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MEASURING THE SOURCES OF ECONOMIC GROWTH IN THE EU WITH PARAMETRIC AND NON-PARAMETRIC METHODS

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Abstract. The standard neoclassical growth accounting (parametric) framework serves to explain only a minor part of labour productivity growth and its cross-country differences, thus implying an important role (as yet unexplained) for the *Solow Residual* or the Total Factor Productivity (TFP). However, the increased application of non-parametric methods in growth accounting, and in particular with Data Envelopment Analysis (DEA), has revealed that, along with the direct effect on output, a higher capital stock will have a substantial indirect effect that has been disregarded by the neoclassical framework. In line with an *appropriate technology* model (Basu, Weil, 1998), a higher capital stock allows a country to use a better technology.

This paper extends the evidence regarding the relevance of an *appropriate technology* view to those Eastern European countries that were not previously included in a growth accounting investigation using non-parametric methods. It also reveals that the *appropriate technology* view is useful in explaining labour productivity growth and its cross-country differences within the EU. Furthermore, the results are robustly subject to assumptions on capital formation and on whether labour productivity has been adjusted with regard to the cross-country differences in employment structure by the various sectors and by natural resource endowment. Given both the direct and indirect effects of capital accumulation, it might prove to be a much more important tool for determining labour productivity growth than is usually considered within a neoclassical framework.

Key words: *growth accounting, Data Envelopment Analysis, efficiency, appropriate technology, total factor productivity.*

JEL code: C14, D24, E22, O33, O47.

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INTRODUCTION

There are three fundamental questions to the better understanding of economic growth: why does income differ so much between countries, why does income grow over time and why is income growth faster in some countries than in others? (Jones C.I., 2002).

Empirical research has shown that the standard growth accounting framework, which is based on a neoclassical growth model, leaves these questions largely unanswered (i.e., they are mostly explained, instead, by a residual term – Total Factor Productivity (TFP) or by the *Solow Residual*).

For instance, in summarising growth research over the past 25 years, *physical capital* accounts for about 20% of income differences across countries whereas *Human capital* could well explain another 10–30% (Hsieh, Klenow, 2010). This implies that TFP accounts for the remaining part (50–70%) of income gaps. A similar conclusion from earlier research efforts was made by (Khan, 2009): "TFP is found to explain between 50 and 75 percent of the observed differences in income per capita". Easterly and Levine (2002) even stated the new stylised fact of growth that TFP explains about a half of the average per-capita output growth and 90% of the cross-country variation in growth rates. However, the term TFP continues to be a 'black box' to a great extent (it is exogenous if considered within a neoclassical growth model) and captures "all other factors", i.e., those that remain unexplained by any standard growth accounting framework.

Within the neoclassical setting, capital accumulation and TFP are mutually independent.

However, this proposition was questioned by the *appropriate technology* model (Basu, Weil, 1998). Even if the various technologies flow freely across state borders, the advances designed for big capital to labour ratios are not usable or at least are not so productive in any low capital to labour environment.

As Basu and Weil stated, "...an advance in transportation technology in Japan may take the form of a refinement of the newest maglev train. Such an advance may have very few spillovers to the technology of the transportation sector in Bangladesh, which relies in large part on bicycles and bullock carts". Capital accumulation in Bangladesh may, however, allow it to use (at least some of) Japanese technical advances. Therefore, along with a direct effect on labour productivity, captured by the neoclassical growth model, capital accumulation exerts a substantial indirect effect by allowing a state to employ a more productive technology.

The impact of capital accumulation on labour productivity growth could be empirically decomposed between these two effects by the application of non-parametric methods of growth accounting research. By estimating the *world production frontier* using the Data Envelopment Analysis (DEA) method and then by measuring the impact of capital accumulation, the shift of the world production frontier and the consequent efficiency catch-up on labour productivity growth, various papers have shown that both direct and indirect effects of capital accumulation are important (for instance, Kumar, Russell, 2002; Jerzmanowski, 2007; Merkina, 2009). By ignoring the indirect effect, the neoclassical growth model thus underestimates the role of capital accumulation and overestimates the role of TFP in economic growth.

