, points to an even faster growth in knowledge as the factor of production. It remains to be seen, though, how accumulation of these measures of knowledge combined with the accumulation of physical capital help to explain the growth in the world's income per capita.

2.1 Growth accounting

The measure of knowledge capital stock developed in the preceding section is without a greater significance unless it is actually employed as a factor of production in a standard practice of growth accounting. In assigning the role factors of production have played in productivity improvements in the world economy in its post war history, we may use the aggregate production function of the following general form:

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

where Y is income, K is the physical capital stock, and huN denotes the effective labour input. A refers to the residual that remains after the factor inputs have been accounted for (using the share of capital in value added, α). This residual could loosely be interpreted as the total factor productivity, but under our hypothesis there is no scope for improvements in the total factor productivity besides the accumulation of knowledge.

The effective labour input, huN, derives from the decision of all representative households to allocate the total time of their members to work, uN, augmented by their average level of productivity, h. The average productivity is the skill (or knowledge) level acquired through a conscious process of knowledge accumulation. Again, we refer to it as knowledge, rather than human, capital in order not to confuse it with education, which most of the literature interprets as human capital.

In this interpretation of the aggregate production function N would stand for the total hours available in the economy and u, as before, for the share of the time devoted to knowledge (skill) accumulation. Households split their time into three activities: leisure, work and learning (knowledge accumulation). Because our framework has nothing to say about the allocation of leisure time, we treat this decision as exogenous, driven by factors outside our consideration. Then, we can reinterpret N as the total of non-leisure hours available in the economy. Adjusting the aggregate production function by the total number of workers in the economy, L, we obtain the following intensive representation:

$$\frac{Y}{L} = A\left(\frac{N}{L}u\right)^{1-\alpha}\left(\frac{K}{L}\right)^{\alpha}h^{1-\alpha}. \tag{6}$$

This is the formulation we use for our aggregate growth accounting. The last two terms represent the level effect of the accumulated factors of production (expressed in the intensive form), while the first two relate to other than factor accumulation determinants of productivity level. They are, however, two distinct elements. One is the index of the technological residual, A, of which we have nothing more to say, while the other, $\frac{N}{L}u$, denotes the average hours worked, which reflects two types of household decisions: leisure vs. non-leisure and work vs. learning time allocation. Accounting for the combined effect of accumulated factors on productivity will therefore leave us with the composite of both these effects:

$$T = A\left(\frac{N}{L}u\right)^{1-\alpha} = \frac{Y/L}{(K/L)^{\alpha}\, h^{1-\alpha}}. \tag{7}$$

Unless we have a measure of fluctuations in average worked hours, we cannot decompose the equation further to obtain an estimate of the autonomous movements in the technological residual. Because our growth accounting exercise is conducted for a large set of countries, for most of which such a measure is not available, we resign to a further decomposition[9]. Hence, from now on, we will refer to the composite of $A\left(\frac{N}{L}u\right)^{1-\alpha}$ as a residual with the caveat that movements in this measure are only indicative about fluctuations in technology to the extent that average hours worked stay constant over time[10].

The data on income and capital per labor come from Easterly and Levine (2001)[11]. As for the share of capital in value added we also employ their number of 0.4 and apply it across all countries to keep things simple[12].

[9]One may attempt to use a measure of hours actually spent at work as a proxy for hours worked $\frac{N}{L}u$. For instance, the Groeningen institute reports estimates of hours at work for about 40 countries sometimes going as back as 1950. In our view, however, this measure takes little or no account of the distinction between time actually worked and time spent on on-the-job training. In such a case, this would measure only $\frac{N}{L}$ variation and provided no significant help in searching for an estimate of A. Primarily for this reason and also from the desire to keep the arguments void of additional complicating assumptions, we don't go this route. Nevertheless, we think this is a logical area for further work and research.

[10]An alternative route to overcome the lack of reliable data on working hours for most countries would be to re-interpret N as the total size of the population, assuming away variations in average working hours. Instead of postulating that each person splits her or his time between work and knowledge accumulation, we may simply suppose that each representative household decides on how many of its members spend their time working (fraction of u), while others are occupied with knowledge accumulation or leisure. This interpretation then implies that we measure labor input using the number of workers, L, such that $L = uN$. The normalized versions of this production function in terms of the total population and total workers can therefore be written as:

$$\frac{Y}{L} \equiv \frac{Y}{uN} = A\left(\frac{K}{uN}\right)^{\alpha} h^{1-\alpha}. \tag{8}$$

[11]These data can be retrieved from the following website: http://www.worldbank.org/research/growth/GDNdata.htm. As for the capital stock data, we used estimates based on aggregate investment. The initial 1950 value was constructed using the average accumulation rate in the 1950s.

[12]We have, nevertheless, also experimented with the share of capital at 0.3 without significant effects on the results for OECD countries. The reason is that the growth in physical and knowledge capital are about the same for OECD countries, so the share parameter is immaterial. This parameter becomes important for country groups whose accumulation rates of physical and knowledge capital differ substantially, such as Latin America or East Asia. For the world as a whole, the lower share of physical capital is going to increase the contribution of TFP to productivity growth from about 5 to 10 %. These results may be obtained from the authors upon request.

The results for various parametrization and assumptions are displayed using two different types of tables in the Appendix. The tables with individual country data contain in the their left panels inputs to the growth accounting exercise: the fourth column gives the index of income per worker, the fifth the index of physical capital per worker, and the sixth the index of knowledge capital. The last column in this part of the tables displays the implied index of the total factor productivity (unadjusted for average hours worked), which results from the previous columns on the basis of formula (7). The right panel of the individual country tables translates the information from the left panel into the conventional growth accounting format, displaying the average annual growth rate in productivity and the contribution assigned to the relevant factors of production. The very last column gives the implied unexplained bit of the productivity growth rate, the growth in the technological residual, which should be approximately zero under our theory.

For better clarity, however, the individual country results have also been summarized by geographical groups[13] in separate tables, which give the decomposition of average annual growth rates in income per worker into the factor components.

2.1.1 Traditional Measure of Knowledge Capital

We begin our growth accounting exercise using educational attainment as the conventional proxy for knowledge capital[14]. This should serve as a point of reference to which our later results should be compared and also provide a check with respect to other studies published on this subject. Table 1 gives a summary of the growth accounting exercise for various geographical country groups, while Table 2 provides country details.

The results for OECD countries emphasize the point made in the introduction: residual accounts for almost a third of the observed productivity growth. If the average growth of capital per worker was additionally adjusted for the part of the accumulation due to increase in marginal productivity, unexplained technology would stand as a dominant source of productivity growth.

On the other hand, the results for other country groupings contradict this finding and for the world as a whole factor accumulation over-explains the productivity growth. This stands in a contrast to findings of other studies (e.g. Easterly and Levine, 2001) and highlights the sensitivity of the exercise to various

[13]The results with simple averaging are of no special meaning here, but can be obtained from the authors on request.

[14]This is just one possibility how to treat education as human capital that is common in the literature, see e.g. Barro and Lee (1993) or Temple (2001). Others include enrolment ratios or quality adjusted attainments. This example is not meant to encompass the growth accounting results with various measures of education in place of human capital obtained in the literature.

data sets and methodologies used. In our view, there are several possible sources of this surprising outcome. First, the numbers for the world as a whole have clearly been influenced by the fast post-war growth in educational levels in the third world countries (e.g. Middle East and Africa), which began with very low educational attainments. Here it appears that adjustment for quality of education is most needed. Second, the results are sensitive to the period and data source. This is best manifested by comparing our individual countries data on productivity growth and capital accumulation to the results of detailed growth accounting studies, although substantial data differences are reported for measures of educational attainment as well (Krueger and Lindahl, 2001).

Taking Latin America as an example, Table 2 demonstrates that the recorded contributions of unexplained residual for several countries fall well short of the estimates ascribed to TFP by Elias (1990). For instance, while we find the technology residual played no role in productivity growth in Chile, he assigns it more than 1.5 p.p. of average annual contribution and similarly for other countries he considers. However, his sample includes the decade from 1940-1950 when Latin American countries grew at above average rates. Also for some later periods his output growth numbers come slightly above those in the Easterly and Levine dataset. As a result, his average implied growth of productivity significantly exceeds the numbers from Table 2. With Chile for instance, the difference is more than 0.5 p.p., which bridges some of the gap in the resulting contribution of technology. The rest is necessarily ascribed to differences in methodology.

Another prominent example of a detailed country study is Young's (1995) account of the East Asian growth miracle. Although his conclusions concur with Table 1 in that factor accumulation is the chief engine of this phenomenon, Table 2 reveals there are important country differences. For instance, while he finds no role for TFP in Singapore, we cannot assign to factors of production almost 30% of the observed productivity growth. However, even here the primary data inputs differ. Young reports the average output growth in Singapore at 4.2 %, while the Easterly and Levine data set implies as much as 5.9 %. The difference is exactly the gap in the reported TFP contributions, although his methodology is much more detailed and accurate. For South Korea, another example of a big difference, he reports an average output growth in the period 1965-90 of 4.9 %, while Easterly and Levine over the same period imply 6.5 %. Again, the difference accounts for the gap in TFP contributions.

Taking stock, this comparison of the standard approach to measurement of knowledge capital and other studies highlights a few important points. First, the claim that the unexplained residual accounts for a large share of the observed productivity growth is only confirmed in OECD countries. Elsewhere, disproportionately high growth in educational attainment and different data sources reduce the technology contribution substantially, which is not confirmed by other individual country studies. For this reason, we will be concerned in the next subsection mostly with the results for the OECD countries and interpret the outcomes for other geographical groupings with caution. Above all, then, the review confirms the necessity to look at individual countries' experience in detail. Nevertheless, the broad perspective taken in this paper appears to be a quite useful starting point.

2.1.2 Alternative measurement of knowledge capital

We turn our attention to the thrust of our work, which rests in the new measurement of knowledge capital based on educational data as in (4). Table 3 summarizes the growth accounting exercise for the country groups and Table 4 lists individual countries for our benchmark calibration. Interestingly, we observe that the residual contribution to productivity growth fell marginally below zero for the OECD group, while it remained close to zero for other groupings with the exception of East Asia[15]. Evidently, our measure of knowledge capital has dramatically increased the significance of this production factor in accounting for the post-war growth in productivity in OECD when compared to the results of traditional accounting both from the preceding section or other literature (Easterly and Levine, 2001). Perhaps surprisingly though, this increased significance of knowledge capital seems to be just enough to remove most, if not all, of the scope for the technology driven productivity growth across all country groups[16]. Given the gross simplifications made throughout and the reliability of educational data, where no attempt was made to adjust them for apparent differences in quality (Crafts and Toniolo, 2000), one cannot resist interpreting accumulation of human capital as a good candidate explanation for the total factor productivity movements in accounting for the post-war growth record. This is certainly the case of the OECD, where the average productivity more than doubled between 1960 and 1990, the physical capital quadrupled and knowledge capital doubled, while the total factor productivity residual actually fell by negligible 3% over the whole period.

Tables 5 and 6 provide a sensitivity check on the robustness of our results. The high value of γ further enhances the role of knowledge capital accumulation, so the contribution of technology residuals appears

[15]Even there, though, the relative contribution of the technology is still below 20%.

