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Development Accounting across European countries: from 1950 to 2014.

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1 Introduction

One of the most important questions in economics and specially in economic growth is the following: why some countries are richer than others? Focusing on the results obtained from past papers, the main finding is that TFP is more relevant than input factors when it comes to explain why income per working age population differ between less developed and developed countries. However, Hall and Jones (1999) suggest that if we focus our interest on OECD countries it seems that human capital might be more relevant when it comes to explain why countries differ in income per working age population. Nevertheless, Jones (2015) suggests that the relevance of those variables seems to vary through time. Thus, based on these previous results, the idea here is twofold. First of all the aim is to compute by how much the variation in income per working age population across European countries can be due to input factors (physical capital and human capital), and by how much it can be explained by differences in Total Factor Productivity (TFP). And secondly to see whether the relative importance of the factors of production, in relation to the TFP, has varied over time or not.

In order to study the above mentioned question, we are going to make use of the Development Accounting methodology. Many authors used this methodology to carry on this kind of research. Caselli (2005), Hall and Jones (1999) and Klenow and Rodríguez-Clare (1997) are some of the most relevant papers in this field.

Regarding the Development Accounting methodology, this is similar to that of Growth Accounting and it answers the question about how much of the differences in income per worker between countries can be attributed to differences in the factors of production or differences in TFP. Unlike Growth Accounting it is done at a given time. For other authors (such as Hsieh and Klenow (2010)), "Development accounting" goes further and also tries to explain which are the factors that drive the observed differences in the factors of production.

Several papers made an attempt to understand the differences in TFP and in the input factors across countries making use of the development accounting method. Many hypothesis have been brought up. Hall and Jones (1999) tried to estimate the effect of social infrastructure, and suggests that differences in social infrastructure across countries cause large differences in capital accumulation, educational attainment, and productivity, and therefore large differences in income across countries. Beugelsdijk, Klasing and Milionis (2017) worked on the role of the total factor productivity (TFP) in regional economic development in the European Union for 2007. This paper focuses on 257 regions inside the EU, and concludes that diffusion of technology between regions is limited. Hendricks (2016) analyzed the role of institutional arrangements for all countries for which there was data, and Hsieh and Klenow (2010) suggest that the misallocation of inputs across firms and industries may be an important factor in order to explain differences in TFP. Apart from this above mentioned papers, there are some more papers that concentrate on TFP and that suggest different kind of hypothesis.

However, from all these arises a new and more relevant question: why do we want to know by how much do input factors and TFP differences explain income per worker differences?

From an egalitarian point of view, we are searching for equal income distribution given that inequality in income distribution could be considered morally objectionable. In praxis, in order to reach this ideal situation, we must begin by understanding income differences, that is, by identifying which are the differences between countries that explain differences in income per worker and by quantifying by how much differences in those variables can explain differences in income per worker. This last question would be answered via development accounting method and with the findings obtained, we might achieve a more equal income distribution by working in those policies that would reduce inequalities in those variables that most explain income per worker differences.

Knowing that there are not equal initial allocations of resources across countries, neither similar historical backgrounds we will consider countries that not only are quite homogeneous in terms of initial resources but also in terms of institutional, cultural, economical and social background. To achieve the above simplification, we are going to select only the European countries. This simplification will make comparison between countries easier, because does it make sense to compare such unequal countries as Germany and Ethiopia?

First of all, given differences in the productive structure such different countries may not fit equally well to the same production function (the Cobb-Douglass in this case), and this could arise to incorrect results. But apart from that, across the world there are countries that suffered such problems as colonisation or repression, and even differ in institutional background, in development of financial intermediation, in protection of intellectual property, etc. and all these factors lead inequalities to such an extent that make our development accounting analysis insignificant. Insignificant because with such differences among the sample we could expect that almost all income per worker differences would be explained by residual differences. However, this does not entail that differences in TFP must be insignificant when we are working with homogeneous samples.

Nevertheless, we are aware that European countries do not guarantee absolute homogeneity, because although a sample of European countries is more homogeneous than the one which contains all existing countries, there are ample differences between European countries. For instance, in terms of output per worker, there exists substantial differences between western and eastern countries across Europe [1], and thus we will also make a separate analysis for both groups of countries to see whether higher levels of homogeneity have impact on final results.

Overall, this paper is divided into six different chapters were this introductory chapter is followed by the methodology. The methodology is divided in four subsections that lay the foundations of our investigation: the production function, the physical capital, the human capital and the success indicator. In subsection 2.1 we define and rearrange the Cobb-Douglass production function, as it is going to be used for further analysis. In subsections 2.2 and 2.3 we analyse the inputs of our model, the physical capital and the human capital

[1] See Table 5 in the Appendix.

respectively. Were apart from pointing out how the data is obtained, we show how physical and human capital are computed and also we make a literature review about each production factor. To finish the methodology section, we introduce the success indicator which is mostly used in this type of literature.

Section 3 makes the development accounting exercises. First of all we will compute and analyse the results obtained from the development accounting methodology for 2014 in subsection 3.1, and after that we will incorporate a deeper analysis over time in order to see whether results from 2014 were robust over time or not. Finally, in order to conclude with our investigation, section 4 will capture the final conclusions, and sections 5 and 6 will incorporate the references and the appendix respectively.

2 Methodology

2.1 The production function

In order to compute by how much the differences in income per working age population across European countries is due to input factors (physical capital, human capital) and by how much it can be explained by differences in Total Factor Productivity (TFP), we must start by defining our production function. Our analysis is going to be based on the Cobb-Douglas production function taking physical and human capital as sole inputs. Hence, let us consider the following aggregate production function:

$$Y_i = K_i^{\alpha}(A_i H_i)^{(1-\alpha)} \tag{1}$$

Here, Y_i represents real GDP, A_i is the residual or total factor productivity (TFP), K_i is real physical capital and H_i is human capital, where i represents country i. Regarding α, the measure of capital elasticity, we are going to choose a value equal to 1/3 for all countries, because it is typically assumed that the elasticity of physical capital and human capital in the production function is the same among countries. Now, we can rearrange the above equation in order to express it in per worker terms. To do so, we must divide each variable by the labor force.

$$y_i = k_i^{\alpha}(A_i h_i)^{(1-\alpha)} \tag{2}$$

It has to be clarified that, according to the neoclassical growth theory, whenever there is an increase in the TFP, physical capital per worker will endogenously increase as a response to that increase in TFP. Any increase in the TFP, increases income per worker and thus the possibility of consuming and saving more. Independently that the saving rate is exogenous as in the Solow-Swan model or endogenous as in the Ramsey model, any increase in the income per worker will increase the capacity of saving. Moreover, greater savings lead to greater investments, and greater investments lead to greater physical capital. Therefore, physical capital per worker increases endogenously due to the increase in the TFP.

Hence, any change in A will affect both capital and output per worker. Therefore, the idea is to to rearrange the production function to isolate the effect of physical capital from the effect of TFP as it follows:[2]

$$y_i = A_i \left(\frac{K_i}{Y_i}\right)^{\frac{\alpha}{1-\alpha}} h_i \tag{3}$$

We know from the neoclassical growth theory that at the balanced growth path k and y will grow at the same rate g as the productivity of labor A, so if we deal with the physical capital-output ratio rather than with physical capital-labor ratio, the growth rate of the TFP will not affect the capital-output ratio and thus we will succeed in isolating physical capital.

