A Quantitative Exploration in Economic Growth

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Abstract

This paper develops a growth accounting exercise in order to estimate the aggregate production function as well as the main determinants of total factor productivity (TFP). Our study considers a wide sample of countries and develops a new methodology for the elaboration of stock data. Also, we introduce a methodology for the estimation of parameter values by using simulation-based estimators that help us to get the best fit for our aggregate production function. Our framework of analysis considers a two-sector growth model with human and physical capital. This estimation procedure takes into account additional variables affecting TFP, and contemplates various scenarios in which factors of production may or may not be quality adjusted.

Journal of Economic Literature Classification Numbers: O41, ,O47, O57.

1 Introduction

This paper develops a growth accounting exercise with a view towards estimating an aggregate production function as well as the main determinants of total factor productivity (TFP). Our study departs from previous work in the selection of the sample of countries, the elaboration of stock data, and further methodological aspects regarding the estimation of parameter values. We merge growth accounting with simulation-based estimation to get the best fit for our aggregate production function. This estimation procedure takes into account additional variables affecting TFP, and contemplates various scenarios in which factors of production may or may not be quality adjusted. To keep these exercises manageable, we assign values to depreciation rates and other parameters defining physical and human capital accumulation.

As amply documented [cf., Summers and Heston (1991) and Maddison (1995)], there is a great disparity of output per worker across countries. There is also a considerable variability of output growth rates both across countries and over time. Indeed, some initially retarded countries have experienced rapid growth and convergence to the group of high-income countries whereas others have remained stagnant. One primary candidate to account for these growth patterns is factor accumulation as fast-growing countries usually exhibit higher investment rates in physical capital and education. Along these lines, Mankiw, Romer and Weil (1992) report high correlations between aggregate output and the stocks of physical and human capital; Young (1995) concludes that factor accumulation is the main force behind the economic growth of the four East Asian Tigers; and a more recent branch of the literature [Manuelli and Seshadri (2007) and Erosa, Koreshkova and Restuccia (2007)] highlights human capital accumulation as a major propagation mechanism for income disparity. But starting with the original work of Solow (1957) many studies have documented sizable variations in TFP. Although these effects may be lessened by adjustments in factor quality [e.g., Jorgenson and Griliches (1967) and Kendrick (1976)], the modern growth accounting literature has conferred a prominent role on this residual component and more moderate effects on factor accumulation [cf. Hall and Jones (1998), Klenow and Rodriguez-Clare (1998), Prescott (1998), McGrattan and Schmitz (1999) and Caselli (2005)].

Underlying these studies there are various technical aspects regarding measurement of aggregate quantities and specification of the production functions for output and factor accumulation. We provide new methods of analysis to address these issues in the hope of getting more conclusive results. We refine the measurement of capital stocks, explore the effects of factor quality adjustments and production externalities on growth accounting, and provide a systematic analysis of the determinants of TFP.

Our selected countries meet certain minimal requirements of size and data quality. Each country is populated by at least one million people at the starting date 1960, and has not been involved in any major war or confrontation over this period. Second, for some countries the national accounts are not all that reliable. The Penn World Table (PWT) grades each country according to data quality [Summers and Heston (1991)]. We rule out every country with grade D in our sample, and include every country with grade B. Third, within the grey line of countries with grade C, we have used several criteria such as economic importance and geographical balance within our sample, participation in benchmark studies of the International Comparison Programme (ICP), and quality of disaggregated data in physical investment and schooling that is needed in our study. Using these criteria, we gather 47 countries over the period 1960-2000 with 26 countries that belong to the OECD. There are a few other countries which can arguably be added to our sample.

We then build series of physical and human capital for our sample of countries. Some authors [e.g., see Gort, Greenwood and Rupert (1999), and Greenwood, Hercowitz and Krusell (1997) and Hulten (1992)] have argued that US output growth can largely be explained by quality improvements in physical capital. This suggests that vintage capital models may have additional explanatory power in accounting for some basic growth patterns. However, this premise has never been tested in cross-country data. To build the physical capital stock, we first decompose capital investment into equipment and structures. Then, we apply a quality index to each of these components. This decomposition accommodates the more pronounced technological improvements in equipment, and may avoid potential estimation biases as investment in equipment displays more variation than investment in structures across countries. Regarding the stock of human capital, it is widely acknowledged that the quality of education may vary considerably across countries. Hence, years of schooling seems a poor indicator of the average stock of human capital. In an effort to pick up the quality of these investments, our human capital stocks are constructed from the law of motion of our model where the primary input is the time devoted to schooling.

To provide a better understanding of the evolution of TFP, we introduce external effects in the aggregate production function of the economy. These externalities are present in many models of economic growth [e.g., Aschauer (1989), Benhabib and Jovanovic (1991), Lucas (1988), and Romer (1987)]. We determine the size of the external effects for both types of capital stocks in the average productivity of the economy by a simulation-based estimator which imposes the residual of the growth accounting exercise to be orthogonal to variations in capital stocks. From the growth accounting exercise we construct a data panel to control for the presence of unobserved time-invariant heterogeneity–which is harder to tackle with cross-sectional regression analysis. The main problem caused by unobserved heterogeneity is that if the characteristics that affect both dependent and independent variables are omitted, then some explanatory variables may be correlated with the error term and hence the corresponding estimates will be biased.

Jointly with the estimation of the external effects, we also study how other variables may affect TFP and economic growth. Among these variables we find that R&D expenditures and public investment have a positive influence on productivity. The presence of these variables together with factor quality sharpens the estimation of the external effects: The coefficients of the external effects are considerably smaller when these variables and adjustments in factor quality are included. Other variables commonly discussed in the literature seem to influence the relative price of investment but not the level of TFP. Therefore, in our analysis we acknowledge three potential margins for a variable to affect output: (i) The level of TFP, (ii) Factor accumulation, and (iii) Factor quality or efficiency of investment. The investigation of variables significant for the first component is the objective of our growth accounting exercise. The other two channels are considered in a companion paper using data on savings rates and relative prices of investment from the PWT.

The two-sector growth model that conforms our framework of analysis is set out in Section 2. For its empirical implementation we need to gather data on investments in physical capital and the efforts devoted to schooling. The methodology for the construction of the capital stocks is explained in Section 3 and in further detail in the appendix. Section 4 describes the econometric methodology for the calibration of the model. Parameter values of the aggregate production function for the external effects of the physical and human capital stocks are estimated from growth accounting data via an iterated procedure defining a simulation-based estimator. The main results of our growth accounting exercise are presented in Section 5. We find that the size of the external effects is not negligible, but the value we obtain for the external effect of physical capital is well below the estimates of Aschauer (1989) and Romer (1987) and the value for human capital is also much lower than the estimate of Lucas (1988). Using these estimates we report further evidence on output growth and human capital accumulation. Our analysis suggests that most of the income disparity can be explained by the variation in the capital stocks. Thus, if we regress the natural logarithm of the growth rate of output per worker against the natural logarithm of our estimated growth rate of output per worker we obtain an R^2 of 0.91 for the OECD, and around 0.86 if we include all the countries in our sample. Nevertheless, the evidence shows that TFP growth has been slightly higher in less rich countries. Section 6 concludes with a recapitulation of our main findings.

2 The framework of analysis

Our growth accounting exercise is intended to explore the performance of a family of economic growth models with physical and human capital. In the process of model selection we take a comprehensive view of various margins which may be of potential interest. Accordingly, our framework of analysis contemplates several sources of economic growth. Besides the human capital externality for aggregate production in Lucas (1988) we also allow for exogenous variations in TFP and in the efficiency of investment, and external effects from physical capital accumulation. The theoretical building blocks underlying our empirical investigation are a production function for the aggregate good and laws of motion for the two types of capital. Our functional forms for the production function and accumulation laws are compatible with the existence of a balanced growth path in which factors of production may grow at different rates. Human capital accumulation displays a constant returns to scale technology so that this factor can be an engine of growth–in addition to embodied and disembodied technological change. We refer the reader to our earlier work [Santos (2001) and García-Belenguer (2007)] for a broad discussion of steady-state properties and transitional dynamics for models with physical and human capital, taxes and externalities.