[16]Interestingly, the results report a substantial negative contribution of TFP to the productivity growth in USA, which serves as our sensitivity check. This, in our view, suggests that the high value of parameter γ is perhaps inappropriate for the USA, and the lower alternative should be attempted. Indeed, as shown later, with the low value of the parameter, the implied TFP growth in USA collapses to almost zero.

even lower for all country groups than in our benchmark calibration. Although it is negative for some groups (e.g. OECD), it is so only marginally and for the world as a whole the residual's contribution is just zero. The alternative lower value of parameter γ, on the other hand, considerably reduces the measure of knowledge capital and hence leaves much more room for the technology determinant of income growth. Table 6 shows that the growth contribution of the knowledge capital and the unexplained residual are just about equal now for both the OECD group and the world group as a whole. Yet, this still leaves technology with only about a 25% contribution to average income growth in OECD compared to as much as 50 % found in other studies (Easterly and Levine, 2001)[17] or 30% in the previous subsection.

Lastly, we perform the growth accounting for the new measure of knowledge capital based on the calibration of individual γ. Tables 7 and 8 provide a summary of this exercise. Evidently, residual's contributions center around zero in all country groups with the exception of East Asia, interpreting the post world growth record in terms of factor accumulation rather than exogenous productivity shifts. Interestingly, Table 8 demonstrates that the unexplained component of the productivity growth in the US, which served a basis for the lower bound of a common γ, is in this case indeed zero.

To sum up the growth accounting exercise: the new measure of knowledge capital enables us to assign most of the post war productivity growth in the world economy to the accumulation of production factors, i.e. physical and knowledge capitals. The new measure of knowledge capital thus seems to fit very well with the theory linking the total factor productivity improvements to the levels of knowledge capital.

2.2 Variance accounting

The other standard accounting exercise[18] tries to explain the observed differences between individual growth records using variance decomposition. In this exercise, the observed variance in the long run productivity growth rates among individual countries is being decomposed into the contributions made by the variance of the individual factors and the technology residual, and their cross covariances. Such a decomposition can readily be obtained from (6):

$$\begin{aligned} var(\hat{Y/L}) &= \alpha^2 var(\hat{K/L}) + (1-\alpha)^2 var(\hat{h}) + var(\hat{T}) \\ &\quad +2\alpha(1-\alpha)\left[cov(\hat{K/L},\hat{h}) + cov(\hat{K/L},\hat{T}) + cov(\hat{T},\hat{h})\right]. \end{aligned} \tag{9}$$

[17]Our reference point, using education in place of knowledge capital, in Table 6 attributes only about a third of the OECD income growth to technology, however.

[18]Note that we cannot perform the level accounting of Hall and Jones (1998), because we lack a reliable estimate of the initial level of knowledge capital. Hence we can only account for long run growth rates in productivity.

The results of this decomposition for the various country groups are shown in the series of Tables[19] 9 through 13, each with a different value of the parameter γ. The tables display relative shares of individual factors in the group variance according to formula (9).

The standard results found in the literature (see e.g. Easterly and Levine, 2001) ascribe a vast majority (about 60%) of the inter country variation in growth rates to the variation in the growth of the technology residual productivity growth, T. The contribution in variation of the physical capital accumulation hovers around 20%. Table 9, for instance, shows the results of variance accounting with the knowledge capital measured directly by educational attainment. There the variance of the implied residual growth even exceeds the observed variance in income growth for all country groups except OECD, where the share is about 33%.

By contrast, with the new measure of knowledge capital based on formula (4) and our benchmark calibration, the relative contribution of the residual variation falls below 30% for the world as a whole and remains at about 33% for the OECD group (Table 10). This finding appears very robust across the alternative calibrations of a common γ: the relative contribution of the residual variation falls even slightly lower at the lower bound (Table 11), and remains at about the same for the upper bound (Table 12).

Evidently, the variation of improvements in knowledge capital as such has a negligible direct impact on the total variance in productivity growth rates. In other words, the individual productivity growth records differ much more than their records in improvements in human capital. However, indirectly through correlation with other variables, our measure of knowledge capital is able to reduce the direct contribution of variance in the growth rates of the unexplained residual to the contribution attained by physical capital. For instance, for the world group and the benchmark calibration of γ, the contribution of the variation in physical capital growth already exceeds the contribution of the variation in the growth of the unexplained residual.

On the other hand, with specific γ the contribution of residual variation falls to zero for the OECD group (Table 13). Although one may have expected the result, given the higher variance of the knowledge capital estimate induced by specific calibration of γ, the intuition is not confirmed for the world as a whole where the relative contribution of the unexplained residual actually rose above 30%.

In summary, the unexplained (technology) improvements in productivity appear to remain an impor-

[19]As before, the tables compute group variances using 1975 labor weights.

tant element explaining the vast differences observed in the post war growth record among individual countries, but with a significantly diminished role. Allowing for non-parallel BGPs, we even find the variance of the residual's contributions among OECD countries close to zero.

3 Calibration to Data: EU Periphery Catch-Up Process

In this section we wish to demonstrate how the technique of knowledge stock measurement introduced in earlier sections can be used in answering more specific questions than those posed by an aggregate growth accounting. In particular, we want to see how it can improve our understanding about the catch up process that has taken place in few EU countries in the past 20 years. Apart from that, the case study can also shed some light on the convergence possibilities of the new EU accession countries, majority of which emerged from the previous command economy system[20].

3.1 EU Peripheral countries: stylized facts

Kejak, Seiter and Vavra (2001a) examine the post-war development of the cohesion countries, namely Greece, Ireland, Portugal and Spain, hoping to identify the factors responsible for the observed patterns of growth and convergence since early 1960s. They find that the group as a whole until relatively recently failed to keep up with the predictions of neo-classical growth theory as regards convergence to

[20]Investigating likely development trajectories of transition countries have been a vivid theme in the literature in 1990s (see the great contribution of Blanchard, 1997, on the specifics of the transition process). Following Fisher, Sahay and Vegh (1998) most researchers investigating future development of transition countries have focused on growth regressions and their determinants (see e.g. Crafts and Kaiser, 2000). Taking a different route, Kejak et al. (2004) employ a stylized growth model of Lucas type to investigate the likely future trajectories of several EU accession countries. The use of such a model requires its validation by calibrating to stylized facts of transition economic development. Although we cannot find in the economic history examples of transitions from centrally planned to market economies, we do have several examples of the integration process to the European Union. Out of them, it seems to us that the recent experience of a subset of the EU countries, commonly referred to as peripheral, can provide enough guidance about the likely development paths of the CEE countries and thus help us in calibrating the theoretical model. This intuition is supported by several facts.

First, many of the EU candidate CEE countries have already undergone most of the reforms and are a long way through the accession to the EU. The specifics of the transformation process become relatively less important and the economic development is being shaped more by standard market mechanisms. Second, peripheral countries upon their accession into the EU shared many characteristics (identified in the literature as important for growth) similar to the conditions prevailing now among the candidate CEE countries. In particular, their income per capita levels were about the same, they are relatively small and open economies and their infrastructure was underdeveloped relative to the core of the EU. Third, the economic development of the peripheral countries since their accession resembles the most recent experience of transition countries in that it required a massive reallocation of resources on the wake of progressive trade liberalization, rapid technological change, influx of foreign capital (especially in the form of foreign direct investment) and high speed of both physical and human capital accumulation.

These similarities show that the recent economic experience of the EU periphery can indeed become a single useful tool for studying the process of convergence of the most advanced among the transition countries. This fact has already been recognized by other studies on transition economies (see for instance, Barry et al., 2000, Barry et. al., 2003, and Kejak and Vavra, 1999).

the EU average income per capita standards. Most recently only Ireland drifted away from the group and surpassed the EU average.

The pattern of convergence in the EU periphery has not been monotonic, though. Peripheral countries displayed higher than EU average growth rates and partly converged in the period of 1960-1975. Yet, they remained among the poorest in Western Europe. This feature prevailed in the next decade 1975-1985, when they hardly maintained their relative income per capita standards. It was only in the late 1980s when the process of convergence resumed and the peripheral countries, led by Ireland, began to approach EU average income levels. It was also then, when the relative homogeneity of the group was broken and differences between forerunners (Ireland and Spain) and a laggard (Greece) became more apparent.

Kejak et al. (2001a) review most of the basic channels identified by theory as important for long-run growth in order to see whether they are capable of explaining the observed phenomena in the process of peripheral convergence. They found, however, that taken individually these factors cannot account for most of the observed patterns. In particular, the rates of capital accumulation have always been higher and the size of government smaller in the periphery than in the core, yet the countries failed to converge. The enrolment ratios have been rising steadily throughout as well as the exposure of countries to international trade flows. The combining of the individual growth factors in standard growth regressions did not proved very helpful. The authors were able to find that the factors together predict reasonably well within group variations in growth rates until the end of 1980s, but are not capable of explaining the stagnation of 1975-1985. Likewise, they failed to predict differences in individual records over the recent decade, partly perhaps because the measures we have used were no longer adequate.

The study vaguely attributes the relative success of these countries since mid 1980s to the progress of accession and integration within the EU, even though the cohesion countries generally entered the Communities in different periods (notably Ireland being the member already since 1973). Numerous attempts have already tried to identify the channels through which the progress of integration could have impacted positively on the recent convergence record in the EU periphery and would also have the potential of explaining the stagnation of the pre and early accession periods. For instance, Barry (2002) argues that it was primarily the presence of hi-tech and outward oriented foreign multinational enterprizes, whose presence was stimulated by stable macroeconomic environment in which the room for discretionary policy actions have largely been confined. However, both him and Bradley (2002) concur in stressing the importance of positive externalities that have ensued from well educated labor force and improved infrastructure. The EU has played a pivotal role in both these respects, for it has distributed large amounts of regional aid under the CSF programme designed to improve physical and human infrastructure, and also as a direct aid to enterprizes in Bradley (2002). This aid has been aimed as a supply-side device enhancing the competitiveness of the lagging EU regions vis-a-vis the introduction of the Single Market in 1992 and the peripheral countries ended up being the main beneficiaries of this programme. Message that clearly emerges from this literature is that to understand such complex effects one needs a macroeconomic perspective that fully embodies the findings of the modern growth literature on the mechanics of knowledge and infrastructure externalities, and international capital movements, especially with respect to locational decisions of the MNEs.

3.2 Stylized catch-up implications of an endogenous growth model

As a partial step along this route of studying the implications of the EU membership on the development of EU peripheral countries, we have chosen to follow a highly stylized concept of endogenous growth through knowledge accumulation where the accumulation technology benefits from the learning technology of a leading country. This approach has been pioneered by Nelson and Phelps, but more recently it has also been used in a Lucas type framework, such as in Kejak's (1997) model of S-shaped externalities in the learning sector. The learning productivity benefits from the leading technology only to the extent to which this is made possible by ad hoc, say institutional, factors and openness of financial markets.

This framework seems to be especially useful in studying the experience of the EU periphery, because it is general enough to account for various stages of economic development as a function of the initial conditions and the way productivity in the knowledge sector benefits from the state of the art technology. In particular, a country can experience a protracted period of low growth or stagnation before the potential of the leading technology begins to be realized. Only then the country starts to take off and converge to the BGP prescribed by the leading technology. One of the implications of this framework, through which we would like to test this theory on the experience of the peripheral countries, concerns the optimal relative proportion of production factors at various stages of the economic development. Specifically, countries which have not yet begun to profit from the technological potential should experience higher ratios of physical to knowledge capital than those closer to the BGP. Closer to BGP countries enjoy higher productivity in learning and hence a unit of knowledge capital is cheaper relative to the cost of physical capital in terms of income foregone by learning.