According to Hsieh and Klenow (2010) when it comes to large and persistent differences across countries, the balanced growth path assumption might be a good proxy. However Caselli (2005) doesn't agree with the rearrangement in equation (3) and suggested a capital-labor ratio production function as in equation (2).

[2]This rearrangement has been defended by Mankiw, Romer and Weil (1992), Klenow and Rodriguez-Clare (1997), Hall and Jones (1999) among others.

2.2 The physical capital

In the case of physical capital, we are going to obtain all data from PWT 9.0. Here, the physical capital stock is estimated based on the perpetual inventory method, but instead of taking a unique depreciation rate, they catalog all assets into six asset types, and they assign different depreciation rates to each of them as in the following table:

Table 1: Assets covered and geometric depreciation rates

Asset	Depretiation rate[3]
Structures (residential and non-residential)	2%
Transport equipment	18.9%
Computers	31.5%
Communication equipment	11.5%
Software	31.5%
Other machinery and assets	12.6%

Source: Inklaar and Timmer (2013).

If we analyse past literature, almost all research papers used the perpetual inventory method to calculate the stock of physical capital (with a unique depreciation rate because it is implicitly assumed only one good economy). This method is based on the following expression:

$$K_t = I_t + (1 - \delta_t)K_{t-1} \tag{4}$$

where K is the stock of physical capital, I the investment at constant prices and δ the physical capital depreciation rate. Given that physical capital in period t depends on the physical capital of the previous period $t-1$, it is necessary to specify another equation to compute physical capital in the initial period:

$$K_0 = \frac{I_0}{g_I + \delta} \tag{5}$$

where g_I is the growth rate of the investment at constant prices. This way of obtaining the initial value of the stock of capital is assuming that the economy

[3]Depreciation rates are based on official BEA deprecation rates of Fraumeni (1997).

is on a balanced growth path. In this trajectory, all the aggregate variables grow at the same rate. The problem with this method is that in general, countries are not on their balanced growth path. However if the initial value of K_0 is sufficiently far from the period for which the study is conducted, it should not affect the path of the capital stock that is obtained.

There is not enough available data on investment for all European countries nor for all OECD countries. For instance, Czech Republic, Estonia, Latvia, Slovenia or Slovakia do not have enough data for investment till 1990 (Hungary and Poland till 1970), and taking into account that the study must be done sufficiently far from the initial value, the analysis could not be done till 2010 at least. Thus, in the same way as Jones (2015) we decided to take the data about physical capital from PWT 9.0.

2.3 The human capital

When it comes to estimate the human capital level it has to be pointed out that there exist a wide variety of methodologies and frameworks. In our case, given that we used the data provided by PWT 9.0, we opted for one of the most thoroughly used method in development accounting.

Despite having obtained all data from PWT 9.0, we are going to explain how the human capital stock has been computed with the intention of having a clear idea of the structure of our data. First of all the average level of human capital for each country is collected, and after that in order to convert average schooling years into human capital, they assume a Mincerian log linear relationship between years of schooling and human capital:

$$H_i = e^{\varphi(E_i)} L_i \tag{6}$$

Here, E_i denotes the average years of schooling in country i, L_i represents labor (it is assumed to be homogeneous within a country and that each unit of labor has been trained with E_i years of schooling[4]) and $\varphi(E_i)$ will represent

[4]This assumption is the same as in Hall and Jones (1999), and unlike Mincer (1974), experience is not taken into account.

the Minncerian regression, which is specified as it follows:

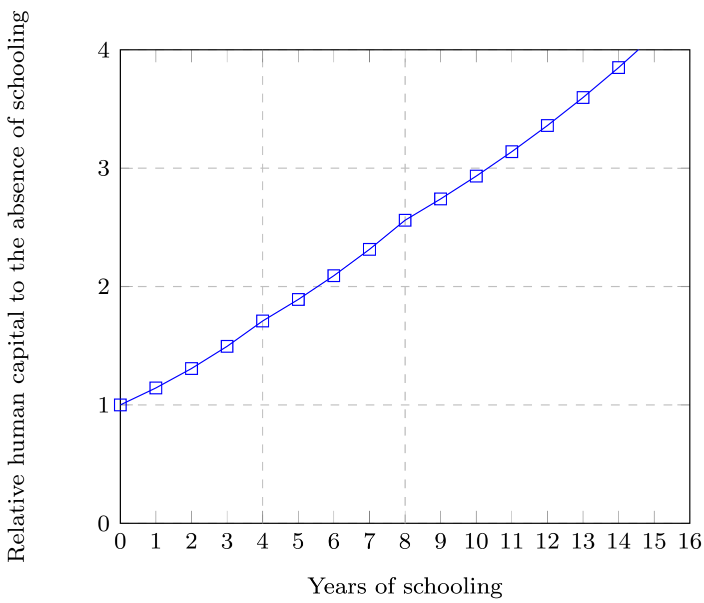
$$\varphi(E_i) = \beta_{i,0} + \beta_{i,1} E_i \tag{7}$$

$\beta_{i,0}$ represents the Mincerian intercept (which is assumed to be equal across individuals for a given country i) and $\beta_{i,1}$ is the Mincerian return to years of schooling. We can rewrite equation (6) in per worker terms and thus obtain the following expression:

$$h_i = e^{\varphi(E_i)} \tag{8}$$

We specify the form of $\varphi(E_i)$ as in Weil (2005) and Hall and Jones (1999), where it is assumed that function $\varphi(E_i)$ is piece-wise. This is because the return to schooling estimates are piece-wise. Following Psacharopoulos (1994), for the first 4 years of education, we assume a rate of return of 13.4 percent, for the next 4 years, we assume a return value of 10.1 percent and for years that are beyond the 8th year we assume a return value of 6.8 percent. Next figure shows the impact of education in wages.

Figure 1: The impact of education in wages



Source: own construction using schooling returns from Psacharopoulos (1994).

However, this method could cause some flaws because of the underspecification, given the fact that variables such as the quality of education or human capital externalities are not measured in our model. We are going to mention some of these models and their main findings.

Focusing on Manuelli and Seshadri (2010), they build up a human capital model which includes the quality of human capital. They highlight that there exist differences in the quality of human capital across countries, and thus they build up a model which incorporates the human capital stock as an endogenous variable allowing $\beta_{i,0}$ to vary across countries. They claim that the quality of the human capital is captured by the TFP. Note that in perfect competition the wage rate is equal to the marginal productivity of labor, and marginal productivity of labor depends positively on the TFP level. Hence, countries with higher levels of development will display higher human capital levels (assuming same years of education).