The purpose of this paper is to undertake an empirical test on the relevance of an *appropriate technology* viewpoint in assessing the sources of labour productivity growth and its cross-country differentials within the EU, using both parametric and non-parametric methods.

None of the previous studies used non-parametric methods for the study of growth accounting in Eastern European countries, possibly because of unavailability of reliable capital stock data. Therefore, the **first task** in the empirical part of this paper is to construct a capital stock time series for each of the twelve new EU member states. Moreover, very few papers have assessed the impact of economy structural changes on results. For instance, if in any particular country, labour moves into the productive sectors or the use of natural resources becomes more intense, then the aggregate labour productivity goes up, and this may be wrongly interpreted as a catch-up to the world production frontier. Thus, the **second task** is to make labour productivity data comparable both internationally and between time periods. Finally, the results may depend on assumptions used, therefore, the **third task** is to analyse the robustness of results subject to alternative assumptions regarding capital formation.

This paper is organised as follows. Section 1 reviews methodology, Section 2 describes data, and Section 3 discusses the results. This is followed by a summary of conclusions and main findings and offers some suggestions for further research.

RESEARCH RESULTS AND DISCUSSION

Methodology

Assuming no scale effect, unit elasticity of substitution between labour to physical capital and Hicks-neutral technology, neoclassical multi-country production function in a Cobb-Douglas form is given by:

$$Y_{it} = K_{it}^{\alpha} L_{it}^{1-\alpha} \cdot A_{it} \tag{1}$$

where Y – Gross Domestic Product (Output) in real terms;

K – stock of physical capital in real terms;

L – hours worked (Labour);

A – Total Factor Productivity (TFP) or *Solow Residual*;

α and (1-α) – GDP elasticity with respect to capital (typically found to be about 1/3) and labour respectively;

i and t – country and time period respectively.

Note that Y, A, K, and L in (1) are country and period-specific, whereas α is assumed to be the same across countries and time. Under standard Cobb-Douglas decomposition, labour productivity (equivalent to income) can be expressed as a function of capital stock per hour and *Solow Residual*:

$$y_{it} = k_{it}^{\alpha} \cdot A_{it} \tag{2}$$

where $y = \frac{Y}{L}$ and $k = \frac{K}{L}$ is labour productivity and capital stock per working hour respectively.

In its turn, under the non-parametric representation, labour productivity can be expressed as:

$$y_{it} = \Phi_t(k_{it}) \cdot E_{it} \tag{3}$$

where $\Phi(k)$ is the world production frontier (also referenced as *production possibilities frontier* and *world technology frontier*), reflecting the highest attainable labour productivity given the endowment of physical capital (measured by capital to labour ratio).

E – measure of output technical efficiency (see (Coelli, 1996) for details).

Note the two differences between (3) and (2) above. Firstly, the non-parametric representation does not require an assumption about the elasticity of output to capital which is allowed to vary with time. For each time period, the *world production frontier* is estimated using empirical data. Thus, the DEA is less robust to the changes in the country sample and rather sensitive to outliers: if the *world production frontier* consists of one or more outliers, it may bias the efficiency estimates for other countries. Nevertheless, the DEA offers a more realistic form of world production frontier than does, for instance FDH (*Free Disposal Hull*: world production frontier consists only of vertical and horizontal lines) and therefore is more widely used in academic research. While a SFA (*Stochastic Frontier Analysis*) may overcome some DEA drawbacks, it is not a non-parametric method and is left open for further research efforts. Secondly, the term TFP is now changed by a measure of technical efficiency. However, the interpretation of a country's position relative to the *world production frontier* is broadly similar to that of the TFP. The *world production frontier* "should be interpreted quite broadly to encompass institutions and policies as well as purely technological phenomena" (Kumar, Russell, 2002).