The purpose of the next sections is, therefore, to position the economic development of several cohesion countries, namely Greece, Ireland, Portugal and Spain, within the highly abstract nature of such a theoretical model and calibrate model parameters consistent with their individual experiences. We search for the period of technological take-off in the EU periphery by examining the periods immediately preceding and following the accession of these countries to the EU.

In terms of the model language the process of accession can manifest itself using two basic channels. On the one hand, as progressive opening of the economy in terms of trade and capital flows, and on the other, as a massive technological transfer that enables fast technological catch-up with the technological frontier of the advanced countries. Hence, it is precisely the developments in the periods around the accession that can be used to validate the implications of an endogenous growth theoretical approach[21].

3.3 Calibration of knowledge capital in EU Periphery

In order to implement the catch-up technology into the framework of earlier sections we would have to generalize the linear Uzawa-Rosen formulation of the production function for knowledge capital assuming that the level of productivity in the education sector, B, depends on the developmental level of a society expressed by the average level of human capital :

$$\dot{h} = B(h)(1-u)h. \tag{10}$$

The function $B(h)$ is now made to represent[22] a more complex technology than the simple linear constant in (5), such as that in Kejak et al. (2004):

[21]Taking each channel in turn, each of the peripheral countries did see their share of exports substantially rise around the time of they entry into the Communities (Kejak et al., 2001a). Apart from Greece, all of the countries managed to preserve and increase the shares since, with Ireland almost doubling its initial value. Higher trade openness went along improved access to international financial markets. Higher capital mobility envisaged by the process of integration should have enabled better opportunities for intertemporal substitution of consumption as well as for financing of the local physical capital build-up. As a consequence of higher local marginal returns to capital, foreign savings would be attracted.

In line with the theory, current account deficits rose rapidly, financed from various sorts of capital inflows. Buch (1999) reports that following the entry, the structure of capital inflows shifted away from bank loans and investment towards FDI and portfolio investment.

[22]Much like Zilibotti (1995) we consider eventual large advances of technological innovations as being exogenous in the sense that economic activity has no effect on the occurrence of revolutionary advances. Instead, we focus on more cumulative and continuous progress during which the society learns how to use this potential. This type of innovation depends on the gap between the present level of technology and the frontier productivity level given by the first type of innovation (see Nelson and Phelps, 1966). We assume here, consistent with Lucas (1988) and Azariadis and Drazen (1990), that technical progress is driven by investment in human capital such that:

$$\frac{\dot{B}_t}{B_t} = \phi \frac{B_H - B_t}{B_H} \dot{h}_t. \tag{11}$$

Solving the equation gives us the formula in the main text.

$$B(h) = \frac{B_H}{1 + (\frac{B_H}{B_0} - 1)e^{-\phi h}}, \tag{12}$$

where B_H means the frontier productivity, $B_H \geq B_t$, $\phi > 0$ is the parameter of the speed of diffusion and h is the average level of human capital in the economy. Consistently with Parente and Prescott (2000), the diffusion parameter is a measure of the barriers to knowledge adoption. B_0 is the initial level of productivity related to a zero level of human capital. We can easily see from (12) that there is an upper bound of productivity given by B_H (i.e. if h goes to infinity, productivity converges to B_H). We also observe that the farther from the frontier an economy is and higher the diffusion parameter, the faster the growth of productivity for a given level of investment.

The process of knowledge accumulation in this framework occurs along two lines. First, on the BGP, it is simply driven by the ability to innovate on the technological frontier, B_H:

$$\frac{\dot{h}_{BGP}}{h_{BGP}} = B_H(1 - u). \tag{13}$$

This resembles very much the simple relationship considered earlier. Second, if the country's productivity in the knowledge sector is below the frontier, knowledge accumulates gradually as the society learns how to use the frontier potential. This we call a quasi balanced growth path (QBGP). An economy on a QBGP can experience long periods of steady, but low, growth before openness and other institutional arrangements enable it to reap benefits of the more advanced learning technology.

We construct a measure of human capital in very much the same way as in the previous section to preserve simplicity. Nevertheless, our discussion illuminates that this time we require our measure to allow for the experience of various stages of economic development, such as stagnation (exemplified by a QBGP) and high growth. For instance, an empirical counterpart of the specification (10) and (12), employed in Kejak et al. (2004), considering the appropriate effect of education, could take the following general form:

$$\frac{\dot{h}_t}{h_t} = f(E) + g(E)\frac{B_H - B_t}{B_H}, \tag{14}$$

where $f(.)$ and $g(.)$ are increasing functions of educational attainment, E. The first term simply recognizes that it is the level of educational attainment which drives knowledge accumulation on the BGP. The last term reflects the effect of the catch-up potential on the knowledge accumulation, proxied by the distance of productivity from the level of the most technologically advanced country.

The possibility that impact of the catch-up potential depends on the level of educational attainment recognizes that ability to innovate acquired through education also facilitates adoption of foreign ideas and inventions. This specification corresponds to the functional form of Benhabib and Spiegel who interpret the first term as the impact of capacity to innovate domestically, while the latter represents the impact of diffusion of foreign ideas. For the poor countries they find the latter term to dominate over the effect of domestic innovation and vice versa for the richest tier of the countries. These conclusions are consistent with the implications of our model framework, for the poorer countries tend to find themselves in the course of the productivity take-off.

Nevertheless, constructing a measure of knowledge capital from (14) requires many additional assumptions and sophistication, while our goal is to demonstrate how even a rather crude specification can improve our understanding of the EU periphery catch-up process. Rather we will again rely on the simple relationship (2) of the earlier sections:

$$\frac{\dot{h}_t}{h_t} = \gamma_t \log(E_t). \tag{15}$$

In order to ensure at least basic compliance with the implications of our framework, we allow for the productivity parameter to take on different values according to the phase of a country's development. In particular, we set the impact of education higher during the productivity take-off than before or after it. This can be handled by different values of γ, which should be high during the productivity take-off, and lower before (or after)[23]. We adopt the growth rate of income per capita as a proxy discriminating between these cases. Because we are mostly interested in explaining the productivity performance of the EU peripheral countries in two different stages of their development, we conveniently allow only for two values of γ: before (and inclusive of) 1985 (the moment since which we have observed the convergence) and after. We substitute the productivity growth rate for the rate of knowledge accumulation in (2) and compute γ for every year of data on educational attainment. We then average the gammas in the period

[23]As regards the calibration of γ, in order to employ equation (2) we need a measure that would be closely correlated with the rate of knowledge accumulation. As before, a natural candidate appears to be the rate of productivity growth, g. This rate would however equal the rate of knowledge accumulation only on the BGP, where the joint growth rate is given by parameters independent of the level of h. The rate of knowledge accumulation outside the BGP is affected by two additional considerations. First, on the QBGP before the productivity take-off, it is influenced by the perceived potential of technological catch-up. As we said, we can handle this by different values of γ during and before the productivity take-off.

The second complication stems from the transitional dynamics out of QBGP that make h behave differently from (14). Because we assume the effect of this distortion is greater the further we go back in history (the possibility that the country is far from its QBGP increases), we account for it by averaging γ only in 1975-1985 period, instead of 1960-1985. We then use this γ_{75-85} in constructing the human capital index for the whole 1960-1985 period and γ_{86-00} for the 1986-2000 period with the help of (2).

of 1986-2000 (representing the take-off) and before[24].

3.4 Review of stylized catch-up implications

Our estimates of the evolution of knowledge and physical capital stock in the four peripheral countries since 1960 are summarised in Tables 10 and 11 of the Appendix. As we said in the introduction to this part, we want to examine whether the ratio of physical to knowledge capital evolves according to the theory in the various stages of the economic development. In order to see this, we have graphed the outcomes of the calibration process in $k-h$ plane in Figures 1 through 3 of the Appendix.

In general, the observed patterns conform very well to the theoretical predictions of the growth mode based on catch-up in the learning sector. First, the initial period since 1960 to 1975 was characterized by a high rate of physical capital accumulation alongside only moderate improvements in knowledge. The trajectory of k versus h is therefore very steep in this period for all the peripheral countries. This corresponds to a relatively low BGP rate of growth through the low productivity in the knowledge sector. The fact that the countries did experience fast growth and convergence during this period is due to transitional dynamics along the lines of conventional neoclassical growth models. As a check, we also observe that German trajectory in the same period is much steeper. This corresponds to the intuitive relative positioning of these countries as a technological leader (Germany) and laggards (periphery). The development across the peripheral countries was also quite uniform, as they maintained their initial relative standing.

Second, we begin to see interesting differences in the 1975-85 period, when the $k-h$ trajectory for the group as a whole began to bend towards that of Germany. This may suggest that the potential of the take-off began to be realized already in this phase, at least for some countries. The behavior of the group was influenced by the developments in Portugal and Spain, where the trend from the previous period

[24]Because the period of interest for the cohesion countries only partially overlaps with the the one from the preceding sections, we also had to construct a new dataset. We chose to do so from the available data published in the European Economy (2000) which also cover the most interesting (from the EU periphery perspective) 1990s period. Concurrently, we adopt GDP per capita in 1995 prices as our measure of economic performance and formulate all intensive variables with respect to total population. We choose the year 1960 as our starting period and normalize the starting level of GDP per capita so that EU15 equals 100.

In a similar vain, the necessity to construct a measure of physical capital per worker , $\frac{K}{L}$, over the 1990s made us employ the perpetual inventory formula starting with a notional value in 1960. To derive this notional value, $\left(\frac{K}{L}\right)_{1960}$, we took the average growth rate of investment per worker over the 1960s, g, and assumed the rate of depreciation, δ, of 7%. Then, we determined $\left(\frac{K}{L}\right)_{1960}$ as $\frac{(I/L)_{1960}}{(g+\delta)}$. Using this approach, the potential bias in the notional value would rapidly fall and arguably will have disappeared by the onset of the 1980s, which is our period of interest. To check for this bias we also experimented with the notional value set according to stylized fact for developed economies: $\left(\frac{K}{L}\right)_{1960} = 2.5\left(\frac{Y}{L}\right)_{1960}$.

was broken. We already noted in an earlier remark that it was precisely in these two countries where the announcement effects of the likely accession materialized in high FDI inflows prior to accession. Because we interpret FDI as carriers of technological change, these developments are entirely consistent with the model predictions. Interestingly, trajectories of Greece and Ireland continued to be very steep in this period, pointing to low productivity in knowledge sector without the catch-up potential.

Third, in the period 1985-2000, bluntly identified as the period of the catch-up, we observe that the slope of trajectories of all countries, inclusive of Ireland and Greece, has approached that of Germany (in the 1985-1990 period). The fact that the EU periphery in this period did begin to converge is therefore not surprising in the light of the model prediction. The failure of Greece (whose trajectory has interestingly had the lowest slope since 1980) to converge is pathological and is most likely attributable to social and institutional obstacles that has so far prevented it from capturing the benefits of higher technological potential.

Similarly difficult to interpret is the sudden rise in the slope of the Irish trajectory in the most recent period. Although it may be linked to accounting and measurement problems, it may also be fully consistent with the underlying theory. Over the period in question Ireland lowered substantially its corporation tax, thus increasing marginal product of capital[25]. In an extended set-up of the above model, it could be shown that this would lead to a steeper BGP trajectory in the $k-h$ plane. The jury, however, is still out. Because this recent experience of Ireland has shifted also the slope of the group average, we do not comment on it, until more country specific research is done.