Apart from that, Manuelli and Seshadri (2010) also differentiate between the stock of human capital obtained in early-childhood, during schooling and after schooling (in the labor market). This distinction makes possible to show that a high early-childhood human capital stock entails higher human capital stocks in the future. The main results suggests that when we are dealing with output differences across countries, differences in the quality of human capital are able to explain a large part of those differences in output. For instance, according to their analysis, countries with the lowest output per worker have a 63% of the TFP level in the USA. As a matter of fact, their work is of high relevance for development accounting, given that the results obtained from their analysis are opposite to the ones from Hall and Jones (1999) or Klenow and Rodríguez-Clare (1997) who suggest that differences in TFP are essential to understand differences in output per worker.

Some other authors tried to include other alternative variables in order to improve the estimation of human capital. It is worth to mention how Bils and Klenow (2000) tried to build up an alternative human capital model that include the influence of teacher's human capital level and experience in the labor market.

Caselli (2005) extended the human capital framework of Klenow and Rodriguez (1997) and Bils and Klenow (2000) allowing countries to differ in the quality of the education. In this case the amount of human capital can be expressed in the following way:

$$h_i = A_h e^{\varphi(E_i)} \quad where \quad A_h = p^{\varphi p} m^{\varphi m} k_h^{\varphi k} h_t^{\varphi h} \tag{9}$$

where p represents the teacher-pupil ratio, m the stock of teaching materials per student, k_h is the stock of structures per student and h_t is the human capital of teachers. Caselli (2005) tries to estimate the values for all those variables that are essential for the calculation of the human capita stock, and also tries to calibrate the elasticities of each variable, however the results are too ambiguous to have a concrete interpretation.

Apart from the above model to estimate the quality of schooling, Caselli (2005) proposes to quantify the quality of schooling via test scores. To do so, it suggests the following model where τ is the score obtained in reading, science and math tests.

$$A_h = e^{\varphi_\tau \tau} \tag{10}$$

To compute the quality of schooling, Caselli (2005) takes test scores provided by Lee and Barro (2001), however it suggests that the results obtained through this kind of model are not far from the ones obtained in previous models.

Regarding human capital externalities, several papers such as Rauch (1993), Acemoglu and Angrist (2000) tried to measure their relevance. Rauch (1993) included average years of schooling of workers in labor markets to the Mincerian wage regression and found out that human capital externalities were quite significant. Nevertheless, Acemoglu and Angrist (2000) instead of focusing on cities as Rauch (1993) did, they concentrated on the states of U.S and the results obtained were opposite to Rauch (1993), that is that externalities of human capital do exist but they are not very important comparing with private returns. Hence, although results regarding human capital externalities are quite ambiguous, they might be significant to explain differences in output across countries.

2.4 Success

Once that we have data on k, h, and y, and choosing the value of α equal to 1/3, the only unknown in equation (3) is A which we can solve it straight away.

$$y = Ay_{KH} \quad where \quad y_{KH} = \left(\frac{K_i}{Y_i}\right)^{\frac{\alpha}{1-\alpha}} h_i \tag{11}$$

Now notice that we can rearrange equation (3) to a factor-only model as in equation (11). The idea is to quantify how successful are the production factors at explaining cross-country income differences, and to do so, firstly we must decompose the variance of the logarithm of y:

$$var[ln(y)] = var[ln(y_{KH})] + var[ln(A)] + 2cov[ln(A), ln(y_{KH})] \tag{12}$$

In order to compute the "success" of this factor-only model we follow Caselli (2005). The paper suggests two different ways to calculate the indicator[5].

$$success^1_{KH} = \frac{var(ln(y_{KH}))}{var(ln(y))} \tag{13}$$

This indicator shows by how much the variation in the accumulation of factors ($var[ln(y_{KH})]$) help to explain the variation in cross-country income differences ($var[ln(y)]$).

Obviously, $success^1_{KH}$ is based on variance decomposition, and since variances suffer the effect that outliers create on them, a second indicator ($success^2_{KH}$) is proposed which is less sensitive to outliers. In this case, $success^2_{KH}$ is based on the inter-percentile differences.

$$success^2_{KH} = \frac{y^{90}_{KH}/y^{10}_{KH}}{y^{90}/y^{10}} \tag{14}$$

However, since we are not dealing with a large sample of countries, we consider that $success^2_{KH}$ could lead us to mismeasure the contribution of the variation in inputs in the variation in output per worker. Hence, we are only going to focus on $success^1_{KH}$.

[5]Note that we are assuming that the covariance between the TFP and y_{KH} is equal to zero because of the assumption of independence between both variables.

3 Data analysis

In order to carry out the Development Accounting method, we will obtain all data[6] from Penn World Table 9.0 database. All variables (physical capital, human capital and income) are computed as above mentioned. Thus, in this section apart from displaying all data for 2014 (the last year that development accounting can be done with the available data) and pointing out the most remarkable findings in each of the factors, we will also plot all findings through time in order to see whether there were changes in the relevance of each factor.

3.1 Data analysis for 2014

Note that we have expressed the value of each variable in relation to the value observed for Norway, the richest country in Europe in 2014[7]. All countries in Table 2 are ranked by their output per worker position. The country with the highest output per worker is set in the first position while the one with the lowest output per worker is set in the last position. Given that there are some discrepancies between output per worker and output per capita, Table 5 in the appendix displays how countries are ranked by output per worker, output per capita and workers per capita.

Regarding the capital-output ratio, note that almost all countries are above Norway, in particular Czech Republic, Cyprus, Greece, Portugal or Latvia are the ones which are remarkably above. The variation of the capital-output ratio is quite high which has a standard deviation of 0.1833, similar to income per capita or the TFP. However, in Figure 2 we can see that the correlation between output per worker differences and physical capital differences is quite low ($\rho_{y,k} = 0.331$).

[6]The variables used for the development accounting method are the following ones: *"cgdpo":Output-side real GDP at current PPPs (in mil. 2011US$)*, *"emp": Number of persons engaged (in millions)*, *"ck": Capital stock at current PPPs (in mil. 2011US$)* and *"hc": Human capital index, based on years of schooling and returns to education.* In order to build up the output per capita and the workers per capita in Table 5 we have also used the *"pop": Population (in millions)* variable. In the robustness section the *"labsh": Share of labour compensation in GDP at current national prices* was taken as referent to fix the maximum capital share.

[7]Norway is the richest country in Europe since 2001.