And finally, the *Cobb-Douglas assumption* of α = 1/3 could be incorporated into a DEA framework (i.e., mixed case). After splitting the *Solow Residual* into the indirect effect of capital accumulation T and (residual) efficiency E, labour productivity could be expressed as:

$$y_{it} = k_{it}^{\alpha} \cdot T_t(k_{it}) \cdot E_{it} \tag{4}$$

The equation for labour productivity growth in each of the three cases could be obtained by log differencing (2), (3) and (4) above. For instance, for a mixed case by taking the logs of (4) we get:

$$\log y_{it} = \alpha \cdot \log k_{it} + \log T_t(k_{it}) + \log E_{it} \tag{5}$$

By differentiating (5), we get that labour productivity growth in each particular country and time period depends on the speed of capital accumulation (times α), shift of the *world production frontier* (subject to a particular capital endowment) and an efficiency catch-up process:

$$\Delta \log y_{it} = \alpha \cdot \Delta \log k_{it} + \Delta \log T_t(k_{it}) + \Delta \log E_{it} \tag{6}$$

Thus, average labour productivity growth (in a country sample) could be expressed as:

$$\overline{g}_{y_t} = \alpha \cdot \overline{g}_{k_t} + \overline{g}_{T_t} + \overline{g}_{E_t} \tag{7}$$

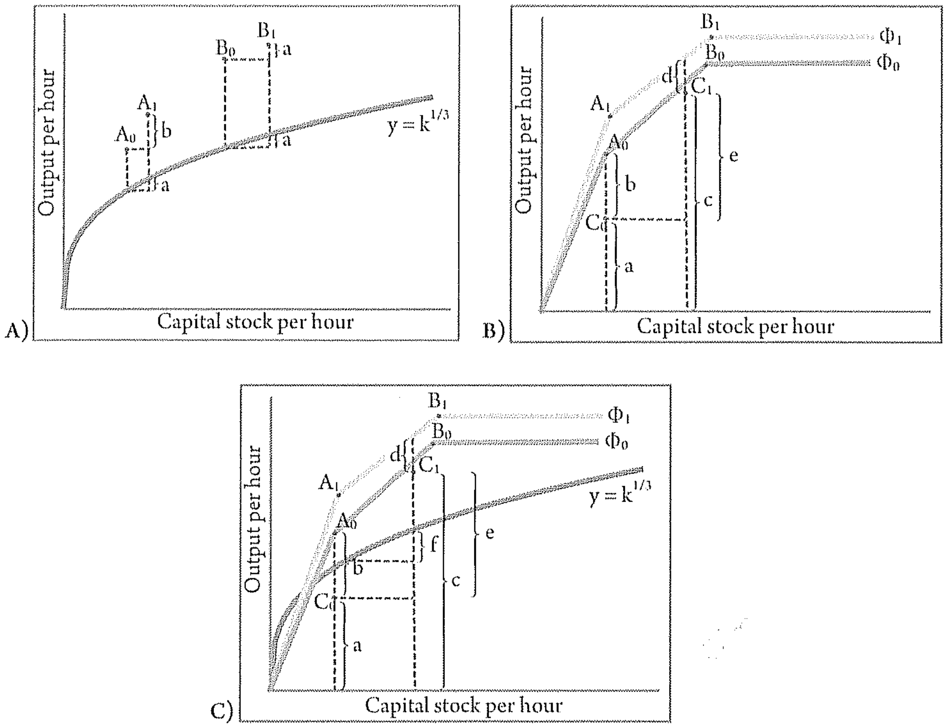
where $\overline{g}_X$ is the average growth rate (in a country sample) of a variable X.

Note that the contribution of capital accumulation, a shift of the *world production frontier* and an efficiency catch-up to the labour productivity growth (average in a country sample) in a particular time period **t**, is given respectively by V'_{F_t}, V'_{T_t} and V'_{E_t}:

$$V'_{F_t} = \frac{\alpha \cdot \overline{g}_k}{\overline{g}_y} \; ; \quad V'_{T_t} = \frac{\overline{g}_T}{\overline{g}_y} \; ; \quad V'_{E_t} = \frac{\overline{g}_E}{\overline{g}_y} \tag{8}$$

For instance, a high V'_{T_t} means that the *appropriate technology* model is relevant, i.e., fast capital accumulation in Bangladesh allows this country to use (at least some of) Japanese technologies. Moreover if V'_{T_t} is higher than V'_{F_t}, the indirect effect of capital accumulation is even more important for labour productivity growth than a direct effect captured by the neoclassical model. At the same time, a high V'_{E_t} points to efficiency catch-up over time (the average distance to the *world production frontier* tends to decrease). On the contrary, if V'_{E_t} is at about zero, then labour productivity growth could be fully explained by (both direct and indirect effects of) capital accumulation.