Taking stock, the experience of the EU peripheral countries in the 1975-1995 fits model predictions reasonably well. This allows us to use the model insight in explaining the seeming puzzle of the relative stagnation in the EU periphery in 1975-1985 and the convergence of the recent period, which could not be accounted for using conventional growth factors and techniques (Kejak et al., 2001a). It appears that the stagnation of the 1975-85 period was an outcome of the low technological potential when the forces of transitional dynamics through physical capital accumulation of the previous period had petered out and technological potential could not be realized through various (mostly institutional) obstacles. Only increased openness and inflows of FDI, enabled by the EU membership, paved the way for the diffusion of knowledge from the technologically more advanced countries.

[25] We thank a referee for raising this point.

4 Conclusions

We restrict our attention on the theory that explains the productivity (or total factor productivity) growth through the embodied forms of knowledge and try to calibrate a measure of knowledge capital consistent with the theory. We construct a new measure of an average worker's skill level as an aggregate production factor in the sense of Lucas (1988) and employ it in a standard growth and variance accounting exercise. As standard in the literature, we base this measure on the available data on educational attainment. Unlike the standard approach, though, we do not use education data as a proxy for this skill level, essentially because we do not think that level of education is the appropriate stock concept of a production factor. Rather we interpret education as the capacity to increase one's skill level. This interpretation concurs with the specification of Nelson and Phelps and is also supported by the empirical literature. In order to prevent further confusion, we call this measure knowledge capital rather than human capital, because the latter term is repeatedly used in the sense of educational attainment.

Decomposing the post war growth record in the world economy into the share attributable to factors of production and the technology parameter, we find that the bulk of the growth in income per capita has been explicable in terms of factor accumulation. The scope for unexplained (technology) residual remained largely negligible, although there are important differences among various country groups. The results appear to suggest that factor accumulation has indeed been the chief engine behind the world post war growth record. This comes as a direct contradiction to the conventional results on growth accounting using education as a factor production in place of knowledge capital. The good fit of the theory can be interpreted as an indication that the theory provides a reasonable candidate explanation for the total factor productivity growth.

Unlike the results on growth accounting, explaining the variation in the average performance of the individual countries still leaves a bulk of it unexplained by variation in the rates of factor accumulation. This supports the common finding that the variation in the total factor productivity is an important element in the variation of the productivity growth. Yet, this part is significantly smaller than what other studies have ascribed to the variation of the technology residual. At limits of our parametrization, the variation of the residual is almost absent among the OECD countries.

Lastly, we have shown how our measure of knowledge capital may be used to test predictions of a theoretical growth model of the Lucas type regarding the recent convergence experience in the EU periphery. We observe that indeed the data fit very well the model predictions and we give an illustrative account of the major forces behind the catch-up in the EU periphery. Although these results are quite promising, further tests will be necessary to justify the theory. Accession countries, for instance, appear in many respects similar to the EU peripheral countries in the early days of their EU membership. Testable predictions for their growth profile based on the proposed theory are an agenda for further research.

References

[1] Aghion, P., and P. Howitt, 1998, *Endogenous Growth Theory*, MIT Press, Cambridge Massachusets.

[2] Azariadis, C. and A. Drazen, 1990, Threshold Externalities in Economic Development, *The Quarterly Journal of Economics*, 105, 501-526.

[3] Barro, R.J., and J. Lee, 1993, International Comparisons of Educational Attainment. Journal of Monetary Economics, 32, 263-394.

[4] Barry, F., 2002, R&D and FDI effects on competitiveness of accession countries. Paper presented at the IIASA workshop on *Catching-up and EU accession - conditions for fast areal convergence in the candidate countries,* Bratislava, Slovakia, February

[5] Barry, F., J. Bradley, M. Kejak, and D. Vavra, 2000, The Czech Economic Transition: Exploring Options Using Macrosectoral Model. Working Paper 158, CERGE-EI.

[6] Barry, F., J. Bradley, M. Kejak, and D. Vavra, 2003, The Czech Economic Transition: Exploring Options Using Macrosectoral Model. *Economics of Transition*, forthcoming.

[7] Benhabib, J. and M. M. Spiegel, 1994, The Role of Human Capital in Economic Development: Evidence from Aggregate Cross-Country Data, *Journal of Monetary Economics*, 24, 143-173.

[8] Bradley, J., 2002, National Development Plans and pre-accession Structural Funds: The experiences of Ireland, Latvia and Estonia. Paper presented at the IIASA workshop on *Catching-up and EU accession - conditions for fast areal convergence in the candidate countries,* Bratislava, Slovakia, February

[9] Buch, C.,M., 1999, Capital Mobility and EU Enlargement, *Weltwirtschaftliches Archiv*, 135(4)

[10] Easterly, W., Levine, R., 2001, It's Not Factor Accumulation: Stylized Facts and Growth Models. *World Bank Economic Review*, Volume 15, Number 2.

[11] Elias, Victor J. 1990, *Sources of Growth: A Study of Seven Latin American Economies*, CA: International Center for Economic Growth

[12] Hall, J., Jones, CH., 1999, Why do some countries produce so much more output than others? *Quarterly Journal of Economics* 114(1), February 1999, 83-116

[13] Kejak, M., 1998, Stages of Growth in Economic Development, Working Paper No. 138, CERGE-EI.

[14] Kejak, M., 2003, Stages of Growth in Economic Development, *Journal of Economic Dynamics and Control*, 27, 771-800.

[15] Kejak, M., S. Seiter, and D. Vavra, 2001a, Convergence and Growth in EU Periphery: Stylised Facts, Final report to the ACE-Phare project P97-8034.

[16] Kejak, M., S. Seiter, and D. Vavra, 2001b, Endogenous Growth Theory and Trajectories of Accession: Motivation, Final report to the ACE-Phare project P97-8034.

[17] Kejak, M., S. Seiter, and D. Vavra, 2004, Accession Trajectories and Convergence: Endogenous Growth Perspective, *Structural Change and Economic Dynamics*, forthcoming.

[18] Kejak, M., and D. Vavra, 1999, Modeling the Macroeconomic Impact of the CSF on the Czech Republic Using the HERMIN Model: Some Preliminary Results. Discussion Paper No. 1999-27, CERGE-EI.

[19] Klenow, Peter and Andres Rodrigues-Clare, 1997, Economic Growth: A Review Essay, *Journal of Monetary Economics*, 40: 597-617

[20] Krueger, A., B., Lindahl, M., 2001, Education for Growth: Why and For Whom?, *Journal of Economic Literature*, vol. 39, pp. 1101-1136

[21] Lucas, R. E. Jr., 1988, On the Mechanics of Economic Development, *Journal of Monetary Economics*, 22, 3-42.

[22] Nelson, R. R. and E. S. Phelps, 1966, Investments in Humans, Technological Diffusion, and Economic Growth, *American Economic Review*, 56, 69-75.

[23] Parente, S. L., and E. C. Prescott, 2000, Barriers to Riches. Cambridge, MA: MIT Press.

[24] Psacharopoulos, G., 1994, Returns to Investment to Education: A Global Update. World Development, 22(9), 1325-1343.

[25] Romer, P., 1990, Human Capital and Growth: Theory and Evidence, *Carnegie Rochester Conf. Ser. on Public Pol.* 32:0, pp 251-86

[26] Rosen, S., 1976, A Theory of Life Earnings, *Journal of Political Economy*, 84, 454-567.

[27] Temple, J., 2001, Generalizations that aren't? Evidence on education and growth. *European Economic Review*, May 2001, 45(4-6), 905-918.

[28] Topel, R., 1999, Labor Markets and Economic Growth, in *Handbook of Labor Economics*. Orley Ashenfelter and David Card, eds., Amsterdam: North Holland

[29] Uzawa, H., 1965, Optimum Technical Change in an Aggregative Model of Economic Growth, *International Economic Review*, 6, 18-31.

[30] Young, Alwyn (1995). The Tyranny of Numbers: Confronting the Statistical Realities of the East Asian Growth Experience, *Quarterly Journal of Economics*, 110: 641-680

[31] Zilibotti, F., 1995, A Rostovian Model of Endogenous Growth and Underdevelopment Traps, *European Economic Review*, 39, 1569-1602.

Table 1 Growth accounting with education in place of human capital*

Country group	No. of Countries	Average annual contribution to income p.w. growth			
		Income p.w.	Physical Capital p.w.	Knowledge Capital p.w.	TFP***
OECD	23	2.94	1.46	0.56	0.91
Latin America	22	1.75	1.00	0.96	-0.20
Middle East	8	1.02	1.50	3.37	-3.64
South Asia	4	2.01	1.11	1.88	-0.95
East Asia	10	4.09	2.64	1.90	-0.40
Africa	29	0.81	0.70	2.41	-2.20
World**	96	2.44	1.38	1.40	-0.32

Legend:

* $h = E$

** Excludes former socialist countries and China

*** Includes both TFP and variation in actual worked hours (see text)

p.w. ... per worker

Group and world weighted averages have been computed using the size of employment in 1975