Table 2: Development accounting for 2014

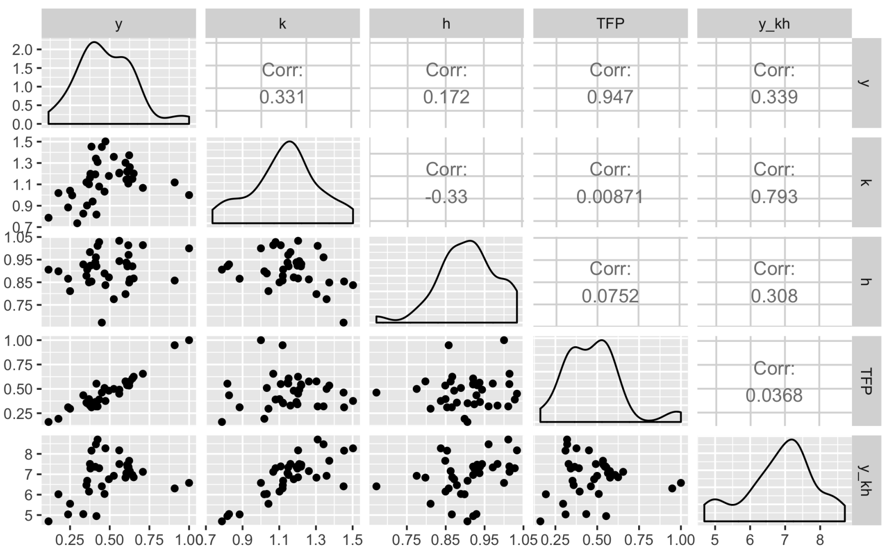
	Output per worker	Inputs		TFP
Country	y	$(K_i/Y_i)^{\alpha/1-\alpha}$	h	A
Norway	1.0000	1.0000	1.0000	1.0000
Ireland	0.9093	1.1181	0.8576	0.9482
Switzerland	0.7089	1.0672	1.0141	0.6550
France	0.6509	1.2022	0.8668	0.6247
Netherlands	0.6429	1.1509	0.9205	0.6069
Belgium	0.6266	1.2613	0.8627	0.5759
Italy	0.6225	1.3726	0.8488	0.5343
Denmark	0.6187	1.1488	0.9711	0.5546
Germany	0.6170	1.1080	1.0137	0.5493
Austria	0.6117	1.2184	0.9204	0.5455
Luxembourg	0.6099	1.2201	0.9309	0.5370
Sweden	0.6048	1.1449	0.9370	0.5638
Spain	0.5994	1.3027	0.7977	0.5768
Finland	0.5608	1.2090	0.9435	0.4916
United Kingdom	0.5599	1.2027	1.0333	0.4505
Cyprus	0.5258	1.3580	0.7753	0.4994
Iceland	0.4947	1.1789	0.8717	0.4815
Greece	0.4730	1.5021	0.8374	0.3760
Lithuania	0.4673	1.0321	0.8891	0.5092
Portugal	0.4502	1.4506	0.6717	0.4620
Slovakia	0.4333	1.0798	1.0277	0.3905
Czech Republic	0.4235	1.3093	1.0109	0.3199
Poland	0.4163	0.8172	0.9207	0.5533
Slovenia	0.4128	1.3414	0.9603	0.3205
Croatia	0.4090	1.1938	0.9382	0.3652
Latvia	0.3850	1.4535	0.8535	0.3104
Hungary	0.3784	1.1991	0.9235	0.3418
Estonia	0.3753	1.1609	0.9832	0.3288
Malta	0.3695	1.1012	0.8495	0.3950
Serbia	0.3581	1.1211	0.9062	0.3525
Romania	0.3532	1.1192	0.8787	0.3591
Russian Federation	0.3334	0.8262	0.9290	0.4344
Albania	0.2500	1.0411	0.8110	0.2961
Bulgaria	0.2377	0.8838	0.8657	0.3108
Ukraine	0.1767	1.0187	0.8985	0.1931
Republic of Moldova	0.1144	0.7875	0.9058	0.1603
Average, 36 countries	0.4772	1.1319	0.9063	0.4715
Standard Deviation	0.1810	0.1833	0.0773	0.1732
Correlation w/ y (logs)	1.0000	0.3310	0.1720	0.9470
Correlation w/ TFP (logs)	0.9470	0.0087	0.0752	1.0000

Source: own construction using the data from Penn World Table 9.0, assuming $\alpha = 1/3$.

In the case of the human capital there is no much variation between countries. Note that the standard deviation is quite low (a standard deviation of 0.0733). Hence, differences in human capital may contribute little in explaining the differences in output per worker across European countries.

Finally, focusing on the TFP, we can see the magnitude of the differences in TFP. The countries that most differ are Albania, Bulgaria, Republic of Moldova, Romania and Ukraine. Note that these countries are the poorest countries of Europe in 2014 (in terms of GDP per capita). In addition, Figure 2 shows how differences in TFP and GDP per worker variables are positively and strongly correlated given the fact that its correlation coefficient is close to 1 ($\rho_{y,TFP} = 0.947$). Although the sample in Jones (2015) is more heterogeneous than in our analysis and it is done for 2010, this correlation between differences in output per worker and differences in TFP is very similar to the one obtained in Jones (2015) ($\rho_{y,TFP}^{Jones(2015)} = 0.96$).

Figure 2: Correlation matrix for 2014



Source: own construction using the data from Penn World Table 9.0, assuming $\alpha = 1/3$.

Nevertheless, $success^1$ indicator might be useful to see whether the variation observed in GDP per worker is mostly explained by the variation observed in TFP or by the variation observed in the production factors (assuming that the covariances are equal to zero). For 2014 the value of $success^1_{KH}$ is 0.1313 (Caselli (2005) obtains a value of 0.233 for 1996), that is, the large fraction of differences in output per worker are explained by the differences in TFP. Note from Figure 2 that the correlation between the differences of the variable that merges both production factors y_{KH} and differences of output per worker is quite low ($\rho_{y,y_{KH}} = 0.339$), and thus the result obtained from the $success^1_{KH}$ indicator is quite consistent with the results obtained from the correlations between these variables. However, while $success^1_{KH}$ quantifies by how much the variation observed in income per worker is due to the variation observed in the input factors, the correlation measures the degree to which these variables move in relation to each other.

3.2 Data analysis over the 1950-2014 period

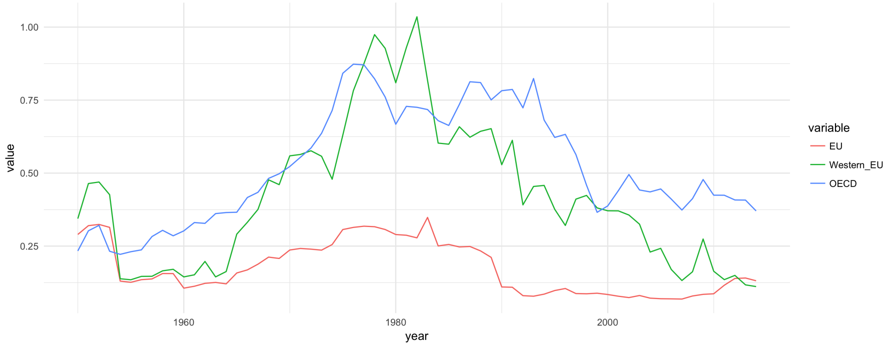
3.2.1 Success indicator over the 1950-2014 period

In the previous section the development accounting method for 2014 suggests that differences in the TFP are what mostly explain the differences in income per worker. To see whether this has been the case in the past or not, we have computed the development accounting for each year from 1950 to 2014 (2014 is the last year for which there is data).

The success indicator for 2014 showed by how much the variance of income is explained by the variation in the production factors (the value of the success indicator for 2014 was 0.1312). Notwithstanding, we must compute this success indicator for each period in order to see whether there were variations over time or not.