Figure 1 (below) shows the sources of labour productivity growth according to the three methods described above. The horizontal axis reflects the capital stock per hour worked while the vertical axis reflects labour productivity (output per hour worked). We may assume that the TFP exceeds unity so that labour productivity level in either hypothetical country is located above the $y = k^{1/3}$ curve. Under the standard (parametric) Cobb-Douglas decomposition, labour productivity growth in a country A (which is denoted by **b**), could be expressed as a sum of a contribution of capital accumulation (**a**) and the contribution of TFP (**b** – **a**; see Figure 1A). In country B, the only source of labour productivity growth is capital accumulation. Since the contribution of capital accumulation is equal in both countries (**a**), faster labour productivity growth in country A is a result of TFP rise.



Source: author's construction

Fig. 1. **Measuring the sources of cross-country growth differentials using: A) the Cobb-Douglas Framework; B) the DEA Framework; C) a combination of the Cobb-Douglas and DEA Frameworks (mixed case).**

In the non-parametric representation, we first need to estimate a *world production frontier* using empirical data. The *world production frontier* includes countries that achieve the highest level of labour productivity in a country sample given their capital to labour ratio. Figure 1B shows that over a period (0), two hypothetical countries (A and B) belong to the *world production frontier* (Φ_0) and, thus, are considered efficient. At the same time, country C operates below the *world production frontier* and is considered inefficient. While countries A and C have the same capital to labour ratios, country C achieves lower labour productivity so the whole labour productivity gap between countries A and C is explained by an efficiency term. Inefficiency (more specifically, output technical inefficiency) can be measured by a vertical distance between a respective country and a frontier (**b**). Output technical efficiency of country C (E_{Ct} from equation 3) can be calculated as $\frac{a}{a+b}$. In the next period, the *world production frontier* shifts up to Φ_1. Since the *efficiency* of countries A and B did not change (these countries again are considered fully efficient) it both increased their labour productivity solely due to capital accumulation. Note that country C is still *inefficient* during period 1. However, it increased labour productivity substantially (by **e**), at the same time becoming more efficient (vertical distance to a frontier decreased from **b** to **d**). Contribution of efficiency and capital accumulation to labour productivity growth in country C is given by **b** – **d** and **e** – (**b** – **d**) respectively.

When combining the Cobb-Douglas and DEA frameworks (mixed case), again, labour productivity in country C increases by **e** and the contribution of efficiency to labour productivity growth is the difference between **b** and **d** (see Figure 1C). However, now, the contribution of (the direct effect of) capital accumulation is assessed by **f.** The larger the capital stock, the higher is the labour productivity given the same technology. The remaining part of the labour productivity rise is due to an indirect effect of capital accumulation in line with an *appropriate technology* view and is represented by **e** – **f** – (**b** – **d**), implying that a higher capital to labour ratio allows a country to use a more productive technology.

Sources of labour productivity growth differentials could be measured using a variance decomposition exercise. After denoting $\alpha \cdot g_{k_t}$, g_{T_t} and g_{E_t} as $\hat{F}_t$, $\hat{T}_t$ and $\hat{E}_t$ respectively, variance of labour productivity growth for a mixed case could be shown as (based on Jerzmanowski M., 2007):

$$Var(g_{y_t}) = Var(\hat{F}_t) + Var(\hat{T}_t) + Var(\hat{E}_t) + 2 \cdot Cov(\hat{T}_t, \hat{E}_t) + 2 \cdot Cov(\hat{F}_t, \hat{T}_t) + 2 \cdot Cov(\hat{F}_t, \hat{E}_t) \quad (9)$$

where *Var* and *Cov* denotes variance and covariance respectively.