Table 2 Individual countries data with education in place of human capital*

			Index of (Initial period=1)				Average annual contribution to income p.w. growth			
Country Code	Initial Period	End Period	Income p.w.	Physical Capital p.w.	Knowledge Capital p.w.	TFP***	Income p.w.	Physical Capital p.w.	Knowledge Capital p.w.	TFP***
aus	1960	1990	1.57	1.75	1.07	1.21	1.47	0.73	0.14	0.61
aut	1960	1990	2.49	4.09	1.23	1.26	2.99	1.86	0.39	0.74
bel	1960	1990	2.22	2.36	1.13	1.46	2.60	1.12	0.24	1.23
can	1960	1990	1.77	1.86	1.25	1.20	1.85	0.81	0.44	0.59
dnk	1960	1990	1.69	2.40	1.13	1.10	1.70	1.15	0.24	0.32
fin	1960	1990	2.36	2.66	1.77	1.14	2.81	1.28	1.11	0.41
fra	1960	1990	2.25	3.20	1.31	1.20	2.65	1.53	0.52	0.60
dfa	1960	1990	2.16	2.67	1.09	1.38	2.52	1.29	0.17	1.05
grc	1950	1990	5.14	8.76	2.06	1.40	4.07	2.17	1.07	0.82
irl	1960	1990	2.87	3.33	1.32	1.50	3.46	1.58	0.54	1.32
ita	1950	1990	4.90	5.00	1.51	2.01	3.95	1.60	0.61	1.71
jpn	1950	1990	8.72	14.97	1.20	2.65	5.42	2.73	0.27	2.40
nld	1960	1990	1.83	2.12	1.63	1.01	1.96	0.98	0.96	0.02
nzl	1960	1990	1.19	1.50	1.17	0.92	0.57	0.53	0.30	-0.25
nor	1960	1990	2.05	2.01	1.78	1.10	2.34	0.91	1.12	0.30
prt	1960	1990	3.43	3.97	2.23	1.22	4.05	1.82	1.57	0.64
esp	1960	1990	3.22	4.49	1.67	1.30	3.85	1.99	1.00	0.84
swe	1960	1990	1.64	1.94	1.25	1.10	1.60	0.86	0.44	0.30
che	1960	1990	1.63	2.59	1.36	0.93	1.59	1.25	0.60	-0.25
tur	1950	1990	4.66	6.38	3.95	0.97	3.82	1.85	2.04	-0.07
gbr	1950	1990	2.29	3.37	1.19	1.27	2.05	1.20	0.26	0.58
usa	1950	1990	1.79	1.94	1.51	1.08	1.44	0.65	0.61	0.18
isl	1960	1990	1.99	2.15	1.41	1.19	2.24	1.00	0.67	0.56
isr	1955	1990	3.18	2.58	1.38	1.79	3.26	1.07	0.54	1.63
irn	1960	1990	1.14	3.01	5.33	0.27	0.42	1.45	3.33	-4.16
irq	1960	1985	1.24	3.56	11.14	0.18	0.82	2.00	5.83	-6.48
jor	1960	1990	2.82	9.28	3.85	0.51	3.40	2.98	2.67	-2.12
syr	1965	1990	2.08	2.51	3.25	0.71	2.86	1.44	2.78	-1.31
bhr	1980	1985	0.72	0.94	1.21	0.66	-5.37	-0.42	1.95	-6.78
cyp	1960	1990	3.64	2.40	1.96	1.71	4.25	1.15	1.32	1.75
kwt	1985	1985	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00
arg	1950	1990	1.38	2.57	1.78	0.67	0.79	0.93	0.85	-0.98
bra	1960	1990	1.99	2.46	1.33	1.17	2.24	1.18	0.55	0.51
chl	1950	1990	1.73	1.92	1.62	1.00	1.34	0.64	0.71	-0.01
col	1950	1990	2.30	2.02	1.95	1.16	2.05	0.69	0.99	0.37
mex	1950	1990	2.49	3.15	2.53	0.90	2.25	1.14	1.37	-0.25
per	1960	1990	1.09	1.38	1.96	0.64	0.26	0.42	1.32	-1.44
ven	1950	1990	1.21	1.13	2.43	0.68	0.47	0.12	1.32	-0.95
bol	1960	1990	1.60	1.13	1.12	1.42	1.53	0.15	0.23	1.14
brb	1965	1985	1.45	1.98	1.39	0.90	1.77	1.32	0.95	-0.49
cri	1950	1990	2.36	3.41	1.59	1.09	2.12	1.22	0.68	0.22
dom	1960	1990	1.67	2.81	1.81	0.78	1.67	1.35	1.16	-0.82
ecu	1950	1990	2.63	3.00	2.52	0.97	2.39	1.09	1.37	-0.06
gtm	1950	1990	1.63	1.87	2.15	0.80	1.20	0.61	1.13	-0.54
guy	1960	1990	0.53	1.00	1.55	0.41	-2.03	-0.01	0.86	-2.85
hnd	1960	1990	1.37	1.42	2.18	0.74	1.01	0.46	1.53	-0.95
hti	1965	1985	1.26	3.77	2.97	0.39	1.11	2.61	3.20	-4.44
jam	1960	1990	1.19	1.01	1.85	0.82	0.55	0.01	1.20	-0.65
nic	1950	1990	1.21	2.48	2.37	0.50	0.46	0.90	1.28	-1.68
pry	1950	1990	1.81	5.41	2.28	0.56	1.46	1.68	1.22	-1.39
slv	1950	1990	1.61	2.62	2.52	0.63	1.16	0.95	1.37	-1.13
tto	1960	1990	1.18	2.26	1.59	0.64	0.53	1.07	0.90	-1.42
ury	1960	1990	1.21	1.48	1.33	0.87	0.61	0.51	0.56	-0.45

bgd	1960	1990	1.73	0.94	2.77	0.96	1.79	-0.08	2.01	-0.13
ind	1960	1990	1.84	2.48	2.54	0.73	1.98	1.19	1.83	-1.01
pak	1960	1990	2.29	2.73	3.64	0.71	2.71	1.32	2.55	-1.12
lka	1960	1990	1.64	3.81	1.53	0.74	1.60	1.76	0.83	-0.96
hkg	1965	1990	3.51	3.43	1.71	1.56	4.95	1.94	1.25	1.71
idn	1965	1990	3.18	7.46	2.43	0.84	4.55	3.21	2.08	-0.69
mys	1960	1990	3.05	5.33	2.37	0.93	3.66	2.22	1.69	-0.23
phl	1950	1990	2.66	4.35	2.92	0.78	2.41	1.46	1.59	-0.62
sgp	1965	1990	4.45	6.51	1.68	1.54	5.91	2.99	1.21	1.68
kor	1955	1990	6.39	15.51	2.80	1.15	5.29	3.17	1.74	0.39
tha	1960	1990	3.59	5.43	1.55	1.40	4.20	2.24	0.86	1.09
fji	1965	1990	1.57	1.36	1.59	1.05	1.74	0.47	1.08	0.19
npl	1965	1985	1.62	3.09	7.70	0.30	2.33	2.21	6.13	-5.52
png	1965	1990	0.94	1.87	1.68	0.54	-0.23	0.98	1.21	-2.37
gha	1960	1990	0.92	0.61	4.84	0.43	-0.28	-0.63	3.13	-2.66
ken	1960	1990	1.28	0.58	2.48	0.92	0.81	-0.69	1.79	-0.26
ner	1965	1985	1.00	1.40	2.47	0.51	-0.01	0.65	2.64	-3.19
zaf	1960	1990	1.52	1.81	1.26	1.04	1.36	0.78	0.45	0.14
ben	1970	1990	0.91	1.84	5.38	0.26	-0.43	1.17	5.01	-6.20
bwa	1965	1985	4.84	7.79	2.24	1.32	7.80	4.11	2.34	1.31
caf	1965	1990	1.07	0.76	4.84	0.47	0.27	-0.42	3.75	-2.90
cmr	1965	1990	1.73	3.91	1.90	0.68	2.12	2.16	1.50	-1.46
cog	1975	1990	1.12	0.93	2.04	0.76	0.73	-0.19	2.73	-1.73
dza	1965	1990	1.84	2.97	4.63	0.48	2.37	1.71	3.64	-2.83
gmb	1975	1990	1.09	4.20	2.04	0.40	0.54	3.76	2.73	-5.57
lbr	1965	1985	1.17	0.66	2.52	0.79	0.73	-0.79	2.70	-1.11
lso	1965	1990	2.68	10.49	1.33	0.88	3.87	3.78	0.67	-0.49
mli	1965	1990	0.88	0.95	3.59	0.42	-0.47	-0.09	3.02	-3.28
moz	1965	1990	0.73	1.12	2.71	0.38	-1.19	0.18	2.35	-3.61
mrt	1990	1990	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00
mus	1950	1990	1.60	1.62	2.35	0.79	1.15	0.47	1.26	-0.57
mwi	1960	1990	1.59	2.87	1.52	0.81	1.51	1.38	0.81	-0.67
sdn	1975	1990	0.98	1.19	2.63	0.51	-0.15	0.44	3.73	-4.12
sen	1965	1990	1.01	0.90	1.44	0.85	0.03	-0.16	0.84	-0.64
sle	1965	1990	0.94	1.09	2.64	0.51	-0.23	0.13	2.28	-2.57
swz	1965	1985	1.49	2.08	2.57	0.63	1.90	1.42	2.76	-2.18
syc	1965	1975	1.43	2.86	1.86	0.65	3.33	4.01	3.49	-3.86
syc	1965	1975	1.43	2.86	1.86	0.65	3.33	4.01	3.49	-3.86
tgo	1965	1990	1.48	2.93	6.16	0.32	1.51	1.69	4.35	-4.25

Legend:

* h = E

** Excludes former socialist countries and China

*** Includes both TFP and variation in actual worked hours (see text)

p.w. ... per worker

Table 3 Growth accounting for benchmark g*

Country group	No. of Countries	Average annual contribution to income p.w. growth Income p.w.	Physical Capital p.w.	Knowledge Capital p.w.	TFP***
OECD	23	2.89	1.44	1.56	-0.11
Latin America	22	1.75	1.00	0.91	-0.15
Middle East	8	1.83	1.57	0.48	-0.20
South Asia	4	2.01	1.11	0.56	0.34
East Asia	10	4.09	2.64	0.82	0.64
Africa	29	0.81	0.70	0.28	-0.16
World**	96	2.44	1.37	0.95	0.12

Legend:

* γ=0.029/log(9.6)=0.0128

** Excludes former socialist countries and China

*** Includes both TFP and variation in actual worked hours (see text)

p.w. ... per worker

Group and world weighted averages have been computed using the size of employment in 1975

Table 4 Individual countries data for benchmark g*

			Index of (Initial period=1)				Average annual contribution to income p.w. growth			
Country Code	Initial Period	End Period	Income p.w.	Physical Capital p.w.	Knowledge Capital p.w.	TFP***	Income p.w.	Physical Capital p.w.	Knowledge Capital p.w.	TFP***
aus	1960	1990	1.57	1.75	2.41	0.74	1.47	0.73	1.73	-0.96
aut	1960	1990	2.49	4.09	2.17	0.89	2.99	1.86	1.52	-0.37
bel	1960	1990	2.22	2.36	2.23	0.97	2.60	1.12	1.57	-0.09
can	1960	1990	1.77	1.86	2.37	0.82	1.85	0.81	1.69	-0.64
dnk	1960	1990	1.69	2.40	2.34	0.71	1.70	1.15	1.67	-1.09
fin	1960	1990	2.36	2.66	2.13	1.02	2.81	1.28	1.48	0.05
fra	1960	1990	2.25	3.20	2.05	0.92	2.65	1.53	1.40	-0.27
dfa	1960	1990	2.16	2.67	2.27	0.89	2.52	1.29	1.61	-0.37
grc	1950	1990	5.14	8.76	2.37	1.29	4.07	2.17	1.28	0.61
irl	1960	1990	2.87	3.33	2.13	1.13	3.46	1.58	1.48	0.39
ita	1950	1990	4.90	5.00	2.29	1.57	3.95	1.60	1.22	1.10
jpn	1950	1990	8.72	14.97	2.83	1.58	5.42	2.73	1.54	1.13
nld	1960	1990	1.83	2.12	2.15	0.86	1.96	0.98	1.50	-0.51
nzl	1960	1990	1.19	1.50	2.47	0.59	0.57	0.53	1.78	-1.69
nor	1960	1990	2.05	2.01	2.19	0.97	2.34	0.91	1.54	-0.11
prt	1960	1990	3.43	3.97	1.49	1.55	4.05	1.82	0.78	1.43
esp	1960	1990	3.22	4.49	1.81	1.24	3.85	1.99	1.16	0.69
swe	1960	1990	1.64	1.94	2.28	0.77	1.60	0.86	1.61	-0.85
che	1960	1990	1.63	2.59	2.30	0.68	1.59	1.25	1.63	-1.26
gbr	1950	1990	2.29	3.37	2.88	0.75	2.05	1.20	1.57	-0.71
usa	1950	1990	1.79	1.94	3.24	0.68	1.44	0.65	1.75	-0.94
isl	1960	1990	1.99	2.15	2.08	0.94	2.24	1.00	1.43	-0.19
isr	1955	1990	3.18	2.58	2.52	1.25	3.26	1.07	1.56	0.62
irq	1960	1985	1.24	3.56	0.96	0.76	0.82	2.00	-0.10	-1.04
jor	1960	1990	2.82	9.28	1.46	0.92	3.40	2.98	0.74	-0.27
syr	1965	1990	2.08	2.51	1.33	1.21	2.86	1.44	0.67	0.74
bhr	1980	1985	0.72	0.94	1.08	0.70	-5.37	-0.42	0.80	-5.73
cyp	1960	1990	3.64	2.40	1.99	1.70	4.25	1.15	1.35	1.72
kwt	1985	1985	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00
arg	1950	1990	1.38	2.57	2.44	0.55	0.79	0.93	1.32	-1.44
bra	1960	1990	1.99	2.46	1.52	1.08	2.24	1.18	0.82	0.24
chl	1950	1990	1.73	1.92	2.37	0.79	1.34	0.64	1.28	-0.57
col	1950	1990	2.30	2.02	1.83	1.21	2.05	0.69	0.89	0.47
mex	1950	1990	2.49	3.15	1.82	1.10	2.25	1.14	0.88	0.23
per	1960	1990	1.09	1.38	1.75	0.68	0.26	0.42	1.10	-1.23
ven	1950	1990	1.21	1.13	1.82	0.81	0.47	0.12	0.89	-0.53
bol	1960	1990	1.60	1.13	1.71	1.11	1.53	0.15	1.04	0.33
brb	1965	1985	1.45	1.98	1.69	0.80	1.77	1.32	1.52	-1.04
cri	1950	1990	2.36	3.41	2.09	0.93	2.12	1.22	1.09	-0.18
dom	1960	1990	1.67	2.81	1.54	0.85	1.67	1.35	0.84	-0.51
ecu	1950	1990	2.63	3.00	1.95	1.14	2.39	1.09	0.99	0.31
gtm	1950	1990	1.63	1.87	1.31	1.08	1.20	0.61	0.39	0.19
guy	1960	1990	0.53	1.00	1.76	0.38	-2.03	-0.01	1.11	-3.09
hnd	1960	1990	1.37	1.42	1.36	0.99	1.01	0.46	0.60	-0.05
hti	1965	1985	1.26	3.77	1.04	0.72	1.11	2.61	0.11	-1.53
jam	1960	1990	1.19	1.01	1.58	0.90	0.55	0.01	0.90	-0.35
nic	1950	1990	1.21	2.48	1.58	0.64	0.46	0.90	0.68	-1.09
pry	1950	1990	1.81	5.41	1.98	0.61	1.46	1.68	1.01	-1.19
slv	1950	1990	1.61	2.62	1.53	0.85	1.16	0.95	0.62	-0.40
tto	1960	1990	1.18	2.26	1.90	0.58	0.53	1.07	1.26	-1.76
ury	1960	1990	1.21	1.48	1.94	0.69	0.61	0.51	1.30	-1.17
bgd	1960	1990	1.73	0.94	1.08	1.69	1.79	-0.08	0.15	1.71
ind	1960	1990	1.84	2.48	1.37	1.06	1.98	1.19	0.61	0.18