Figure 3 displays the success indicator over time for three different kind of samples: EU, Western EU and OECD. For all cases, it suggests that the contribution of the differences of the inputs in differences of output per worker varied over time. Hence, according to the success indicator for the European countries (in red), despite the fact that there were some periods where differences in production factors explained one third of the differences in output per worker (around year 1980), differences in TFP contribute more when it comes to explain differences in output per worker, obtaining similar levels from those

Figure 3: The success indicator over time



Source: own construction using the data from Penn World Table 9.0, assuming $\alpha = 1/3$.

authors whose analysis is based on very heterogeneous samples. Thus, given that these results are opposite to the hypothesis of having a higher success indicator whenever the sample is homogeneous, we could make the sample even more homogeneous by distinguishing between western and eastern European countries or or by choosing only OECD countries to check if the hypothesis is held for these samples. As we pointed out in the introduction, regarding the relative output per worker levels across European countries, there are ample differences between western and eastern countries which could lead to a slight heterogeneity[8].

Thus, we have created a sub-sample for the western European countries and a new sample for the OECD countries. In both cases, Figure 3 suggests that the more homogeneous the sample is, the higher the success indicator is. In the case of the wester European countries (in green), over the 80s, production factor differences were close to explain all output per worker differences. For the OECD countries (in blue) this trend continued until 1995. Nevertheless, for the last years, differences in input factors explained almost a 50% of the differences in output per worker for OECD countries, whereas for western European countries or the European countries explained no more than 15%-20%. Regarding the implied assumption of the indicator, although the covariance is relatively small, for some stretch is negative which might explain why the value of the success is greater than 1 for some periods[9].

[8] See Table 5 in the Appendix.
[9] See the evolution of the covariances for each sample over time in the Appendix, Figure 12.

Once at this point, a new question arises: which path will the success indicator follow in the future? Well, there is no doubt that for present and future policy making this question is of great relevance. To answer it, we begin by analysing if the indicator's time series is stationary, and to do so, we follow the Augmented Dickey-Fuller test and the KPSS test. According to the results[10], the ADF statistic is not smaller than the critical values (1%, 5% and 10%) and thus we do not reject the null hypothesis (for all three versions: unit root, unit root with drift and unit root with drift and trend). Hence, there exist a unit root and therefore the success indicator series is a non-stationary time series (for all three samples: Europe, wester Europe and OECD). We reach to the same conclusion when we are dealing with the KPSS test: the null hypothesis is rejected (for the two versions: unit root with drift and unit root with drift and trend) and therefore the success indicator is non-stationary (for all three samples).

Taking into account that the time series is not stationary, the only way of following an AR(1) process would be ρ to be equal to one. Thus, in order to analyse whether the success indicator is correlated with its own lagged values or not we will plot the autocorrelation function (ACF) and the partial autocorrelation function (PACF)[11]. From the correlograms note that ACF does not converge very fast, and in the case of the PACF only the first lag is statistically significant, which is very close to one. Hence, this results suggests that we are facing a random walk as in equation (15) (we have assumed that there is no drift). That is, the success indicator follows an AR(1) process where $\rho = 1$ and with an existing unit root.

$$success_t = success_{t-1} + \epsilon_t \quad where \quad \epsilon_t \sim iid(0, \sigma^2) \tag{15}$$

In this case, given the fact that a random walk is merely unpredictable, the best thing that we could do would be to use the last year's observation to predict, which is a naive forecast. In brief, the success indicator is stochastic and follows a random walk, which it makes the indicator to be unpredictable. Hence, although we are able to analyse the evolution of the success indicator

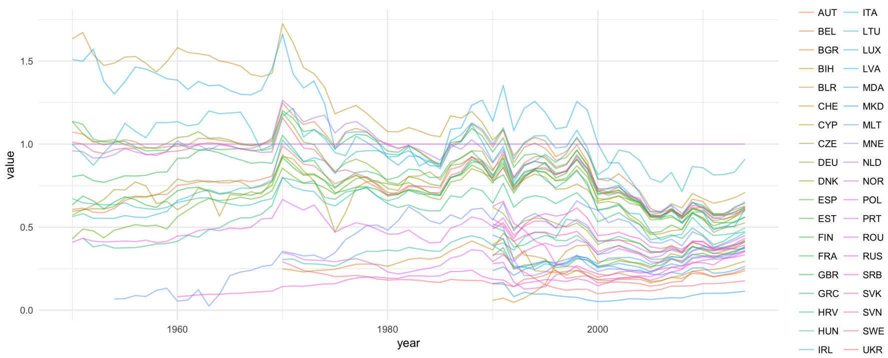
[10] See the results for ADF and KPSS tests in the Appendix, Tables 3 and 4, respectively.
[11] See the Appendix, Figure 11.

for past years, it is not possible to determine its future path given its stochastic nature.

3.2.2 Standard deviation of input factors, TFP and GDP per worker over the 1950-2014 period.

The aim of this subsection is to analyse whether cross country differences in output, inputs and TFP varied over the 1950-2014 period or not, and if they did so, to see by how much. We will begin with the output per worker and then we will analyse the production factors and the total factor productivity.

Figure 4: Output per worker relative to Norway's output per worker over time

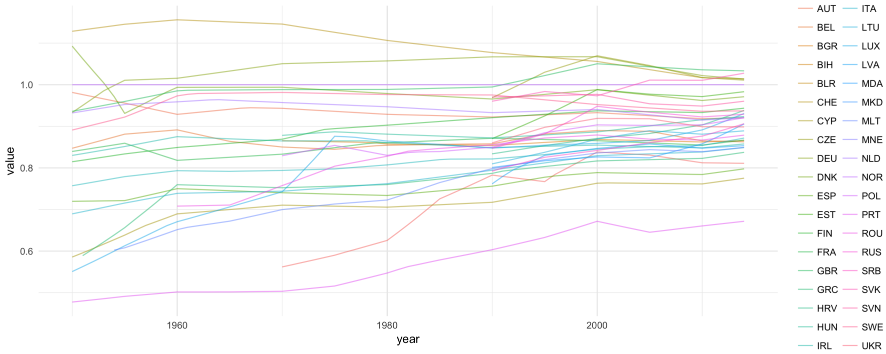


Source: own construction using the data from Penn World Table 9.0.

Figure 4 suggests that the dispersion in output per worker has decreased over the 1950-2014 period. Relative levels in output per worker in 1950 show great deviations, however in 2014 those deviations are far from those of 1950. Given that the dispersion has decreased over time, it is expected that there will be absolute convergence between countries, in other words, that poor countries (in terms of output per worker) tend to grow per worker faster than rich countries. Note also that before 1990 not all countries are displayed given the lack of data.

As regards of the evolution of the stock of human capital over the 1950-2014 period, Figure 5 suggests that there is a reduction in the deviation of relative human capital levels across countries as we have suggested in the case of output per worker. Nevertheless, the reduction in the deviation is not as prominent as in the previous case, the reduction is much more moderate.