Splitting the covariance terms equally between the factors (Klenow, Rodriguez-Clare, 1997; Jerzmanowski, 2007), the contribution of direct and indirect effects of capital accumulation as well as role of (residual) efficiency term in the variance of labour productivity growth in a particular time period ***t*** is given respectively by V''_{F_t}, V''_{T_t} and V''_{E_t}:

$$V''_{F_t} = \frac{Var(\hat{F}_t) + \mathrm{cov}(\hat{F}_t, \hat{T}_t) + \mathrm{cov}(\hat{F}_t, \hat{E}_t)}{\mathrm{var}(g_{y_t})}; \quad V''_{T_t} = \frac{Var(\hat{T}_t) + \mathrm{cov}(\hat{T}_t, \hat{E}_t) + \mathrm{cov}(\hat{F}_t, \hat{T}_t)}{\mathrm{var}(g_{y_t})};$$

$$V''_{E_t} = \frac{Var(\hat{E}_t) + \mathrm{cov}(\hat{T}_t, \hat{E}_t) + \mathrm{cov}(\hat{F}_t, \hat{E}_t)}{Var(g_{y_t})} \quad (10)$$

For instance, if V''_{T_t} is zero, the situation is realistically represented by the neoclassical model in which capital accumulation has no impact on TFP. By contrast, a significant V''_{T_t} would mean that rapid capital accumulation allows fast growing economies to bear fruits from technologies developed in advanced countries.

Data

While focusing overall on the EU member states, this paper includes an assessment of three other countries – Norway, the USA and Japan – that are often regarded as being among the major technology leaders and, thus, should be included in any *world production frontier* in order to correctly assess the efficiency of the remaining countries. Therefore, the sample under discussion consists of 30 countries. Both capital stock and output (gross value added) annual data are expressed in *per hour worked* and in Euro PPP terms in order to take into account international price differences. Output, number of hours worked and PPP index data were obtained from Eurostat. Moreover, both input and output data were filtered with a Hodrick-Prescott filter ($\lambda = 100$) in order to exclude the short-term cyclical impact on output and employment. The annual input and output time series for all countries involves the 1995-2010 period. Reliable macro-economic data for Eastern European countries is not available prior to 1995, thus, growth investigation usually starts at that year (for instance, Vanags, Bems, 2005).

Capital stock data are based on the Groningen Growth Accounting Database (GGAD), which is widely used in a recent growth research (for instance, Apergis, et al., 2010; Ark, et al., 2008). However, the data only covers 16 countries (EU-15 and the U.S.) and the time span until 2004. The following *rule-of-thumb* assumptions were made regarding capital accumulation.

For the EU-15 and U.S., capital stock data were extrapolated to 2005–2010 using the perpetual inventory method (see, for instance, Vanags, Bems, 2005) and gross capital formation data taken from Eurostat. The capital stock time series for each of the EU-12 countries were constructed by assuming an initial (in 1995) capital to GDP ratio to be 100% (150% for Norway and Japan). The capital stock annual depreciation rate was assumed to be 10% for all countries.

Moreover, in exploring the possibility that the capital stock depreciation rate may differ across countries, as well as dealing with the possibility of imprecise initial capital to output ratio estimates, an alternative capital stock estimation method was used (k adjusted).

Firstly, the implied capital depreciation rates were calculated for 16 countries included in the GGAD during 1995–2004 (the GGAD capital stock data and the Eurostat fixed capital formation data were combined in a perpetual inventory method). The average implied capital depreciation rate for the 16 countries was estimated at 10.2%, which is slightly higher than is usually considered for advanced countries in a growth accounting research (for example, a conventional estimate for the USA is usually 6% (Khan, 2009) or 5% (Barro, Sala-i-Martin, 2004)). Nevertheless, cross-country differences are significant with the highest depreciation rate being estimated for Portugal and Ireland (16.5% and 14.0% respectively), which is about two times as much as it is in France and Denmark (7.9% and 8.3% respectively).