pak	1960	1990	2.29	2.73	1.16	1.40	2.71	1.32	0.28	1.10
lka	1960	1990	1.64	3.81	1.77	0.68	1.60	1.76	1.11	-1.23
hkg	1965	1990	3.51	3.43	1.80	1.51	4.95	1.94	1.37	1.59
idn	1965	1990	3.18	7.46	1.37	1.18	4.55	3.21	0.73	0.63
mys	1960	1990	3.05	5.33	1.65	1.16	3.66	2.22	0.98	0.47
phl	1950	1990	2.66	4.35	2.21	0.92	2.41	1.46	1.17	-0.21
sgp	1965	1990	4.45	6.51	1.57	1.60	5.91	2.99	1.05	1.83
kor	1955	1990	6.39	15.51	2.12	1.36	5.29	3.17	1.27	0.86
tha	1960	1990	3.59	5.43	1.68	1.34	4.20	2.24	1.01	0.94
fji	1965	1990	1.57	1.36	1.75	0.99	1.74	0.47	1.31	-0.04
npl	1965	1985	1.62	3.09	0.64	1.35	2.33	2.21	-1.27	1.44
png	1965	1990	0.94	1.87	0.99	0.74	-0.23	0.98	-0.02	-1.17
gha	1960	1990	0.92	0.61	1.26	0.97	-0.28	-0.63	0.45	-0.09
ken	1960	1990	1.28	0.58	1.24	1.40	0.81	-0.69	0.42	1.09
ner	1965	1985	1.00	1.40	0.72	1.06	-0.01	0.65	-0.92	0.27
zaf	1960	1990	1.52	1.81	1.79	0.85	1.36	0.78	1.14	-0.54
ben	1970	1990	0.91	1.84	0.89	0.77	-0.43	1.17	-0.32	-1.26
bwa	1965	1985	4.84	7.79	1.16	1.95	7.80	4.11	0.43	3.23
caf	1965	1990	1.07	0.76	0.88	1.30	0.27	-0.42	-0.30	1.00
cmr	1965	1990	1.73	3.91	1.17	0.91	2.12	2.16	0.35	-0.35
cog	1975	1990	1.12	0.93	1.22	1.03	0.73	-0.19	0.75	0.18
dza	1965	1990	1.84	2.97	1.10	1.13	2.37	1.71	0.21	0.46
gmb	1975	1990	1.09	4.20	0.94	0.64	0.54	3.76	-0.25	-2.77
lbr	1965	1985	1.17	0.66	1.01	1.37	0.73	-0.79	0.03	1.51
lso	1965	1990	2.68	10.49	1.49	0.83	3.87	3.78	0.92	-0.74
mli	1965	1990	0.88	0.95	0.68	1.14	-0.47	-0.09	-0.88	0.50
moz	1965	1990	0.73	1.12	0.80	0.80	-1.19	0.18	-0.51	-0.86
mrt	1990	1990	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00
mus	1950	1990	1.60	1.62	1.85	0.91	1.15	0.47	0.91	-0.22
mwi	1960	1990	1.59	2.87	1.32	0.88	1.51	1.38	0.54	-0.40
sdn	1975	1990	0.98	1.19	0.95	0.94	-0.15	0.44	-0.18	-0.41
sen	1965	1990	1.01	0.90	1.19	0.95	0.03	-0.16	0.40	-0.20
sle	1965	1990	0.94	1.09	0.91	0.96	-0.23	0.13	-0.21	-0.15
swz	1965	1985	1.49	2.08	1.28	0.96	1.90	1.42	0.71	-0.22
syc	1965	1975	1.43	2.86	1.20	0.84	3.33	4.01	1.01	-1.53
syc	1965	1975	1.43	2.86	1.20	0.84	3.33	4.01	1.01	-1.53
tgo	1965	1990	1.48	2.93	0.99	0.97	1.51	1.69	-0.02	-0.13
tun	1965	1990	1.93	1.64	1.14	1.46	2.56	0.76	0.31	1.48
uga	1960	1990	0.95	0.91	1.13	0.92	-0.18	-0.13	0.24	-0.28

Legend:

* γ=0.029/log(9.6)=0.0128

** Excludes former socialist countries and China

*** Includes both TFP and variation in actual worked hours (see text)

p.w. ... per worker

Table 5 Growth accounting for high g*$

Country group	No. of Countries	Income p.w.	Physical Capital p.w.	Knowledge Capital p.w.	TFP***
		Average annual contribution to income p.w. growth			
OECD	23	2.89	1.44	1.73	-0.26
Latin America	22	1.75	1.00	1.00	-0.24
Middle East	8	1.83	1.57	0.53	-0.25
South Asia	4	2.01	1.11	0.62	0.29
East Asia	10	4.09	2.64	0.91	0.56
Africa	29	0.81	0.70	0.30	-0.19
World**	96	2.44	1.37	1.05	0.03

Legend:

* γ=0.024/log(4.1)=0.017

** Excludes former socialist countries and China

*** Includes both TFP and variation in actual worked hours (see text)

p.w. ... per worker

Group and world weighted averages have been computed using the size of employment in 1975

Table 6 Growth accounting for low g*$

Country group	No. of Countries	Income p.w.	Physical Capital p.w.	Knowledge Capital p.w.	TFP***
		Average annual contribution to income p.w. growth			
OECD	23	2.89	1.44	0.73	0.71
Latin America	22	1.75	1.00	0.42	0.32
Middle East	8	1.83	1.57	0.23	0.05
South Asia	4	2.01	1.11	0.26	0.64
East Asia	10	4.09	2.64	0.39	1.08
Africa	29	0.81	0.70	0.13	-0.01
World**	96	2.44	1.37	0.44	0.62

Legend:

* γ=0.015/log(12)=0.006

** Excludes former socialist countries and China

*** Includes both TFP and variation in actual worked hours (see text)

p.w. ... per worker

Group and world weighted averages have been computed using the size of employment in 1975

Table 7 Growth accounting for country specific g^*

Country group	No. of Countries	Income p.w.	Physical Capital p.w.	Knowledge Capital p.w.	TFP***
		Average annual contribution to income p.w. growth			
OECD	23	2.89	1.44	1.57	-0.11
Latin America	22	1.75	1.00	0.79	-0.04
Middle East	8	1.83	1.57	0.61	-0.33
South Asia	4	2.01	1.11	0.69	0.22
East Asia	10	4.09	2.64	2.35	-0.81
Africa	29	0.81	0.70	0.10	0.03
World**	96	2.44	1.37	1.15	-0.07

Legend:

* γ = average annual country growth/log(educational attainment 1990)

** Excludes former socialist countries and China

*** Includes both TFP and variation in actual worked hours (see text)

p.w. ... per worker

Group and world weighted averages have been computed using the size of employment in 1975