The number of agents in the economy is represented by variable L_t which evolves according to the simple law $L_{t+1} = (1 + n_t)L_t$, where $n \geq 0$ is the population growth rate. Each agent is endowed with one unit of time which can be allocated between working and schooling activities. Then, u_t is the average fraction of time devoted to work whereas $(1 - u_t)$ is the average fraction of time devoted to schooling. The production of the aggregate good Y_t is described by a standard Cobb-Douglas neoclassical production function

$$Y_t = A_t(x_t) K_t^{\alpha} (L_t u_t h_t)^{1-\alpha} \tag{2.1}$$

with $0 < \alpha < 1$. Here, K_t is the total stock of physical capital in the economy and h_t is the average level of human capital. Function $A_t(x_t)$ represents the level of productivity available to the economy at period t and it depends on a vector of variables x_t. Among these variables we consider the external effects arising from the average level of physical capital $k_t = K_t/(L_t u_t)$ and human capital h_t, public gross fixed capital investment, and $R\&D$ expenditures. We also run robustness checks for the estimated coefficients whenever we have two available measures of a given variable.

At each date t, output in the economy may be either consumed or invested subject to physical feasibility, $Y_t = L_t c_t + I_t$. New investment goods may embody technological improvements. In the growth accounting literature this type of technological progress is often counted as changes in TFP, but as shown below factor quality adjustments change the estimated coefficients for function $A_t(x_t)$ in (2.1). Following the vintage capital literature, we then postulate the following law of motion for capital accumulation that takes into account embodied technological progress:

$$K_{t+1} = q_t I_t + (1 - \delta_K) K_t \tag{2.2}$$

where $\delta_K > 0$ denotes physical capital depreciation and q_t is the level of exogenous technological improvements for investment goods at time t. This external component conveys the idea that new vintages of capital may be more productive than existing ones; e.g., see Hulten (1992) and Greenwood, Hercowitz and Krusell (1997). We assume that variable q_t evolves according to the rule $q_{t+1} = (1 + \eta_t) q_t$ for $\eta \geq 0$ and for all t. We later decompose investment into equipment and structures, and apply separate quality measures.

Starting with Nelson and Phelps (1966), several authors have stressed that the level of technology adoption may depend on the level of education in the country. This fact is echoed in the PWT, since countries with low levels of technology adoption see their investment ratios diminished when aggregate quantities are expressed in technological units of a common numeraire. Hence, we should emphasize that physical capital in (2.2) will be expressed in terms of a common numeraire and does not necessarily entail the same level of technology adoption across countries.

The technology for human capital accumulation is represented by a production function which is linear in the aggregate stock of human capital. Formally, the average stock of human capital evolves according to the following law of motion:

$$h_{t+1} = B(n_t)[((1 - u_t) h_t)^{\theta} (h_t^e)^{1-\theta}] + (1 - \delta_h) h_t \tag{2.3}$$

where function $B(n_t)$ depends on the fertility rate n_t. There is a distinction here between the direct contribution h_t to the accumulation process and the externality (h_t^e), which is not taken into account at the individual level; $\delta_h > 0$ is the depreciation rate for human capital, and $0 < \theta \leq 1$. Note that expression $[((1 - u_t) h_t)^{\theta} (h_t^e)^{1-\theta}]$ implies decreasing returns to scale in h at the individual level, but constant returns to scale in the aggregate when taking into account the externality effect. There are however decreasing returns to scale in the effort devoted to education, $1 - u$, so that it becomes harder to increase suddenly the quality of human capital.

In most of the literature the stock of human capital is assessed from indices of weighted years of schooling without further considerations to quality. Barro and Lee (1993) construct a data set on the educational attainment of the population aged 15 years and over. They use census and survey figures which are filled in with econometric estimations for the missing data.

These measures have been updated in Barro and Lee (1996) and include data for the period 1960-2000 for 138 countries. Other measures of schooling can be found in Psacharopoulos and Arriagada (1992), who focus on the labor force, and Nehru, Swanson and Dubey (1995) who build on enrollment data adjusted for the rate of mortality.

There is a second class of estimates [Kendrick (1961)] based on enrolment rates, expenditures in formal education and training, and the imputed opportunity costs of students' time. All these items represent current flows rather than stocks. Consequently, this second approach to human capital needs a mapping of these educational expenditures into human capital.

Apart from the lack of quality data in existing measures of schooling, technical reasons led us to construct a human capital index from the law of motion (2.3). For the initial year 1960 data on educational attainment for some countries seems puzzling and may be contaminated by serious misreporting. These errors would bias our estimates of the initial physical capital stock which are calculated from output data using (2.1) and some steady-state conditions. (We make some further allowances for those countries that were thought to be away from their steady states.) Hence, our human capital index incorporates an initial quality adjustment as we pick up the initial condition in accordance with the level of output. Further, quality improvements are accomplished under (2.3) through the effort devoted to schooling, $1 - u_t$.

3 Data

3.1 Countries

Our group of countries has been selected on the grounds of data availability and quality, and geographical and economic considerations. The time span is from 1960 to 2000. This time period rules out some countries such as ex Soviet republics where data is roughly available after 1990. There are also countries that got their independence in recent times such as the Czech Republic and those stemming from the old Yusgoslavia.

Our sample contains all countries graded A in the PWT but Luxembourg that has a population of less than one million. It also includes all countries graded B in the PWT but Iceland (because of population size) and Israel (high military expenditure). Singapore has been kept in the sample, even though this country only has one ICP benchmark.

Our sample contains most countries graded C in the PWT with two ICP benchmarks. For several reasons, the following countries were not included: (a) Bahamas, Barbados, Grenada, St. Lucia, Trinidad & Tobago, and Mauritius have all populations less than one million people. (b) Benin, Bangladesh, Ivory Coast, Congo, Madagascar, Mali, and Senegal do not have good (separate) data for equipment and structures. (The data seem good for their benchmark years. These countries have either two or three benchmarks.) (c) Along the same lines, Ethiopia, Malawi, Nepal, Swaziland do not seem to have good data for equipment and structures separately. Nigeria and Ethiopia are not in the Barro-Lee data set, which is an input of our human capital series. (d) Cameroon, Sierra Leone, Tanzania, Zambia and Zimbabwe have been engaged in major confrontations over the period 1960-2000.

After this recounting, the following countries will comprise our sample:

(i) OECD countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Hungary (data starting 1970), Ireland, Italy, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, Poland (data starting 1970), Portugal, Spain, Sweden, Switzerland, Turkey, UK, USA.

(ii) NON-OECD countries: Argentina, Bolivia, Brazil, Chile, China (data starting 1975), Ecuador, Egypt (substracted the oil sector for each aggregate variable), Hong Kong, India, Indonesia, Iran (substracted the oil sector for each aggregate variable), Kenya, Malaysia, Morocco, Peru, Philippines, Sri Lanka, Singapore, Thailand, Tunisia, Uruguay, Venezuela (substracted the oil sector for each aggregate variable).

Therefore, this is a total sample of 47 countries over the period 1960-2000 with 26 countries that belong to the OECD. The sample keeps a balanced representation of all major economic areas. Some further non-OECD countries could be added to this sample at the cost of lowering our data quality demands.

3.2 Physical capital

We have divided physical capital into structures and equipment. Hence, we define a law of motion for each type of capital as

$$K_{t+1}^{st} = q_t^{st} I_t^{st} + (1 - \delta_{K^{st}}) K_t^{st} \tag{3.1}$$

$$K_{t+1}^{eq} = q_t^{eq} I_t^{eq} + (1 - \delta_{K^{eq}}) K_t^{eq}. \tag{3.2}$$

Superscript *st* stands for structures and *eq* for equipment. As most of the literature, we consider that technological progress in equipment is more pronounced than in structures. For the evolution of technological progress in structures we follow Gort, Greenwood and Ruppert (1999) and assume that q^{st} grows at an annual rate of 1.1 percent. For the construction of the technological progress in equipment we build on the Gordon index (1990) and further projections along the lines of Cummins and Violante (2002). This index entails that q^{eq} grows at an average annual rate of 2.5 percent.