Secondly, it was found that the capital depreciation rate relates positively to the share of manufacturing in the gross value added (GVA) and investment to

GDP ratio, while negatively relating to the share of construction in the GVA and initial capital to output ratio:

$$\hat{\delta} = 2.267 + 0.825 \cdot \frac{\bar{I}}{\bar{Y}} - 4.763 \cdot \left(\frac{\hat{K}}{Y}\right)_0 + 0.218\left(\frac{Ind}{VA}\right) - 0.982\left(\frac{Constr}{VA}\right) \quad (11)$$

p-value: (0.4647) (0.0011) (0.0002) (0.0011) (0.0402)
$R^2 = 0.872$

where $\hat{\delta}$ is implied capital depreciation rate;

$\frac{\bar{I}}{\bar{Y}}$ – investment (gross fixed capital formation) as a share of the GDP (1995–2004 average);

$\left(\frac{\hat{K}}{Y}\right)_0$ – capital to GDP ratio in 1995;

$\left(\frac{Ind}{VA}\right)$ and $\left(\frac{Constr}{VA}\right)$ – share of manufacturing and construction respectively in the GVA (1995–2004 average).

As for the initial capital output ratios, the only factor that showed border significance (p-value is 0.0849) was the share of public services (public administration, education and healthcare) in the GVA which could be regarded as one of the proxies of maturity of the economy.

Thirdly, the initial capital to output ratio and capital depreciation rate was estimated for the remaining 14 countries (EU-12, Norway and Japan). In line with the observation that capital depreciation rates may generally be higher in developing countries than in developed economies (for instance, see Duma, 2007), the capital depreciation rate in the EU-12 was found to be significantly higher compared to the EU-15 (14.9% and 10.2% respectively). With regard to the Baltic states, the capital depreciation rate was estimated at 19.3%, 16.1% and 12.5% for Estonia, Latvia and Lithuania respectively.

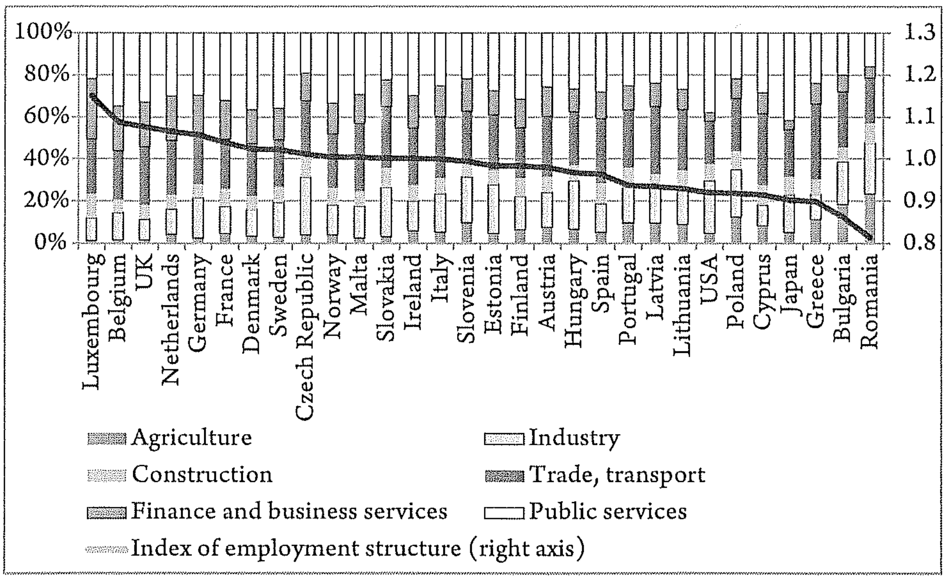
In its turn, the initial capital to GDP ratio for the EU-12 is found to be somewhat lower than in the EU-15 plus USA (1.44 and 1.69 respectively). In regard to the Baltic states, the initial capital to GDP ratio was estimated at 1.594, 1.556 and 1.442 in Latvia, Lithuania and Estonia respectively. This result is in line with the conventional logic that in order for investments flow from Western Europe to Eastern Europe, the capital marginal product in Eastern Europe should be higher than that in Western Europe (Vanags, Bems, 2005). Assuming that the GDP elasticity to capital is similar across countries, this could then be accomplished only if the capital to output ratio is higher in Western Europe than in Eastern Europe.