Table 8 Individual countries data for country specific g*

Country Code	Initial Period	End Period	Index of (Initial period=1): Income p.w.	Physical Capital p.w.	Knowledge Capital p.w.	TFP***	Average annual contribution to income p.w. growth: Income p.w.	Physical Capital p.w.	Knowledge Capital p.w.	TFP***
aus	1960	1990	1.57	1.75	1.55	0.97	1.47	0.73	0.85	-0.10
aut	1960	1990	2.49	4.09	2.35	0.85	2.99	1.86	1.68	-0.53
bel	1960	1990	2.22	2.36	2.14	1.00	2.60	1.12	1.49	-0.01
can	1960	1990	1.77	1.86	1.70	1.00	1.85	0.81	1.03	0.01
dnk	1960	1990	1.69	2.40	1.63	0.89	1.70	1.15	0.95	-0.39
fin	1960	1990	2.36	2.66	2.09	1.03	2.81	1.28	1.44	0.09
fra	1960	1990	2.25	3.20	2.08	0.91	2.65	1.53	1.43	-0.29
dfa	1960	1990	2.16	2.67	2.07	0.94	2.52	1.29	1.43	-0.19
grc	1950	1990	5.14	8.76	3.83	0.96	4.07	2.17	2.00	-0.09
irl	1960	1990	2.87	3.33	2.58	1.00	3.46	1.58	1.86	0.01
ita	1950	1990	4.90	5.00	4.06	1.11	3.95	1.60	2.09	0.26
jpn	1950	1990	8.72	14.97	7.22	0.90	5.42	2.73	2.96	-0.25
nld	1960	1990	1.83	2.12	1.72	0.98	1.96	0.98	1.06	-0.08
nzl	1960	1990	1.19	1.50	1.18	0.92	0.57	0.53	0.33	-0.28
nor	1960	1990	2.05	2.01	1.82	1.08	2.34	0.91	1.17	0.25
prt	1960	1990	3.43	3.97	2.37	1.18	4.05	1.82	1.70	0.52
esp	1960	1990	3.22	4.49	2.67	0.98	3.85	1.99	1.93	-0.07
swe	1960	1990	1.64	1.94	1.57	0.96	1.60	0.86	0.88	-0.14
che	1960	1990	1.63	2.59	1.57	0.85	1.59	1.25	0.87	-0.52
gbr	1950	1990	2.29	3.37	2.17	0.89	2.05	1.20	1.15	-0.30
usa	1950	1990	1.79	1.94	1.70	1.00	1.44	0.65	0.78	0.01
isl	1960	1990	1.99	2.15	1.85	1.01	2.24	1.00	1.20	0.04
isr	1955	1990	3.18	2.58	2.91	1.15	3.26	1.07	1.81	0.38
irq	1960	1985	1.24	3.56	0.97	0.76	0.82	2.00	-0.07	-1.06
jor	1960	1990	2.82	9.28	1.81	0.81	3.40	2.98	1.16	-0.68
syr	1965	1990	2.08	2.51	1.55	1.11	2.86	1.44	1.01	0.40
bhr	1980	1985	0.72	0.94	0.78	0.86	-5.37	-0.42	-2.44	-2.58
cyp	1960	1990	3.64	2.40	2.91	1.35	4.25	1.15	2.10	0.97
kwt	1985	1985	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00
arg	1950	1990	1.38	2.57	1.31	0.81	0.79	0.93	0.39	-0.53
bra	1960	1990	1.99	2.46	1.74	1.00	2.24	1.18	1.09	-0.02
chl	1950	1990	1.73	1.92	1.58	1.01	1.34	0.64	0.68	0.02
col	1950	1990	2.30	2.02	1.92	1.18	2.05	0.69	0.96	0.39
mex	1950	1990	2.49	3.15	1.81	1.10	2.25	1.14	0.87	0.24
per	1960	1990	1.09	1.38	1.07	0.92	0.26	0.42	0.13	-0.27
ven	1950	1990	1.21	1.13	1.15	1.06	0.47	0.12	0.20	0.15
bol	1960	1990	1.60	1.13	1.50	1.19	1.53	0.15	0.80	0.57
brb	1965	1985	1.45	1.98	1.43	0.89	1.77	1.32	1.04	-0.57
cri	1950	1990	2.36	3.41	2.03	0.95	2.12	1.22	1.04	-0.14
dom	1960	1990	1.67	2.81	1.47	0.88	1.67	1.35	0.75	-0.42
ecu	1950	1990	2.63	3.00	2.01	1.12	2.39	1.09	1.03	0.27
gtm	1950	1990	1.63	1.87	1.30	1.09	1.20	0.61	0.38	0.20
guy	1960	1990	0.53	1.00	0.59	0.73	-2.03	-0.01	-1.02	-1.02
hnd	1960	1990	1.37	1.42	1.21	1.06	1.01	0.46	0.36	0.19
hti	1965	1985	1.26	3.77	1.04	0.72	1.11	2.61	0.12	-1.53
jam	1960	1990	1.19	1.01	1.14	1.09	0.55	0.01	0.25	0.29
nic	1950	1990	1.21	2.48	1.14	0.78	0.46	0.90	0.19	-0.61
pry	1950	1990	1.81	5.41	1.56	0.71	1.46	1.68	0.65	-0.84
slv	1950	1990	1.61	2.62	1.35	0.91	1.16	0.95	0.44	-0.22
tto	1960	1990	1.18	2.26	1.15	0.78	0.53	1.07	0.27	-0.79
ury	1960	1990	1.21	1.48	1.18	0.94	0.61	0.51	0.32	-0.22
bgd	1960	1990	1.73	0.94	1.15	1.63	1.79	-0.08	0.27	1.59
ind	1960	1990	1.84	2.48	1.45	1.02	1.98	1.19	0.72	0.07

pak	1960	1990	2.29	2.73	1.45	1.23	2.71	1.32	0.72	0.66
lka	1960	1990	1.64	3.81	1.53	0.74	1.60	1.76	0.83	-0.96
hkg	1965	1990	3.51	3.43	2.90	1.13	4.95	1.94	2.51	0.48
idn	1965	1990	3.18	7.46	2.55	0.81	4.55	3.21	2.20	-0.80
mys	1960	1990	3.05	5.33	2.30	0.95	3.66	2.22	1.63	-0.17
phl	1950	1990	2.66	4.35	2.14	0.94	2.41	1.46	1.13	-0.17
sgp	1965	1990	4.45	6.51	3.38	1.01	5.91	2.99	2.88	0.05
kor	1955	1990	6.39	15.51	4.01	0.93	5.29	3.17	2.36	-0.21
tha	1960	1990	3.59	5.43	2.74	1.00	4.20	2.24	1.98	-0.01
fji	1965	1990	1.57	1.36	1.46	1.10	1.74	0.47	0.88	0.38
npl	1965	1985	1.62	3.09	22.20	0.16	2.33	2.21	9.55	-8.34
png	1965	1990	0.94	1.87	1.00	0.73	-0.23	0.98	0.01	-1.20
gha	1960	1990	0.92	0.61	0.96	1.15	-0.28	-0.63	-0.08	0.44
ken	1960	1990	1.28	0.58	1.13	1.48	0.81	-0.69	0.24	1.27
ner	1965	1985	1.00	1.40	1.00	0.87	-0.01	0.65	-0.01	-0.64
zaf	1960	1990	1.52	1.81	1.46	0.96	1.36	0.78	0.73	-0.14
ben	1970	1990	0.91	1.84	1.09	0.68	-0.43	1.17	0.24	-1.82
bwa	1965	1985	4.84	7.79	2.30	1.29	7.80	4.11	2.43	1.23
caf	1965	1990	1.07	0.76	0.96	1.23	0.27	-0.42	-0.11	0.80
cmr	1965	1990	1.73	3.91	1.34	0.84	2.12	2.16	0.67	-0.66
cog	1975	1990	1.12	0.93	1.09	1.10	0.73	-0.19	0.31	0.61
dza	1965	1990	1.84	2.97	1.16	1.09	2.37	1.71	0.35	0.32
gmb	1975	1990	1.09	4.20	0.25	1.42	0.54	3.76	-5.02	2.21
lbr	1965	1985	1.17	0.66	1.01	1.37	0.73	-0.79	0.03	1.50
lso	1965	1990	2.68	10.49	2.32	0.63	3.87	3.78	1.98	-1.75
mli	1965	1990	0.88	0.95	0.75	1.07	-0.47	-0.09	-0.66	0.27
moz	1965	1990	0.73	1.12	0.31	1.41	-1.19	0.18	-2.65	1.34
mrt	1990	1990	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00
mus	1950	1990	1.60	1.62	1.40	1.08	1.15	0.47	0.49	0.19
mwi	1960	1990	1.59	2.87	1.41	0.85	1.51	1.38	0.67	-0.53
sdn	1975	1990	0.98	1.19	1.03	0.90	-0.15	0.44	0.09	-0.68
sen	1965	1990	1.01	0.90	1.01	1.05	0.03	-0.16	0.01	0.18
sle	1965	1990	0.94	1.09	1.06	0.88	-0.23	0.13	0.14	-0.50
swz	1965	1985	1.49	2.08	1.28	0.96	1.90	1.42	0.71	-0.22
syc	1965	1975	1.43	2.86	1.31	0.80	3.33	4.01	1.49	-2.00
syc	1965	1975	1.43	2.86	1.31	0.80	3.33	4.01	1.49	-2.00
tgo	1965	1990	1.48	2.93	0.99	0.97	1.51	1.69	-0.03	-0.12
tun	1965	1990	1.93	1.64	1.27	1.37	2.56	0.76	0.56	1.23
uga	1960	1990	0.95	0.91	0.98	1.00	-0.18	-0.13	-0.03	-0.02

Legend:

* γ = average annual country growth/log(educational attainment 1990)

** Excludes former socialist countries and China

*** Includes both TFP and variation in actual worked hours (see text)

p.w. ... per worker

Table 9 Variance accounting with education in place of human capital*

Country group	No. of Countries	Physical Capital p.w.	Knowledge Capital p.w.	TFP***	Physical and Knowledge Capital p.w.	Physical Capital p.w. and TFP	TFP and Knowledge Capital
		Relative contribution to variance in group income p.w. average annual growth					
		Variance of average annual growth in			Contribution of covariances between average annual growth rates of		
OECD	23	0.26	0.08	0.33	-0.02	0.50	-0.15
Latin America	22	0.33	0.48	1.73	0.22	-0.28	-1.50
Middle East	8	0.13	1.32	3.19	0.58	-0.61	-3.69
South Asia	4	2.96	1.27	1.36	-0.77	-3.90	0.12
East Asia	10	0.43	1.04	1.83	0.19	0.04	-2.58
Africa	29	0.71	0.95	1.53	0.43	-0.51	-2.10
World**	96	0.36	0.49	1.06	0.04	0.28	-1.26

Legend:
* h = E
** Excludes former socialist countries and China
*** Includes both TFP and variation in actual worked hours (see text)
p.w. ... per worker
Group and world weighted averages have been computed using the size of employment in 1975

Table 10 Variance accounting for benchmark g*

Country group	No. of Countries	Physical Capital p.w.	Knowledge Capital p.w.	TFP***	Physical and Knowledge Capital p.w.	Physical Capital p.w. and TFP	TFP and Knowledge Capital
		Relative contribution to variance in group income p.w. average annual growth					
		Variance of average annual growth in			Contribution of covariances between average annual growth rates of		
OECD	23	0.26	0.02	0.33	-0.06	0.53	-0.10
Latin America	22	0.33	0.10	0.88	-0.18	0.09	-0.25
Middle East	8	0.19	0.15	0.51	-0.12	-0.08	0.32
South Asia	4	2.96	0.61	5.88	2.03	-6.75	-3.76
East Asia	10	0.43	0.26	0.21	-0.03	0.26	-0.13
Africa	29	0.71	0.18	0.27	0.17	-0.28	-0.04
World**	96	0.38	0.16	0.29	0.05	0.27	-0.16

Legend:
* γ=0.029/log(9.6)=0.0128
** Excludes former socialist countries and China
*** Includes both TFP and variation in actual worked hours (see text)
p.w. ... per worker
Group and world weighted averages have been computed using the size of employment in 1975

Table 11 Variance accounting for low g^*

Country group	No. of Countries	Physical Capital p.w.	Knowledge Capital p.w.	TFP***	Physical and Knowledge Capital p.w.	Physical Capital p.w. and TFP	TFP and Knowledge Capital
		Relative contribution to variance in group income p.w. average annual growth					
		Variance of average annual growth in			Contribution of covariances between average annual growth rates of		
OECD	23	0.26	0.00	0.29	-0.03	0.50	-0.04
Latin America	22	0.33	0.02	0.78	-0.08	0.00	-0.07
Middle East	8	0.19	0.03	0.73	-0.06	-0.14	0.23
South Asia	4	2.96	0.13	4.08	0.95	-5.68	-1.46
East Asia	10	0.43	0.06	0.21	-0.02	0.25	0.07
Africa	29	0.71	0.04	0.30	0.08	-0.19	0.07
World**	96	0.38	0.04	0.26	0.03	0.30	0.01

Legend:
* $\gamma = 0.015/\log(12) = 0.006$
** Excludes former socialist countries and China
*** Includes both TFP and variation in actual worked hours (see text)
p.w. ... per worker
Group and world weighted averages have been computed using the size of employment in 1975

Table 12 Variance accounting for high g^*

Country group	No. of Countries	Physical Capital p.w.	Knowledge Capital p.w.	TFP***	Physical and Knowledge Capital p.w.	Physical Capital p.w. and TFP	TFP and Knowledge Capital
		Relative contribution to variance in group income p.w. average annual growth					
		Variance of average annual growth in			Contribution of covariances between average annual growth rates of		
OECD	23	0.26	0.02	0.34	-0.07	0.54	-0.11
Latin America	22	0.33	0.12	0.90	-0.19	0.11	-0.29
Middle East	8	0.19	0.19	0.48	-0.13	-0.07	0.32
South Asia	4	2.96	0.74	6.26	2.24	-6.95	-4.28
East Asia	10	0.43	0.31	0.22	-0.04	0.26	-0.20
Africa	29	0.71	0.22	0.27	0.19	-0.30	-0.08
World**	96	0.38	0.20	0.31	0.06	0.26	-0.21