We introduce a new procedure to get time series for investment in structures, I^{st}, and investment in equipment, I^{eq}, since the PWT data set is incomplete and presents many inconsistencies. Our procedure starts with UN data which are valued in domestic prices. Then, using purchasing parity information available from the PWT, these investments are expressed in a common numeraire. Further, from interpolations over ICP benchmark studies, aggregate investment is finally broken into equipment and structures. We have kept housing as part of investment in structures, since imputed rents of residential housing are included in the GDP figures.

Note that both I^{st} and I^{eq} are expressed in terms of a common numeraire which applies for all countries in the sample. Although the processes q^{st} and q^{eq} have been derived from US data, we take as an outstanding assumption in this study that these technological indices are the same for all the countries. The rationale for this assumption should be found in the process of elaboration of the investment figures in the PWT, which are computed in efficiency units in terms of a common numeraire. That is, at any given time the PWT provides a normalization of investment data across countries. Then, indices q^{st} and q^{eq} should provide the required adjustments in efficiency units over time.

Finally, for given values for K^{st} and K^{eq}, the total stock of capital K_t is defined as the geometric mean

$$K_t = (K_t^{eq})^{\frac{\alpha_{eq}}{\alpha}} (K_t^{st})^{\frac{\alpha_{st}}{\alpha}} \tag{3.3}$$

where $\alpha = \alpha_{st} + \alpha_{eq}$. The values of α_{st} and α_{eq} are chosen to match steady state-values of investment in structures and equipment with OECD sample means for the period 1960-2000.

3.3 Human capital

In our model, the only input in the production of human capital is the time devoted to education, which includes the opportunity cost of the time spent by students, instructors and other personnel in the educational sector. These estimates of schooling effort are embedded in production function (2.3) to derive the law of motion of human capital. Let

$$u = \frac{\text{labor force in the non-educational sector weighted by educational level}}{\text{(total labor force + students) weighted by educational level}} \tag{3.4}$$

Then, variable u_t is meant to represent the share of time (normalized in efficiency units) devoted to non-educational productive activities, and $1-u$ represents the relative effort devoted to education. Unfortunately, our measure of u will be based on formal schooling. On the job training costs will not be considered in these calculations, for these data are not readily available in most countries.[1] Hence, the labor force in the non-educational sector refers to the size of the working population not engaged in formal educational and R&D activities, and weighted by formal years of education. The total labor force includes those workers involved in formal educational and R&D activities. And students are those enrolled in a primary, secondary or terciary educational degree. In our calculations, each additional year of schooling commands a twelve-percent extra premium.

In an earlier version of this paper we propose an operative procedure for the computation of u based on formal schooling and R & D since available data on educational attainment are not useful for our estimation in (3.4) because the distribution of the population over educational categories may not be the same as that of the labor force. Indeed, retirees and other groups not actively participating in the labor market may possess lower educational levels. Thus, in the absence of census data for most countries we need to find a way to map the available information on educational levels for the population over 15 years of age into educational categories for the labor force. We develop an algorithm that has been calibrated so that from the distribution of population over educational categories of the Barro-Lee data set it approximates quite accurately the distribution of the labor force over educational categories for a few selected countries (France, West Germany, Spain and the US) where there are census data on the labor force classified by educational categories. This algorithm is then applied indistinctly to all other countries in the sample.

The labor force in the non-educational sector referred to in (3.4) is obtained by subtracting from the total labor force the administrative and teaching personnel in the educational sector and the auxiliary personnel and staff engaged in R & D. These groups are also adjusted by educational level from data from the Statistical Yearbooks, UNESCO. Observe from these computations that we are implicitly assuming that most R & D expenditures are devoted to learning activities or adoption of new technologies, rather than innovation. This is in fact the view stressed in Jovanovic (1996), and it seems to be the rule for most countries.

Our final item in (3.4) is students weighted by educational category and such information may be extracted in a certain aggregate way from UNESCO data. Although it is possible, no further adjustments for quality were made between students and workers. Students may lack work experience, but for the same years of schooling, their academic qualifications may be higher. A possibly more controversial issue is to assess the working abilities of children. We have assumed that the working abilities of a child between 6 and 10 years of age would be equivalent to 0.4 times those of a corresponding adult, and the abilities of a child between 11 and 14 years of age would be equivalent to 0.7 times those of an adult. Mincer (1994) suggested that the opportunity costs of students' time would be just about 3 percent of US output. This figure appears to us to be downward biased. For instance, for the US in 1990 there were around 55 million students (about 22.5 millions in primary education, about 19.3 in secondary and about 13.7 in higher) and about 123 million workers, and hence the opportunity cost of these students would be higher than 3 percent.

3.4 Output per worker

Output data are taken from the PWT, entry RGDPCH. These output figures have been deflated and are expressed in a common numeraire. We would like to remark that these figures have not been subjected to further quality adjustments. In fact, quality adjustments are not

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[1] It would nevertheless be hard to sign the bias of our final measures, since not all formal schooling may enhance skills at work; moreover, some people acquiring formal education may not join the labor force.

really required in our comparative study, as long as output is measured uniformly and quality improvements occur evenly across countries. Some asymmetric effects of quality improvements on output across countries may emerge from an unequal sectoral composition of output and from the production of goods of different qualities. Also, let us note that our measures of output have been the subject of some controversial discussions since GDP in the PWT is reckoned from itemized expenditure data. According to some writers [cf. Maddison (1983) and Prados de la Escosura (2000)], these methods may create a relative upward estimation in the output of developing countries. This point may deserve serious consideration when interpreting the results of our empirical investigation in Section 5.

Estimated output $\widehat{Y}_t$ refers to output as computed from production function (2.1) coming from capital and labor. More precisely, for our empirical exercise we include physical and human capital externalities and by an abuse of language we write those stocks outside of $A_t(x_t)$. Then, estimated output is defined as

$$\widehat{Y}_t = A(x_t)(\frac{K_t}{L_t u_t})^{\zeta} h_t^{\gamma} K_t^{\alpha} (L_t u_t h_t)^{1-\alpha}$$

where K_t is the aggregate stock of physical capital, h_t is the average level of human capital, and $L_t u_t$ corresponds to the number of workers in the economy. This latter quantity will be normalized by the average number of hours worked in the country. That is, we consider the US as the benchmark economy. Then, for each country we multiply Lu by the factor "*Average number of hours worked in the country/average number of hours worked in the US.*" The data on hours per worker is taken from the "Yearbook of Labor Statistics" at the International Labor Office.

In our growth accounting exercise, we consider observed output per worker $y = \frac{Y}{Lu}$ and estimated output per worker $\widehat{y} = \frac{\widehat{Y}}{Lu}$. In this exercise, we make $y_{1960} = \widehat{y}_{1960}$. Then, from this equality and using some steady-state conditions we compute the values K_{1960} and h_{1960}.

4 Econometric estimation

We divide the set of parameters into three groups. The calibration of the first group of parameters values is quite standard, and will remain fixed in this study. For production function (2.1) the capital share is $\alpha = 0.4$ Regarding laws of motion (3.1) and (3.2), the corresponding depreciation rates are set to $\delta_{K^{st}} = 0.04$ and $\delta_{K^{eq}} = 0.09$. These values fall in the feasible range reported by many empirical studies.

It is possibly more controversial the calibration of the second group corresponding to the human capital technology. In some exercises we include adjustments for fertility and participation rates. Parameters for production function (2.3) are selected to replicate some steady-state predictions for the US economy in the context of a general equilibrium model for physical and human capital [cf. Santos (2001)]. Using our measurement procedures for the construction of human capital series, for the US economy in the sample period 1960-2000 we obtain an average value $u = 0.76$ for the relative effort devoted to work, and hence $1-u = 0.24$ is the relative effort devoted to education. Also, Denison (1962) reports an annual growth rate $g_h = 0.009$ for the human capital. Denison ignores some forms of human capital accumulation such as learning by doing and on the job training. On these grounds we consider that $g_h = 0.010$ is probably a more realistic estimate. To fit the values, $u = 0.76$, $g_h = 0.010$ and a depreciation rate $\delta_h = 0.035$, as steady-state predictions of the aforementioned model [cf. Santos (2001)] we obtain, $B = 0.091$ and $\theta = 0.285$ for a population growth rate $n = 0.015$.