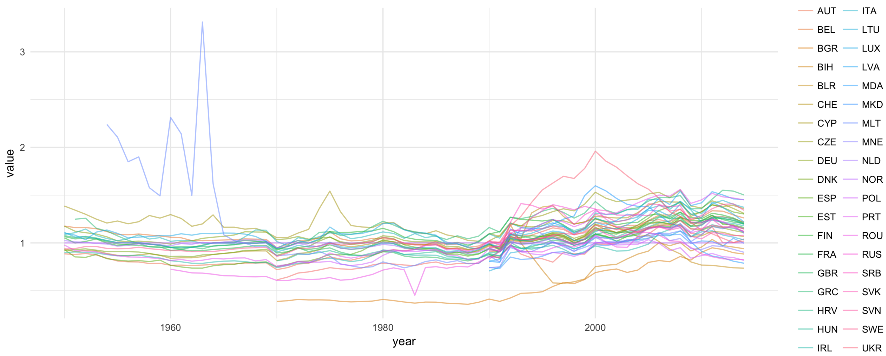
Figure 5: Human capital relative to Norway's human capital over time



Source: own construction of TFP using the data from Penn World Table 9.0.

Focusing on each country, there are some remarkable findings. The country for which the growth in the stock of human capital relative to Norway has been higher is Portugal. From 1950 to 2014 is the country that most differs from the Norway's human capital level. In 1950 had a relative stock of human capital of 0.4775 (Norway=1) and in 2014 0.67. In the case of Switzerland, Germany, Czech Republic or the United Kingdom, they had greater human capital level than Norway in the last 20 years (Germany and Switzerland had greater human capital level than Norway since 1955).

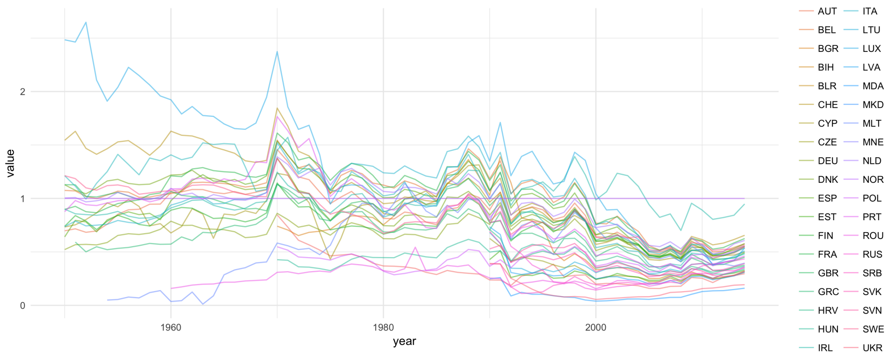
Figure 6: Physical capital per worker relative to Norway's physical capital per worker over the 1950-2014 period



Source: own construction using the data from Penn World Table 9.0.

In the case of the physical capital per worker, results are quite different from the human capital ones. Regarding Figure 6, the deviation from the Norway's physical capital per worker level is small. It is remarkable the low level of physical capital per worker of Bulgaria or the high level of physical capital per worker of Ukraine around year 2000. However, the outlier variations in physical capital per worker of Malta in the 60's is what stands out most. Nevertheless, although there are some exceptions, almost all countries had a similar level since 1950.

Figure 7: TFP relative to Norway's TFP over the 1950-2014 period



Source: own construction using the data from Penn World Table 9.0, assuming $\alpha = 1/3$.

Finally we have the results for TFP and, as we can see, they are very similar to the ones obtained with the output per worker. At first glance, given the similarity between the results of the TFP and output per worker, we could conclude that differences in the TFP could explain most of the differences in output per worker. Figure 7 also suggests that there is sigma-convergence in TFP among European countries over the 1950-2014 period [12].

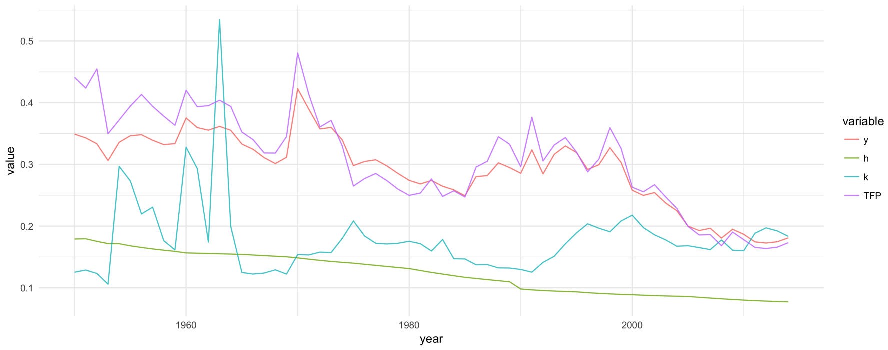
Nonetheless, it will be necessary to compute the standard deviations of each variable over the 1950-2014 period to check if the standard deviations have decreased. Results of those standard deviations are shown in Figure 8.

In the case of the output per worker, the standard deviation decreases since the mid 70s. This decrease in the standard deviation supports the hypothesis of a convergence in income per worker among countries. It draws attention how the most severe downfall of the variation in output per worker across countries took place once we entered in the XXIth century.

The green line shows the standard deviation for the human capital over the 1950-2014 period, where we can see that in 1950 the standard deviation was

[12] It is remarkable the dynamics of the TFP in Norway. Until 1990 several countries had a higher level of TFP than in Norway, but over the last two decades, Norway is the leader country among all European countries.

Figure 8: Standard deviation of variables



Source: own construction using the data from Penn World Table 9.0, assuming $\alpha = 1/3$.

around 0.18 and in 2014 was 0.08 (a reduction of 10 points). Comparing with other variables, the standard deviation of the human capital suffers quite a linear downfall. But what is causing this drop?

The main hypothesis is that human capital reaches to a steady state. Usually individuals do not study for more that 15 years, and thus, once that a certain level of human capital is reached in a given country, it stops growing. Some countries reach the steady state earlier than others, but at the end, all countries will wound up at the same steady state level. In other words, the human capital accumulation might have a limit where the accumulation of such variable stops growing.

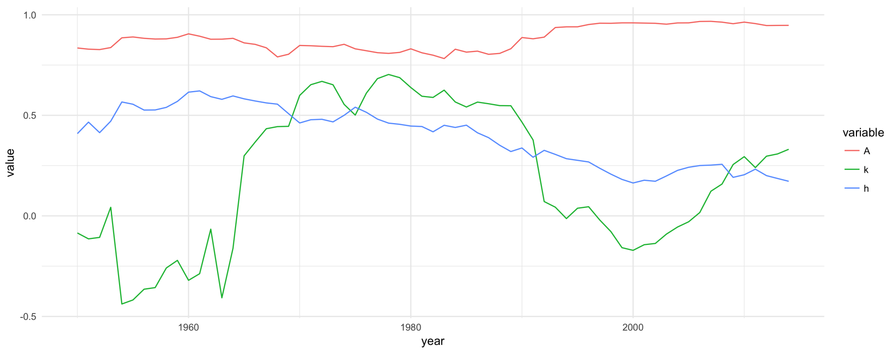
As we can see in Figure 8, the standard deviation of the physical capital per worker did not change much over the 1950-2014 period. Therefore, unlike for the other variables, we can not conclude that there is a sigma-convergence in physical capital among European countries.