Legend:
* $\gamma = 0.024/\log(4.1) = 0.017$
** Excludes former socialist countries and China
*** Includes both TFP and variation in actual worked hours (see text)
p.w. ... per worker
Group and world weighted averages have been computed using the size of employment in 1975

Table 13 Variance accounting for country specific g*

Relative contribution to variance in group income p.w. average annual growth

Country group	No. of Countries	Variance of average annual growth in: Physical Capital p.w.	Knowledge Capital p.w.	TFP***	Contribution of covariances between average annual growth rates of: Physical and Knowledge Capital p.w.	Physical Capital p.w. and TFP	TFP and Knowledge Capital
OECD	23	0.26	0.29	0.01	0.54	-0.05	-0.04
Latin America	22	0.33	0.23	0.26	0.20	-0.28	0.25
Middle East	8	0.19	0.30	0.24	-0.03	-0.17	0.46
South Asia	4	2.96	0.36	4.77	2.04	-6.75	-2.41
East Asia	10	0.43	2.65	2.82	0.18	0.02	-5.20
Africa	29	0.71	0.59	0.40	0.53	-0.64	-0.58
World**	96	0.38	0.59	0.34	0.62	-0.29	-0.62

Legend:
* γ = average annual country growth/log(educational attainment 1990)
** Excludes former socialist countries and China
*** Includes both TFP and variation in actual worked hours (see text)
p.w. ... per worker
Group and world weighted averages have been computed using the size of employment in 1975

Figure 1 Relative evolution of k and h in the EU periphery

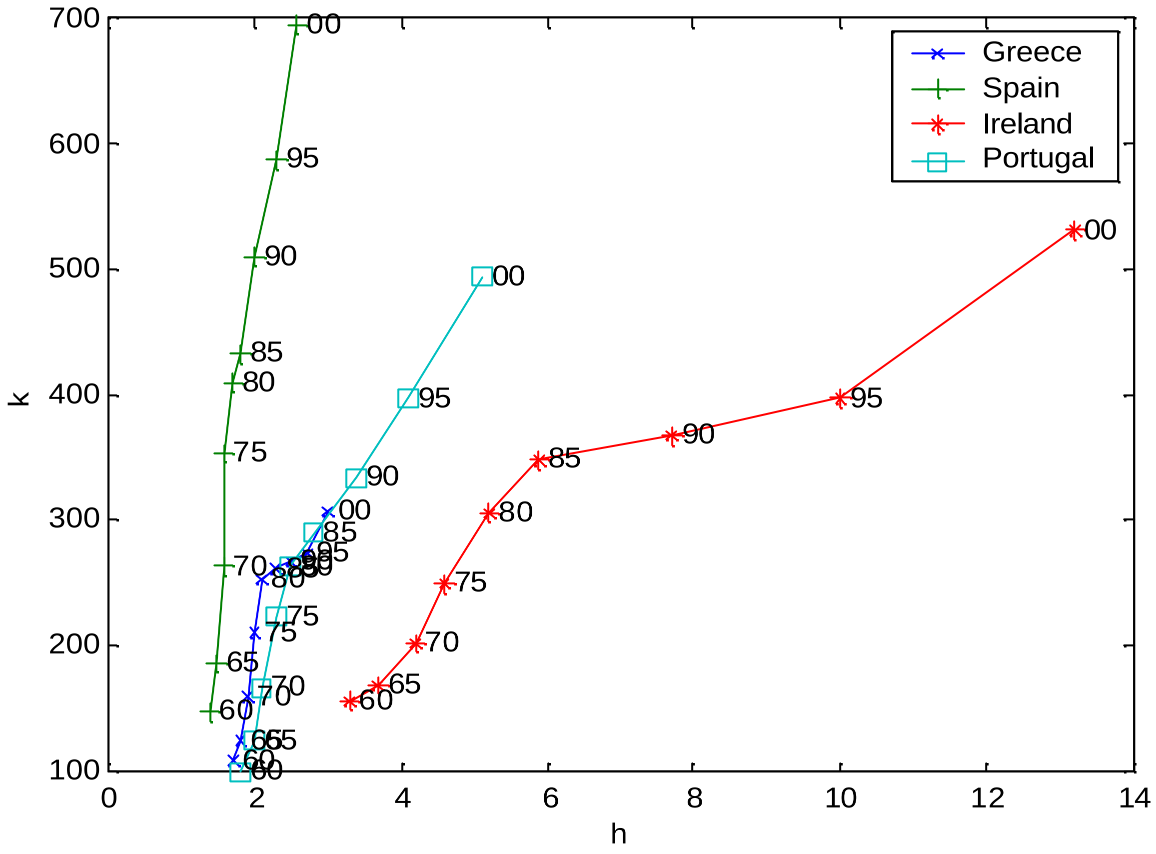


Figure 2 Evolution of k and h in the EU periphery and Germany

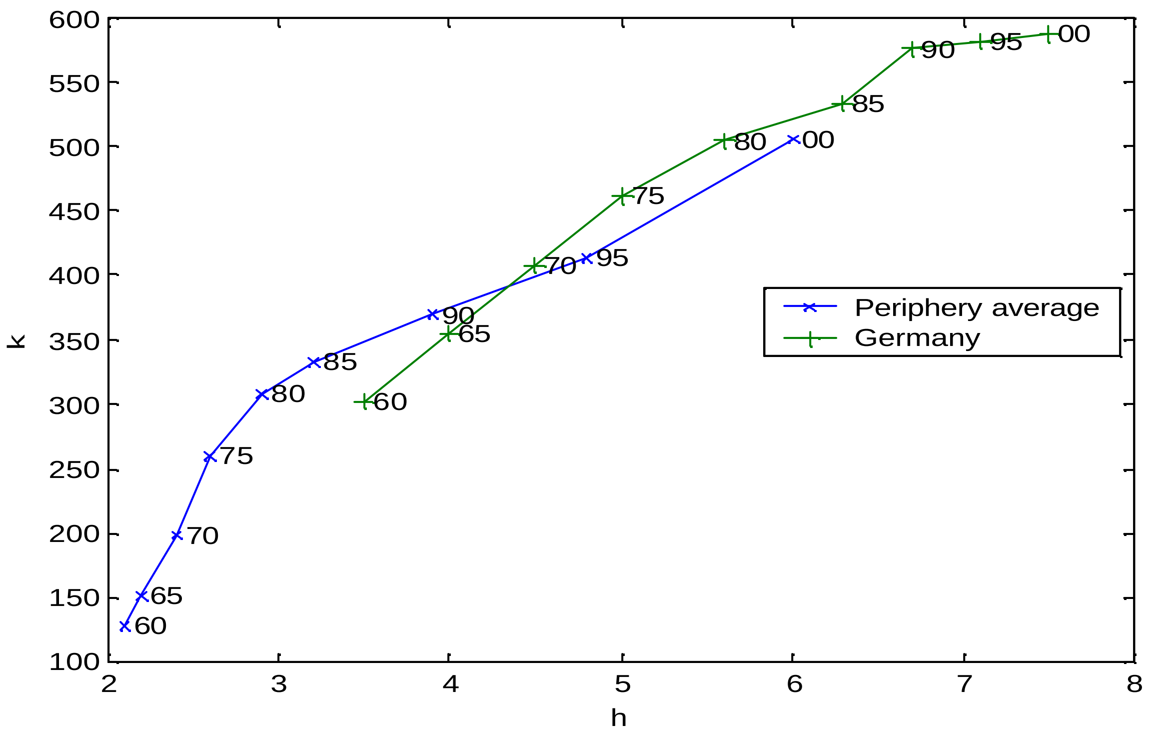
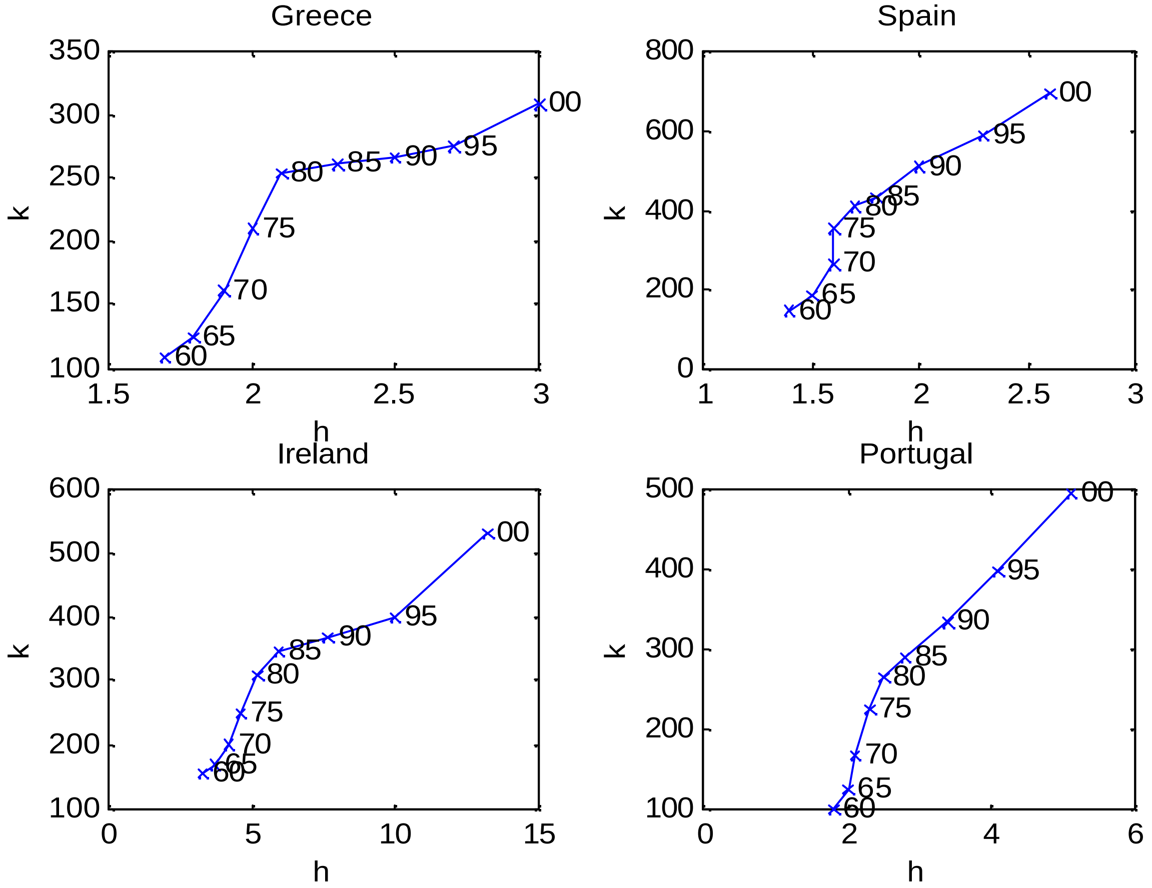


Figure 3 Evolution of k and h in the EU periphery



CERGE-EI
P.O.BOX 882
Politických vezòù 7
111 21 Prague 1
Czech Republic
http://www.cerge-ei.cz