Finally, one of the main contributions of this work is the estimation of the third group of parameters corresponding to the size of the external effects ζ, γ of the average level of physical and human capital. To obtain these estimates we use a simulation-based estimator in which the results of the growth accounting exercise are computed simultaneously to the estimation of the size of the external effects. We therefore perform a continuum of growth accounting exercises and pick *jointly* the parameter values ζ and γ that make the log of the residual of our growth accounting exercise orthogonal to the growth rate of the estimated average physical and human capital stocks $\widehat{k} = \frac{K_t}{L_t u_t}$ and $\widehat{h}$. The following two orthogonality conditions must be satisfied

$$cov(log\frac{y_t^i}{\widehat{y}_t^i}, log\frac{\widehat{k}_t^i}{\widehat{k}_{60}^i}) = 0 \tag{4.1}$$

$$cov(log\frac{y_t^i}{\widehat{y}_t^i}, log\frac{\widehat{h}_t^i}{\widehat{h}_{60}^i}) = 0. \tag{4.2}$$

The residual in the growth accounting exercise for country i and year t is defined as the ratio $y_t^i/\widehat{y}_t^i$, where y_t^i is observed output per worker and $\widehat{y}_t^i$ is estimated output per worker. In the next section we compute this orthogonality conditions by regressing the residual against the growth rate of the capital stocks and pick the value of ζ and γ that jointly satisfy (4.1)-(4.2). Since we have constructed series from 1960 until 2000 for every country in the growth accounting exercise, we have a panel data set for capital stocks, estimated output and observed output. Hence, the covariances in (4.1)-(4.2) are computed both overtime and accross countries.

Panel data allows us to deal with the problem of unobserved time-invariant individual heterogeneity. If there are omitted characteristics correlated with both dependent and independent variables, then regression estimates may be biased. To tackle this problem two sorts of panel data specification are usually considered: Fixed effects (f.e.) and random effects (r.e.). In the f.e. specification both dependent and independent variables are in first differences, implying that the time-invariant regressors are removed. This model specification is always consistent; however, if the time-invariant characteristic is not correlated with the independent regressors the r.e. is more efficient, and hence it is more desirable. To choose between these two specifications we run a Hausman test.

5 Results

In this section we present the results of our growth accounting exercise. As already pointed out, one main goal in our exercise is to estimate the parameters of the production function (3.1) that represent the size of the external effects for the levels of physical capital per worker and average human capital. First, we present the results for the OECD group, then we proceed with the non-OECD group and the whole sample.

5.1 Growth facts.

Because of data availability, our sample is restricted to 47 countries. We have selected the 24 countries that were members of the OECD before 1990 with population greater than one million and we have also included two of the recently incorporated countries of Eastern Europe, Hungary and Poland. To get a more representative picture of growth, we have added some other countries. From South America we include Argentina, Brazil, Chile, Ecuador, Peru, Uruguay and Venezuela; from Africa we include Egypt, Kenya, Morocco and Tunisia; from Asia China, Hong Kong, India, Indonesia, Iran, Malaysia, Philippines, Singapore, Sri Lanka and Thailand. The time interval for our data sample is the period 1960-2000, except for the case of China, Hungary and Poland. Due to the lack of appropriate data for previous years our series start in 1975 for China and in 1970 for Hungary and Poland. The starting date 1960 is chosen on the grounds that the quality of the data begins to be acceptable for the majority of these countries. We have also adjusted the aggregate figures of those countries for which the oil sector represents over 5 percent of output. Hence, for Egypt, Iran and Venezuela we have taken out the contributions of this sector to national GDP, and to investment and the labor force.

Table 1 reports on some aggregate data for the countries in our sample. The first two columns refer to the level of output per worker in 2000 international prices both in 1960 and 2000. These data are obtained from the Penn World Tables (PWT) version 6.2. The third column shows the average annual growth rate of output per worker for the period while the fourth column shows the average investment rate in physical capital in international prices. The remaining columns refer to the evolution of our index for the human capital stock. We have divided our sample into two subgroups, the OECD and the non-OECD countries. At the bottom of each subgroup and of the table we report the coefficient of variation for each column and the grand average. Average output per worker has more than doubled between 1960 and 2000 for the OECD countries. However, the most interesting fact is that the coefficient of variation for the OECD countries was reduced by almost one half, supporting the idea that there has been convergence among these countries. As one can see from columns 4-7, some of the less developed countries in the OECD display higher investment rates and higher growth in human capital, hinting at the possibility that factor accumulation may be behind the process of convergence. Regarding the non-OECD countries, one can notice that this group does not display signs of convergence; the coefficient of variation increased by more than 15% between 1960 and 2000. Moreover, it seems that convergence between the two groups has not been realized, since average output per worker has increased by a factor of 2.4 in the OECD group and 2.1 in the non-OECD group. Notice, however, that in spite of this even growth in output, the investment rates for the second group are lower; that is, the average for the non-OECD group is a 18.9 percent while the average for the OECD is 24.2 percent. This might suggest that TFP growth plays a more prominent role in the first group.

5.2 Results for the OECD group

We carry out our growth accounting exercise under production function (3.1) with $\alpha = 0.4$. Regarding the external effects, we present here the range of possible values for different model specifications and for different groups of countries. Our selected parametrization to present the results on the residual is $\zeta = 0.14$ and $\gamma = 0.1$. As explained before, the procedure followed to obtain the initial conditions implies that observed and estimated output are equalized in 1960. For all other years and countries in the sample, estimated output is obtained from our growth accounting exercise following the methodology explained in section 4. We have considered the period 1960-2000 for all countries in the sample except for Hungary and Poland which start in 1970. Moreover, regarding Germany we only consider the Western part.

In table 3 we present the orthogonality conditions for the OECD sample. In order not to bias the results we have not included Hungary and Poland in the regressions since these countries have belonged to the OECD for less than 10 years and before 1990 were centrally planned economies. Each column contains the results of regressing the residual against the growth rate of equipment, structures and human capital for different regression models. The time interval considered in this estimation is 1981-2000. We do not include years before 1981 to avoid the influence of initial conditions in our estimates. For each regression we report the point estimate for the external effect at which the t-statistic is equal to zero. Also, we give the confidence interval in which the slope coefficient is not significative. In the first column we consider an OLS regression in levels. The value of ζ that makes the residual orthogonal to the growth rate of equipment is 0.3 and the confidence interval is 0.28-0.32. For structures the value found for ζ is 0.29. For human capital the value of γ that makes the growth rate of human capital orthogonal to the residual is less than zero. In column 2 we deal with the problem of time-invariant individual heterogeneity and use the random effects model, which is the one obtained in the Hausman test. The estimate for the physical capital external effect decreases and for human capital increases. Although the estimates obtained so far seem high, they are lower than in previous studies (e.g. Aschauer (1989) and Lucas (1988)). These high values may be because there are omitted variables correlated with the residual and with the growth rate of the capital stocks. In an attempt to solve this problem we have considered other variables in the regression model. Thus, we have included Research and Development (R&D) investment and public investment. In column 3 we add R&D to our regression model. The result is that the estimates for ζ and γ go down. Similar results are obtained when public investment is added, the size of the external effects decreases.

In order to evaluate how quality adjustment influences our results, table 4 presents in column 1 the estimates when no quality adjustment is made to the physical capital stocks in model 4 of table 3. Column 2 has the estimates when we adjust for quality along the lines explained in section 4 and column 3 reports the estimates when we increase the quality adjustment process to 4.1% for equipment and to 1.6% for structures. It is clear from table 4 that as the quality adjustment process is increased, the values of ζ decrease. The size of the human capital external effects seems to be invariant to these changes. Finally, in the last column of table 4 we report the results when we compute the fixed effects estimates for the model in column 3. We show them since when public investment is included in the regressions the Hausman test does not present a clear evidence on which of the two specifications is better. One can observe that the estimates for ζ further decrease to a value of 0.06 and 0.11.