Finally, as regards of TFP, we can see in Figure 8 that the standard deviation of TFP among European countries follows a similar path to the output per worker's standard deviation. It suffers approximately a reduction of the 65% since 1950. This last result is not a surprise given the similarity between Figure 4 and Figure 7.

3.2.3 Correlation between input factors, TFP and GDP per worker over the 1950-2014 period

In subsection 3.1, Figure 2, we made an analysis of the correlations between the variables in 2014. The results suggested that differences in TFP were strongly and positively correlated with differences in GDP per worker. Nevertheless, in order to see whether this results remained back in time or not, we must plot the correlations over time.

Figure 9: Correlations for European countries: 1950-2014



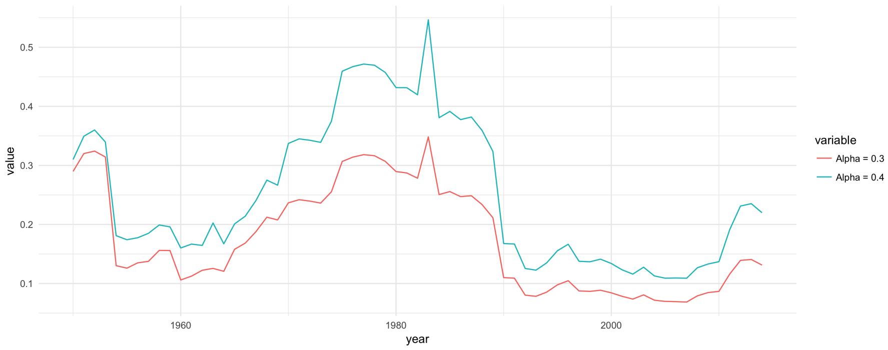
Source: own construction using the data from Penn World Table 9.0, assuming $\alpha = 1/3$.

Figure 9 suggests that the correlation between differences in TFP and differences in output per worker across European countries was the strongest over the period 1950-2014. However, it also shows that correlations fluctuated, specially the correlation between the differences in the physical capital per worker and the differences in human capital. Between 1970 and 1990 *correlation_k* was almost as strong as *correlation_A*, but in the remaining years it was quite low, even reaching negative values in some periods. On the other hand, *correlation_h* was quite stable between 1950 and 2014. The level of correlation lost strength over the last years (since the 80s), but it did not fluctuate as much as *correlation_k*.

3.3 Robustness

The main idea of this subsection is to analyse whether the results obtained in section 3.2 are robust or not. And to do so, we will allow the value of the capital share to change.

Figure 10: Testing success indicator's robustness



Source: own construction using the data from Penn World Table 9.0, assuming $\alpha_1 = 1/3$ and $\alpha_2 = 0.4$.

Figure 3 shows us how the success indicator fluctuated over time, however this analysis is based on the assumption of fixing α equal to $1/3$. Considering that value of α could reach 0.4 or slightly higher than 0.4 in some European countries for several periods, we are going to analyze the dynamics of the success indicator when α is equal to 0.4.

Figure 10 suggests that the dynamics of the success indicator is similar to the one obtained for $\alpha = 1/3$, however, when $\alpha = 0.4$ the success indicator always reaches a higher value. This is straightforward, if we increase the physical capital share we put more weight on the production factors, entailing an increase in the success indicator. These results can be extrapolated to the western European or OECD countries

4 Conclusions

The widespread concern in understanding income differences among countries has been reflected in the extensive literature on this matter, and in the last decades the development accounting method has been of great interest in order to deal with this issue. As a matter of fact, most of this literature concludes that differences in TFP are able to explain most output per worker variations. However, most of that literature is based on the analysis for a specific year, which does not let us see the whole spectrum. Our analysis suggests that the explanation of output per worker variations varied over time. In the European countries, whereas for most years variations in TFP were more relevant in explaining variations in output per capita, between 1975 and 1985 the production factor differences were able to explain more the income per worker variations. Nevertheless, this does not entail that input factors are trivial when it comes to explain output per worker variations. Input factors are able to explain great part of the income per worker variations (around 30% in the 80s and around 10% in the 2000s) and therefore policies that manage to reduce differences in input factors might reduce income per worker differences across countries. However, given the suggested volatility and unpredictability of the results over time, we are not able to determine the success of the production factors in explaining income per worker variations for the future. Moreover, our results suggest that the more homogeneous the sample is, the higher the success of input factor variations in explaining output per worker variations. In fact, production factors explained almost the 50% of the income per worker differences in the case of the OECD countries for the last few years (and even the 85% in 1976). However, most of the literature employs the development accounting method across worldwide countries, and this heterogeneity could boost even more the idea of being variations in TFP responsible of output per worker variations.

Therefore, it seems that periods and samples are of great relevance when it comes to explain differences in income per worker. The success of the input factors and the TFP in explaining income per worker variations fluctuates over the 1950-2014 period and results vary a lot when we deal with different samples. Thus the results apart from suggesting not to draw the same conclusions for all periods and samples, shows how important input factor variations are in explaining income per worker variations (specially for western European and OECD countries), and hence how important are the policies that reduce input factor variations for an equal income per worker distribution across countries.

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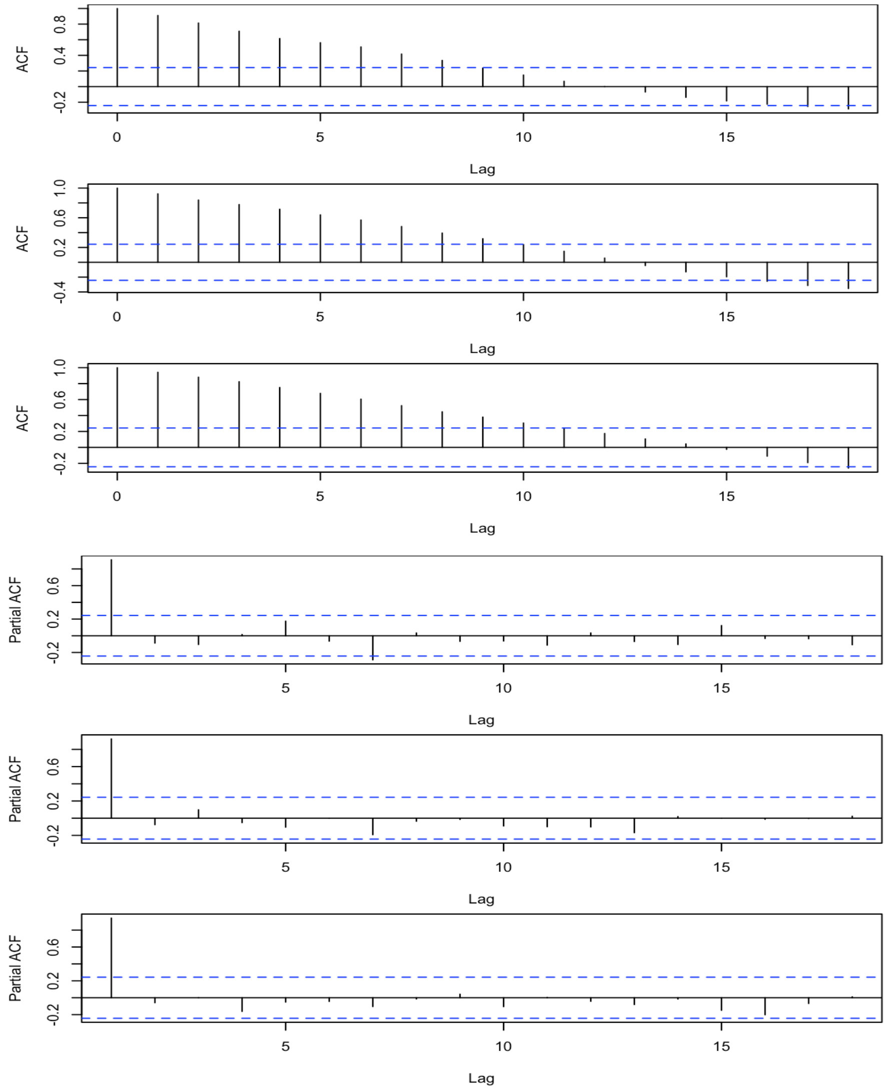
6 Appendix