In table 2 we report for every five years in our sample period the evolution of observed output over estimated output as calculated in our growth accounting exercise. It is important to notice that this residual is different from the traditional Solow residual. Since observed output is not quality adjusted in the National Accounts, the evolution of these ratios is not only determined by differences in TFP. Our purpose, however, is to evaluate the relative performance of each country in the sample. As the BGP assumption seems to fit well US data, we consider the US as a good benchmark in our comparisons. Notice also that the US ratio is close to the average for the OECD group. Hence, assuming that measurement errors of output quality are of the same order of magnitude, all other countries should display fairly similar ratios to those of the US.

Observe from table 2 that these ratios seem fairly close to unity in the 60's, but sharply decline in the 70's and at the beginning of the 80's. (This downward trend may reflect what has been called the *productivity solowdown.*) Then, the trend flattens out at the last part of the period. In addition to these general trends there are remarkable differences in individual performance. For instance, there is an initial period in which Ireland displays slightly higher ratios than the US, but then the trend changes and this country ends up with a ratio which is 50% higher than that of the US. Indeed, according to our calculations Ireland is the best OECD performer in our sample. Some other good performers are Austria, Greece, Portugal, and the UK. The first three have been above the US for most of the time, whereas the UK managed to outweight the US in the last period of the sample. Also Hungary and Poland are above the mean in 2000 but this result may be driven by the higher influence of the initial conditions since the computations for these countries begin in 1970. On the other hand, 11 out of 26 OECD countries are below the US performance. The worst cases are Switzerland and New Zealand, which are about thirty percent below the US mark. It should be stressed that an underperformer simply means that the country has grown less than expected by our computations, but it does not necessarily mean that the country has experienced low growth rates. For instance, Japan has and average growth rate of output per worker of 3.9 percent which is well above the mean growth rate, but its output ratio is only 0.8030 in 2000, which is around the mean.

Therefore, from table 2 we can observe some disparity both across countries an over time. For convenience, for each date the bottom rows of the OECD countries contain the mean and standard deviations of these ratios. It seems that the standard deviation grows in periods of fast economic growth as in the 60's and the second half of the 80's, and it goes down in recession periods as in the 70's and the first half of the 80's. Thus, it appears that countries with better-than-average performance in expansions get more adversely affected by recessions.

In order to evaluate statistically all the prediction biases from our model, we have performed a battery of tests which are reported in tables 8 to 11. A formal justification for these procedures is provided in Santos (2001). We regress $log(y_t^i/y_{60}^i)$ on $log(\widehat{y}_t^i/y_{60}^i)$. As in the case of the orthogonality conditions we use the same panel data models in order to deal with time-invariant unobserved heterogeneity. In table 8 we report the values of ζ that make the slope coefficient equal to one when the size of γ is the value obtained for the corresponding model. In table 9 we report these same values when $\gamma = 0$ and in table 10 when $\gamma = 0.1$. The point estimates in table 8 are obtained when the t-statistic is equal to zero and the confidence intervals show the parameter values for which the test for the slope to be equal to one is accepted. As we can see in column 1 of table 8, we get an $R^2 = 0.9$ for the OLS regression in levels, which attests for an extraordinarily good fit for our model. Also, the estimate for ζ is 0.3. In column 2 we use the random effects model and as in table 3 the estimate for ζ decreases. Moreover, when R&D and public investment are introduced this estimate drops to 0.16 and the R^2 remains almost constant. Finally, the fixed effects model implies again a further decrease in our estimate, ζ is now equal to 0.09. The results in tables 89 and 10 for $\gamma = 0$ and $\gamma = 0.1$ are almost identical.

In summary, our statistical experiments show that our model has a remarkably good fit for the OECD countries; moreover, the calibration of the externality coefficients in the production function seems optimal in the sense that the TFP residual is orthogonal to the growth rates of capital stocks and also to other explanatory variables.

5.3 Results for the non-OECD group

We now carry out a parallel analysis for the non-OECD countries. This group is made up of 21 countries and, as for the OECD group, we have considered the period 1960-2000 for all countries except for China which starts in 1975. There is a more uneven distribution of output per worker within this group. From column 2 in table 1 we can see that the variation coefficient for this variable in 2000 is equal to 0.284 for the OECD group, whereas it is equal to 0.790 for the non-OECD group. (It should be noted that if we exclude Hong Kong and Singapore, this coefficient drops to 0.540.) Furthermore, in 1960 the variation coefficient for the non-OECD countries is also 0.680. Hence, this group does not present any tendency towards convergence.

Looking at the observed over estimated output ratios in table 2, the average ratio in 2000 is 0.8491 which is 10 percent higher than that of the OECD group. A good part of this incremental value could be explained by a moderate decline of the output ratios for these countries in the 70's and early 80's, and hence these countries seem to be much less adversely affected by the so called *productivity slowdown*. But we cannot rule out measurement errors and possible difficulties in adjustments in the initial conditions for physical and human capital. Measurement errors may be reflected in sharp variations in these ratios over short periods of time. For instance, the ratio in Uruguay changes from 1.0582 to 0.7483 between 1980 and 1985. Similar changes occur for Venezuela between 1970 and 1975, and for Philippines between 1980 and 1985. These outliers may be indicative of poor data quality in the National Accounts, and in the PPP parities used in the PWT to translate domestic aggregates to a common numeraire.

The best performers in this group are China, with an output ratio equal to 1.5258 in 2000, and Hong Kong with 1.3115. But several other countries display an outstanding performance as compared to the US. The underperformers are Peru and Venezuela with corresponding ratios equal to 0.5183 and 0.5831. It is interesting the case of China and Hong Kong which are the fastest growing countries in GDP per worker and also have the highest output ratio. The reason for these high ratios may be measurement problems in the national accounts, including underestimation of factor accumulation; also, the fact that Hong Kong is a city might imply more pronounced external effects in production an factor accumulation.

Although this is a small sample, we have performed the same statistical tests as before. We have not included China, the reason is that we use panel data from 1981 to 2000 and the first data available for China is in 1975. Due to the procedure used to compute the initial conditions this may influence the results. Also, for the non-OECD group the public investment variable is not available, hence it has not been included in the regressions. The tests on the orthogonality conditions are displayed in table 5. It can be observed that the estimates for ζ are higher than for the OECD group. The values obtained for the human capital externality are less than zero.

5.4 Results for the whole sample

We have also replicated the above regressions for the all the countries in our sample except China. The results of the tests on the orthogonality conditions are reported in table 6. The estimates for ζ are slightly lower than for the OECD in all the specifications except when physical capital is not adjusted for quality. Moreover, when quality adjustment is increased the orthogonality condition for equipment sets a value for $\zeta = 0.1$ and 0.14 for structures. Regarding human capital, the estimate for γ is always less than zero. In tables 8-10 the estimated values for ζ are similar to table 6. However, the R^2 lowers to values around 0.86, slightly lower than for the OECD. As before, this results are robust for different values of γ.

In summary, these regressions suggest a slightly worse fit of our model for the whole sample. The lower R^2 obtained may suggest that TFP growth has played a more important role in the group of non-OECD countries. This is also reflected in the estimates for the physical capital external effects. Since the correlation of the residual with the growth rate of the capital stock is lower smaller estimates for ζ are obtained. It is also worth mentioning that the value for the human capital external effect is always less than zero for the whole sample and for the non-OECD group. This may imply a different specification of the production function for this set of countries.

5.5 Total factor productivity or factor accumulation?

As pointed out in the introduction, both groups have similar growth rates in output per worker, but investment rates are higher in the OECD. This might suggest a higher TFP growth component in the non-OECD group, which has been confirmed in our growth accounting exercise. It is worth mentioning, however, that investment rates for low-income countries get diminished when investment is expressed in international prices, since equipment goods are relatively more expensive in these countries. This is nevertheless compatible with a theory of technology adoption [e.g., see Santos (2001)] in which there could be equal growth across the world, but high-income countries are more efficient in factor accumulation and so they are associated with higher investment rates. In other words, our exercise suggests that unequal growth in TFP has been partly responsible for some growth patterns for the period 1960-2000. But what are the sources of such an uneven TFP growth?

There are several possible reasons for disparities in TFP growth. In less rich countries the procedures and methodologies to construct the National Accounts are probably not as well established as in more developed countries. This may produce an underestimation of the physical capital investment series. A second reason is that our measure of human capital is based upon schooling and $R\&D$ data. These are the basic sources of productivity improvement in our model along with physical capital accumulation. There are, however, other forms of learning that may enhance labor productivity. Thus, because of lack of data we have ignored other sources for human capital accumulation such as on-the-job-training programs, experience and learning by doing. These alternative ways of learning play a residual role in our analysis. Third, the TFP variable may also reflect advances in the cultural and sociological environments, as well as the degree of openness of a country to new ideas and modes of production. Social changes attached to development and to the incorporation to international organizations such as the OECD or the European Union may have positive effects on TFP. Also, foreign investment and certain additional structural changes may foster the acquisition of knowledge and technology adoption in the less developed areas.

Evidence that geographical and cultural spillovers may have played a fundamental role in the development of some of these countries is reflected in certain growth patterns within geographical areas. Thus, South American countries have experienced low average growth rates of output per worker but high rates regarding human capital. North African countries have similar growth rates for output per worker and have also higher-than-average output ratios in 2000. South East Asian countries –except Philippines– have the highest growth rates for output per worker and relatively low for human capital. Their investment rates in physical capital are the highest and their output ratios are on or above the average –specially for Hong Kong. Finally, not all the countries have been in a BGP for all the period, and may have experienced periods of transition. We have taken care of this fact while making proper adjustments for their initial conditions in 1960.

6 Concluding remarks

This paper presents a growth accounting exercise with the main objective of estimating an aggregate production function and the main factors affecting TFP. The aggregate production function is an important analytical tool in studies of economic growth, business cycles and macroeconomic policy. Indeed, this function allows us to decompose output growth between factor accumulation and TFP, and it determines income shares for capital and labor and the evolution of salaries over time and across countries.

We have selected a sample of 47 countries with 26 countries that belong to the OECD. For each country we build series for physical and human capital for the period 1960-2000. We decompose physical capital into equipment and structures. This avoids potential biases as equipment displays higher cross-country volatility and more pronounced technological progress. Human capital is contructed from a standard accumulation law in which the only input is the time devoted to education. We use a simulation-based estimation procedure to pin down the coefficients of the aggregate production function that includes physical and human capital externalities as well as other determinants of TFP. Here is a summary of our main findings:

(i) Human capital externalities in the aggregate production function [as considered in Lucas (1988)] do not seem to be significative. This is in line with some previous findings [e.g., Benhabib and Spiegel (1994)] who have used human capital indices based on years of schooling. We have used new measures of capital stocks from a standard production function that seems suitable to pick up factor quality, and we obtain the same results. In a companion paper we show that the role of human capital in economic growth is most relevant in technology adoption as reflected in the relative price of investment in the PWT. (There is of course a direct effect of human capital in the production function as labor is a primary input in production.) Again, these results are robust to the data used. They occur when we use our own human capital series or a human capital index based on years of schooling from Barro and Lee.

(ii) Physical capital externalities in the aggregate production function [as considered in Benhabib and Jovanovic (1991) and Romer (1987)] are very significative with a coefficient around 0.14. This value is much lower than some other related estimates [e.g.,Aschauer (1989) and Romer (1987)]. The coefficient gets higher when factors of production are not quality adjusted. We suggest that a good way to interpret physical capital externalities is along the lines of Romer (1990) in a model with a variety of investment goods. For the same amount of investment, the economy becomes more productive with a wider range of varieties.

(iii) When observed output is regressed against estimated output from our aggregate production function with physical and human capital we get an R^2 of around 0.91 for the OECD countries, and of 0.86 for the whole sample. This shows that factor accumulation (rather than TFP changes) can account for a good portion of economic growth. The main differences with respect to previous studies are to be found in the quality adjustments for physical and human capital and the consideration of external effects for these factors. Therefore, a proper specification of the aggregate production function is crucial to understand the sources of growth. And an understanding of the sources of growth is crucial for policy analysis.

(iv) Developing countries show less factor accumulation and higher TFP growth. We interpret this finding in line with our analysis: New investment goods (computers, cell phones, and so on) seem to have had a higher impact in low-income countries (e.g. see the article "cell phones may save the world"). Indeed, some of these countries may have been able to switch directly from relatively old, inefficient technologies to user-friendly equipment goods.

The econometric methodology underlying these results merges simulation-based estimation with growth accounting. It pertains to estimate jointly the coefficients of the production function as well as those of other determinants of TFP. Thus, output is not regressed directly against capital stocks to avoid multicolinearity. (Note that our capital stocks depend on parameter values through depreciation rates and initial conditions.) Moreoreover, a data panel is constructed to avoid biases from unobserved heterogeneity. On the other hand, the usual growth accounting exercise presumes a functional form for the aggregate production function and disregards information from other variables influencing TFP. Finally, since this methodology avoids multicollinearity, it can consider simultaneously different sets of data for a given variable. For instance, a human capital index based on the Barro-Lee data did not have additional explanatory power for the Solow residual over our own human capital series.

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Table 1: Economic Growth in a Sample of Countries, 1960-2000

	Real GDP per worker in 1960	Real GDP per worker in 2000	Average Growth Rate GDP p. worker	Average Investmt. Rate in Intl. Prices	Human Capital in 1960	Human Capital in 2000	Average Growth Rate Human Capital
				OECD Countries			
Australia	26,534	50,606	1.6%	25.4%	3,148	4,287	0.8%
Austria	17,588	58,441	3.0%	26.4%	2,359	3,442	0.9%
Belgium	21,032	59,874	2.6%	22.9%	2,654	4,059	1.1%
Canada	28,376	49,816	1.4%	22.9%	3,386	4,984	1.0%
Denmark	25,051	50,448	1.8%	24.9%	3,046	4,086	0.7%
Finland	17,038	45,192	2.5%	27.1%	2,211	3,399	1.1%
France	19,743	55,286	2.6%	24.3%	2,534	3,993	1.1%
Germany	20,172	52,404	2.4%	25.7%	2,584	3,930	1.1%
Greece	10,276	32,070	2.9%	28.4%	1,691	2,268	0.7%
Hungary(a)	10,780	23,789	2.7%	20.1%	1,786	2,114	0.6%
Ireland	13,416	59,103	3.8%	20.1%	2,173	3,335	1.1%
Italy	17,324	50,853	2.7%	26.6%	2,454	3,817	1.1%
Japan	9,486	44,563	3.9%	32.6%	1,644	2,260	0.8%
Korea	4,357	30,621	5.0%	27.9%	1,172	1,578	0.7%
Mexico	12,400	19,621	1.2%	16.8%	1,919	2,810	1.0%
Netherland	28,806	56,691	1.7%	24.4%	3,214	4,808	1.0%
New Zealand	32,270	40,977	0.6%	21.9%	3,580	5,095	0.9%
Norway	24,129	63,909	2.5%	29.7%	2,822	4,572	1.2%
Poland(a)	7,491	16,643	2.7%	25.5%	1,427	1,848	0.9%
Portugal	9,543	34,000	3.2%	22.2%	1,883	2,722	0.9%
Spain	12,622	44,361	3.2%	25.9%	2,147	3,347	1.1%
Sweden	25,286	46,544	1.5%	22.1%	3,175	4,201	0.7%
Switzerland	32,649	54,306	1.3%	28.7%	3,521	4,531	0.6%
Turkey	4,433	12,205	2.6%	15.9%	1,203	1,556	0.6%
UK	22,340	49,225	2.0%	19.0%	2,700	3,743	0.8%
USA	31,691	67,079	1.9%	19.2%	3,500	5,164	1.0%
Mean	19,440	47,008	2.4%	24.2%	2,530	3,666	0.9%
Var. Coef.	0.440	0.284	0.413	0.170	0.282	0.283	0.185
				Non-OECD Countries			
Argentina	19,925	27,980	0.9%	19.3%	2,504	4,175	1.3%
Brazil	7,703	15,470	1.8%	21.4%	1,372	2,236	1.2%
Chile	15,119	27,995	1.6%	15.4%	2,112	2,988	0.9%
China(b)	969	6,689	6.7%	18.1%	558	624	0.45%
Ecuador	7,086	11,026	1.1%	19.7%	1,369	2,118	1.1%
Egypt(c)	4,059	11,173	2.6%	13.9%	1,124	1,890	1.3%
Hong Kong	8,601	50,288	4.5%	28.3%	1,416	1,707	0.5%
India	1,962	6,033	2.8%	11.6%	852	1,140	0.7%
Indonesia	2,743	7,800	2.6%	14.2%	952	1,404	1.0%
Iran(c)	8,422	14,451	1.4%	18.0%	1,579	2,396	1.0%
Kenya	2,321	2,458	0.1%	12.2%	871	1,151	0.7%
Malaysia	5,209	26,868	4.2%	21.6%	1,373	2,075	1.0%
Morocco	3,552	9,435	2.5%	16.7%	1,030	1,289	0.6%
Peru	9,779	11,108	0.3%	19.5%	1,638	2,595	1.2%
Philippines	5,447	9,229	1.3%	13.9%	1,485	2,192	1.0%
Sri Lanka	2,364	8,967	3.4%	11.5%	1,032	1,446	0.8%
Singapore	12,754	58,750	3.9%	43.5%	1,846	2,639	0.9%
Thailand	2,075	10,876	4.2%	29.4%	723	931	0.6%
Tunisia	6,277	17,289	2.6%	16.8%	1,311	2,127	1.2%
Uruguay	15,144	23,855	1.1%	12.9%	2,302	3,422	1.0%
Venezuela(c)	14,472	14,545	0.0%	17.9%	2,143	3,365	1.1%
Mean	7,751	18,280	2.1%	18.9%	1,452	2,164	1.0%
Var. Coef.	0.680	0.790	0.654	0.403	0.351	0.396	0.253
Mean	14,127	33,950	2.3%	21.8%	2,040	2,983	0.9%
Var. Coef	0.657	0.587	0.520	0.290	0.405	0.407	0.218