Figure 11: The correlograms: ACF and PACF



Source: own construction using the data from Penn World Table 9.0, assuming $\alpha = 1/3$.

Table 3: Augmented Dickey-Fuller test

	EU Countries				Western EU Countries				OECD Countries			
	Critical Values			Statistic	Critical Values			Statistic	Critical Values			Statistic
Type	1%	5%	10%	ADF	1%	5%	10%	ADF	1%	5%	10%	ADF
None	-2.6	-1.95	-1.61	-1.5125	-2.6	-1.95	-1.61	-1.0387	-2.6	-1.95	-1.61	-0.3886
Drift	-3.51	-2.89	-2.58	-2.0107	-3.51	-2.89	-2.58	-1.2616	-3.51	-2.89	-2.58	-1.3822
Trend	-4.04	-3.45	-3.15	-1.8952	-4.04	-3.45	-3.15	-1.2699	-4.04	-3.45	-3.15	-1.0324

Source: own construction using the data from Penn World Table 9.0, assuming $\alpha = 1/3$.

Table 4: KPSS test

	EU Countries				Western EU Countries				OECD Countries			
	Critical Values			Statistic	Critical Values			Statistic	Critical Values			Statistic
Type	1%	5%	10%	KPSS	1%	5%	10%	KPSS	1%	5%	10%	KPSS
Drift	0.739	0.463	0.347	0.6075	0.739	0.463	0.347	0.3529	0.739	0.463	0.347	0.4921
Trend	0.216	0.146	0.119	0.2091	0.216	0.146	0.119	0.3481	0.216	0.146	0.119	0.3873

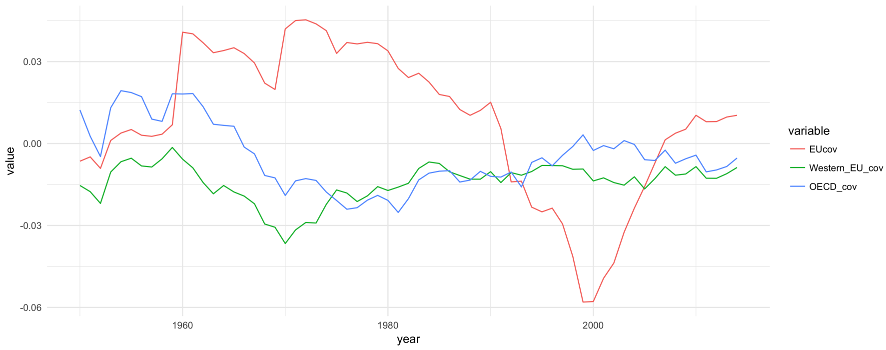
Source: own construction using the data from Penn World Table 9.0, assuming $\alpha = 1/3$.

Table 5: Relative positions for 2014

	Output per worker		Output per capita		Workers per capita	
Position	Country	Index	Country	Index	Country	Index
1	Norway	1.0000	Norway	1.0000	Luxembourg	1.0000
2	Ireland	0.9093	Luxembourg	0.8672	Switzerland	0.8045
3	Switzerland	0.7089	Switzerland	0.8110	Iceland	0.7376
4	France	0.6509	Ireland	0.6747	Norway	0.7033
5	Netherlands	0.6429	Netherlands	0.6242	Germany	0.6935
6	Belgium	0.6266	Germany	0.6084	Austria	0.6839
7	Italy	0.6225	Austria	0.5948	Netherlands	0.6828
8	Denmark	0.6187	Denmark	0.5760	Russian Federation	0.6604
9	Germany	0.6170	Sweden	0.5548	Denmark	0.6548
10	Austria	0.6117	Iceland	0.5189	Bulgaria	0.6534
11	Luxembourg	0.6099	Belgium	0.5123	Sweden	0.6452
12	Sweden	0.6048	United Kingdom	0.5048	Estonia	0.6342
13	Spain	0.5994	France	0.5028	United Kingdom	0.6341
14	Finland	0.5608	Finland	0.4981	Czech Republic	0.6334
15	United Kingdom	0.5599	Italy	0.4600	Finland	0.6248
16	Cyprus	0.5258	Spain	0.4275	Slovenia	0.6166
17	Iceland	0.4947	Czech Republic	0.3814	Malta	0.5986
18	Greece	0.4730	Slovenia	0.3619	Belgium	0.5750
19	Lithuania	0.4673	Portugal	0.3520	Hungary	0.5539
20	Portugal	0.4502	Estonia	0.3384	Portugal	0.5498
21	Slovakia	0.4333	Lithuania	0.3290	France	0.5432
22	Czech Republic	0.4235	Slovakia	0.3286	Poland	0.5403
23	Poland	0.4163	Cyprus	0.3215	Ukraine	0.5376
24	Slovenia	0.4128	Greece	0.3212	Latvia	0.5334
25	Croatia	0.4090	Poland	0.3198	Slovakia	0.5333
26	Latvia	0.3850	Malta	0.3145	Romania	0.5251
27	Hungary	0.3784	Russian Federation	0.3131	Ireland	0.5219
28	Estonia	0.3753	Hungary	0.2981	Italy	0.5197
29	Malta	0.3695	Latvia	0.2920	Spain	0.5016
30	Serbia	0.3581	Croatia	0.2700	Lithuania	0.4952
31	Romania	0.3532	Romania	0.2637	Greece	0.4776
32	Russian Federation	0.3334	Bulgaria	0.2209	Croatia	0.4642
33	Albania	0.2500	Serbia	0.1764	Republic of Moldova	0.4337
34	Bulgaria	0.2377	Albania	0.1432	Cyprus	0.4300
35	Ukraine	0.1767	Ukraine	0.1351	Albania	0.4029
36	Republic of Moldova	0.1144	Republic of Moldova	0.0705	Serbia	0.3465

Source: own construction using the data from Penn World Table 9.0.

Figure 12: The covariances of y_{KH} and TFP through time for each sample



Source: own construction using the data from Penn World Table 9.0, assuming $\alpha = 1/3$. Note: Malta was deleted from the sample in order to diminish the effect that its capital per worker variation made in the covariances.