The output figures have been obtained from the PWT. The figures for investment rates and human capital are authors' estimations.
(*a*) Our investment rates and human capital series for Hungary and Poland begin in 1970.
(*b*) Our investment rates and human capital series for China begin in 1975.
(*c*) We have subtracted the oil sector from output, labor force and investment in physical capital data for these countries.

Table 2: Evolution of the Ratio of Actual over Estimated Output

Year	1.960	1.965	1.970	1.975	1.980	1.985	1.990	1.995	2.000
OECD Countries									
Australia	1.0000	0.9281	0.9182	0.8523	0.8412	0.8181	0.7685	0.7611	0.7291
Austria	1.0000	1.0257	1.1084	1.0400	0.9891	0.9140	0.9135	0.8475	0.8433
Belgium	1.0000	1.0326	1.0733	1.0279	0.9981	0.9092	0.9341	0.8287	0.7948
Canada	1.0000	1.0576	0.9747	0.9147	0.8298	0.7656	0.6969	0.6383	0.6542
Denmark	1.0000	1.0562	0.9747	0.7821	0.7360	0.7544	0.7159	0.7352	0.7353
Finland	1.0000	0.9665	0.9780	0.9224	0.8651	0.8246	0.7975	0.6731	0.7691
France	1.0000	1.0386	1.0435	0.9522	0.9310	0.8710	0.8478	0.7534	0.7723
Germany	1.0000	1.0030	1.0108	0.8959	0.8836	0.7899	0.7924	0.7376	0.7213
Greece	1.0000	1.1446	1.1841	1.0624	1.0555	0.9418	0.9174	0.8627	0.8733
Hungary	-	-	1.0000	1.0630	1.0148	1.0393	1.0299	0.9208	0.9482
Ireland	1.0000	1.0682	1.0849	1.0534	1.0462	0.8954	0.9624	0.9860	1.1791
Italy	1.0000	0.9357	1.0192	0.9031	0.9220	0.8409	0.8374	0.7784	0.7603
Japan	1.0000	1.0693	1.2647	1.0371	0.9897	0.9363	0.9629	0.8557	0.8030
Korea	1.0000	1.0700	1.1392	1.1073	0.9558	0.9567	1.1366	1.0801	0.9731
Mexico	1.0000	1.1672	1.1665	1.1959	1.1748	0.9354	0.8224	0.6819	0.7136
Netherland	1.0000	0.9927	0.9843	0.8774	0.8191	0.7193	0.7087	0.6734	0.6998
New Zealand	1.0000	1.0138	0.8890	0.8438	0.7021	0.6637	0.5809	0.5851	0.5579
Norway	1.0000	0.9017	0.8720	0.8391	0.7643	0.7578	0.6854	0.7403	0.7242
Poland	-	-	1.0000	1.0091	0.7974	0.7122	0.7330	0.7681	0.8459
Portugal	1.0000	1.0486	1.1329	0.9920	0.9997	0.8348	0.9675	0.8645	0.8502
Spain	1.0000	1.1311	1.1111	1.0876	0.9582	0.8912	0.8972	0.7813	0.7813
Sweden	1.0000	1.0317	0.9801	0.9153	0.8436	0.7959	0.7513	0.6756	0.7136
Switzerland	1.0000	0.9309	0.9116	0.7448	0.7767	0.7131	0.6788	0.5966	0.5880
Turkey	1.0000	1.1217	1.2368	1.2152	1.0268	1.1125	1.1212	0.8916	0.8081
UK	1.0000	0.9964	0.9548	0.9168	0.8746	0.8929	0.9055	0.8664	0.8694
USA	1.0000	1.1029	1.0548	0.9401	0.8795	0.8504	0.8072	0.7692	0.7654
Mean	1.0000	1.0348	1.0411	0.9689	0.9106	0.8514	0.8451	0.7828	0.7875
Var. Coef.	0.0000	0.0683	0.1000	0.1215	0.1246	0.1233	0.1634	0.1490	0.1574
Non-OECD Countries									
Argentina	1.0000	0.9679	0.9642	0.8950	0.8185	0.6407	0.5731	0.6560	0.6174
Brazil	1.0000	1.0536	1.1236	1.1799	1.0843	0.9387	0.8748	0.8135	0.7511
Chile	1.0000	0.9189	1.0905	0.8956	1.1156	0.8436	0.8790	0.9491	0.8140
China	-	-	-	1.0000	0.9943	1.1432	1.1648	1.4440	1.4967
Ecuador	1.0000	0.9857	0.9561	1.1993	1.2061	0.9932	0.8154	0.7560	0.6345
Egypt	1.0000	1.0212	0.9420	0.7777	0.7640	0.8226	0.8181	0.8945	0.9340
Hong Kong	1.0000	1.1243	1.1146	1.1287	1.3744	1.3150	1.5338	1.5650	1.3115
India	1.0000	1.0139	1.0711	0.9864	0.9869	1.0194	1.0402	0.9821	1.0027
Indonesia	1.0000	0.8940	1.0877	1.2835	1.2115	1.0029	1.0215	1.0058	0.7761
Iran	1.0000	1.1455	1.2395	0.9906	1.0225	0.9483	0.8055	0.7863	0.6731
Kenia	1.0000	1.0330	0.8771	0.8169	0.8387	0.7666	0.8806	0.7839	0.6924
Malaysia	1.0000	1.1149	1.1214	1.1713	1.1978	0.9753	0.9964	0.9957	0.9449
Morocco	1.0000	1.1750	1.0813	1.0406	1.0503	1.0090	1.0619	0.9319	0.9161
Peru	1.0000	1.0110	1.0497	1.1445	1.0297	0.7981	0.5980	0.6280	0.5183
Philippines	1.0000	1.0386	0.9624	1.0194	0.9330	0.6865	0.7100	0.6712	0.6863
Sri Lanka	1.0000	1.1934	1.2793	1.3338	1.2192	1.1453	1.0819	1.0183	0.9277
Singapore	1.0000	0.8874	1.0020	0.9027	0.9366	0.7734	0.8714	0.9973	0.9398
Thailand	1.0000	1.0330	1.0423	0.9440	0.9499	0.9155	1.0428	1.0732	0.8703
Tunisia	1.0000	0.9563	0.9260	0.9781	0.9589	0.9216	0.9431	0.9020	0.9074
Uruguay	1.0000	0.9109	1.0039	1.0178	1.0582	0.7483	0.8189	0.9007	0.8047
Venezuela	1.0000	1.1044	1.1705	0.9765	0.7669	0.7379	0.6303	0.6895	0.5831
Mean	1.0000	1.0291	1.0553	1.0325	1.0253	0.9131	0.9139	0.9274	0.8491
Var. Coef.	0.0000	0.0894	0.0989	0.1419	0.1559	0.1856	0.2383	0.2559	0.2780
Total Mean	1.0000	1.0322	1.0472	0.9973	0.9618	0.8790	0.8758	0.8474	0.8150
Total Var. Coef	0.0000	0.0776	0.0986	0.1341	0.1522	0.1586	0.2048	0.2275	0.2247

Table 3: Orthogonality Conditions. OECD

	(1) OLS	(2) Panel(r.e.)	(3) (2)+R&D(r.e.)	(4) (3)+P. Inv.(r.e.)
		Equipment		
Point estimate	0.3	0.18	0.15	0.13
C.I.	0.28-0.32	0.14-0.22	0.1-0.19	0.05-0.21
		Structures		
Point estimate	0.29	0.27	0.21	0.21
C.I.	0.29-0.33	0.23-0.32	0.17-0.26	0.14-0.27
		Human Capital		
Point estimate	≤0	0.24	0.2	≤0
C.I.	≤0	≤0-0.36	≤0-0.36	≤0-0.33

Table 4: Orthogonality Conditions. Quality Adjustment. OECD

	Panel+R&D+Public Investment			
	(1) (r.e)+No Qual.	(2) (r.e.)	(3) (r.e.)+More Qual.	(4) (f.e.)+More Qual.
		Equipment		
Point estimate	0.15	0.13	0.12	0.06
C.I.	0.07-0.22	0.05-0.21	0.04-0.2	0-0.14
		Structures		
Point estimate	0.22	0.21	0.17	0.11
C.I.	0.15-0.28	0.14-0.27	0.11-0.23	0.04-0.18
		Human Capital		
Point estimate	≤0	≤0	0.03	0.17
C.I.	≤0-0.32	≤0-0.33	≤0-0.36	≤0-0.36

Table 5: Orthogonality Conditions. Non-OECD

	Panel+R&D		
	(1) No Qual.(r.e.)	(2) (r.e.)	(3) More Qual.(r.e.)
		Equipment	
Point estimate	0.24	0.21	0.17
C.I.	0.19-0.29	0.16-0.26	0.12-0.22
		Structures	
Point estimate	0.29	0.27	0.21
C.I.	0.23-0.34	0.22-0.32	0.16-0.26
		Human Capital	
Point estimate	≤ 0	≤ 0	≤ 0
C.I.	≤ 0	≤ 0	≤ 0

Table 6: Orthogonality Conditions. Whole Sample

	(1) OLS	(2) Panel(r.e.)	(3) (2)+R&D(r.e.)	(4) (3)+No Qual.	(5) (3)+More Qual.
			Equipment		
Point estimate	0.26	0.16	0.14	0.16	0.1
C.I.	0.24-0.28	0.12-0.19	0.1-0.17	0.13-0.2	0.07-0.14
			Structures		
Point estimate	0.29	0.25	0.23	0.25	0.14
C.I.	0.27-0.3	0.21-0.29	0.2-0.27	0.22-0.29	0.15-0.21
			Human Capital		
Point estimate	≤ 0	≤ 0	≤ 0	≤ 0	≤ 0
C.I.	≤ 0	≤ 0	≤ 0	≤ 0	≤ 0

Table 7: Orthogonality Conditions. Fixed effects Moving Average.

	(1) (f.e.)+R&D+No Qual.	(2) (f.e.)+R&D	(3) (f.e.)+R&D+More Qual.
OCDE			
Equipment			
Point estimate	0.19	0.16	0.13
C.I.	0.14-0.25	0.11-0.21	0.08-0.18
Structures			
Point estimate	0.28	0.25	0.19
C.I.	0.23-0.33	0.2-0.3	0.14-0.23
Human Capital			
Point estimate	0.02	0.04	0.16
C.I.	<0-0.36	<0->0.36	<0->0.36
Whole Sample			
Equipment			
Point estimate	0.17	0.14	0.1
C.I.	0.13-0.21	0.1-0.18	0.06-0.13
Structures			
Point estimate	0.29	0.27	0.2
C.I.	0.25-0.32	0.23-0.3	0.17-0.23
Human Capital			
Point estimate	<0	<0	<0
C.I.	<0	<0	<0

Table 8: Regression of Obs. Output, $log(y_t^i/y_{60}^i)$, on Est. Output, $log(\widehat{y}_t^i/y_{60}^i)$

OECD					
	(1) OLS	(2) Panel(r.e.)	(3) (2)+R&D+P. Inv(r.e.).	(4) (3)+M. Qual.	(5) (3)+M. Qual.(f.e.)
Point est.	0.3	0.24	0.18	0.16	0.09
C.I.	0.28-0.33	0.19-0.28	0.11-0.24	0.09-0.21	0.03-0.16
R^2	0.9	0.9	0.89	0.89	0.84

Whole Sample					
	(1) OLS	(2) Panel(r.e.)	(3) (2)+R&D(r.e.)	(4) (3)+M. Qual.	(5) (3)+M. Qual.(f.e.)
Point est.	0.27	0.2	0.18	0.14	0.12
C.I.	0.25-0.29	0.17-0.23	0.15-0.22	0.11-0.17	0.09-0.15
R^2	0.85	0.85	0.86	0.87	0.86

Table 9: Regression of $log(y_t^i/y_{60}^i)$ on $log(\widehat{y}_t^i/y_{60}^i)$. $\phi = 0$

OECD					
	(1) OLS	(2) Panel(r.e.)	(3) (2)+R&D+P. Inv(r.e.).	(4) (3)+M. Qual.	(5) (3)+M. Qual.(f.e.)
Point est.	0.3	0.24	0.18	0.16	0.09
C.I.	0.28-0.33	0.2-0.29	0.11-0.24	0.09-0.21	0.03-0.16
R^2	0.9	0.9	0.89	0.89	0.84

Whole Sample					
	(1) OLS	(2) Panel(r.e.)	(3) (2)+R&D(r.e.)	(4) (3)+M. Qual.	(5) (3)+M. Qual.(f.e.)
Point est.	0.27	0.2	0.18	0.14	0.12
C.I.	0.25-0.29	0.17-0.23	0.15-0.22	0.11-0.17	0.09-0.15
R^2	0.85	0.85	0.86	0.87	0.86

Table 10: Regression of $log(y^i_t/y^i_{60})$ on $log(\widehat{y}^i_t/y^i_{60})$. $\phi = 0.1$

OECD

	(1) OLS	(2) Panel(r.e.)	(3) (2)+R&D+P. Inv(r.e.).	(4) (3)+M. Qual.	(5) (3)+M. Qual.(f.e.)
Point est.	0.3	0.24	0.18	0.16	0.09
C.I.	0.28-0.33	0.2-0.28	0.11-0.24	0.09-0.21	0.03-0.16
R^2	0.9	0.9	0.89	0.89	0.84

Whole Sample

	(1) OLS	(2) Panel(r.e.)	(3) (2)+R&D(r.e.)	(4) (3)+M. Qual.	(5) (3)+M. Qual.(f.e.)
Point est.	0.27	0.2	0.18	0.14	0.12
C.I.	0.25-0.29	0.17-0.23	0.15-0.22	0.11-0.17	0.09-0.15
R^2	0.85	0.85	0.86	0.86	0.86

Table 11: Regression of $log(y_t^i/y_{60}^i)$ on $log(\widehat{y}_t^i/y_{60}^i)$. Fixed Effects and Moving Average

OECD			
	(1) (f.e.)+R&D+No Qual.	(2) (f.e.)+R&D	(3) (f.e.)+R&D+M. Qual.
Point est.	0.24	0.22	0.16
C.I.	0.2-0.29	0.17-0.27	0.12-0.21
R^2	0.90	0.90	0.89

Whole Sample			
	(1) (f.e.)+No Qual.	(2) (f.e.)	(3) (f.e.)+M. Qual.
Point est.	0.23	0.2	0.15
C.I.	0.2-0.26	0.17-0.23	0.12-0.18
R^2	0.85	0.86	0.87