Along with an unadjusted measure of labour productivity, this paper also uses the adjusted level (y adjusted) taking into account the impact of structural effects on aggregate labour productivity. As labour productivity differs by sectors, and is positively related to natural resource endowment, those countries which increase the intensity of the usage of their natural resources or in which labour moves to productive sectors, will report a higher labour productivity rise. Since the growth model ignores natural resources and deals only with homogenous labour, this may be wrongly assessed as an efficiency rise, i.e., as a catch-up to the *world production frontier*. Adjusted labour productivity reflects hypothetical labour productivity values if the composition of employment in any country would be regarded as being similar to the EU-27 average and subtracting a natural resource rent. Similar adjustments were made respectively by (Barrow, Sala-i-Martin, 2004) and (Merkina, 2009).

The adjustment on the employment structure was done as follows. Firstly, employment structure index S_{it} was calculated using Eurostat data on *value added* and employment breakdown by six sectors according to the NACE 1.1. classification. This reflects the relative labour productivity in country **i** if each particular sector in country **i** would be as productive as in EU-27 on average:

$$S_{it} = \sum \gamma_{jt} \cdot w_{ijt} \qquad (12)$$

where γ_{jt} i s the EU average labour productivity in sector **j** and period **t**;
w_{ijt} – is the sector **j** share in total working hours in country **i** and period **t**.



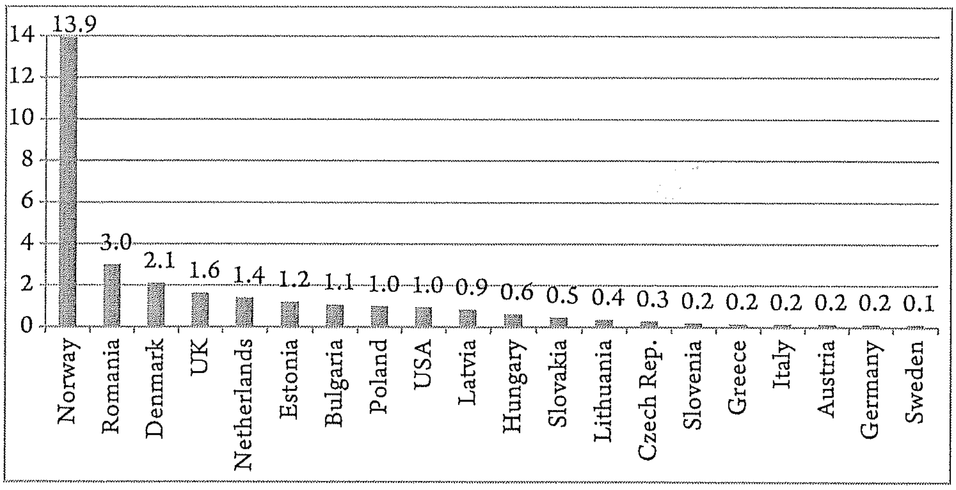
Source: author's calculations based on Eurostat data

Fig. 2. **Structure of Hours Worked and Index of Employment Structure in 2010**

Figure 2 (above) shows that the employment structure alone explains the about 40% difference of labour productivity between Luxembourg and Romania

(S_{it} is 1.15 and 0.81 respectively). While Luxembourg is specialising at finance and business services (the sector with the highest labour productivity in all countries), Romania reflects the largest employment share in agriculture (lowest labour productivity).

A labour productivity adjustment by natural resource endowment was made by subtracting pure windfall from the natural resource use (i.e., part of the country output "produced" with no labour or capital expended) based on World Bank *genuine savings* data. Three types of natural resource rent can be distinguished: *mineral rent* (includes bauxite, copper, iron ore, lead, nickel, phosphate rock, tin, zinc, gold and silver), *energy rent* (consists of oil, gas and coal) and net *forest depletion rent*. Countries in which natural resource rent exceeds 0.1% of output are shown in Figure 3. Almost all of the natural resource rent in Norway, Romania, Denmark, UK, Netherlands and Estonia consists of energy rent, whereas mineral rent is important in Bulgaria and Poland and forest rent – in Latvia, Lithuania and Slovakia.



Source: author's calculations based on World Bank and Eurostat data

Fig. 3. **Natural Resource Rent in Selected Countries (2000 – 2008 average; % of GDP)**

Results and Discussion

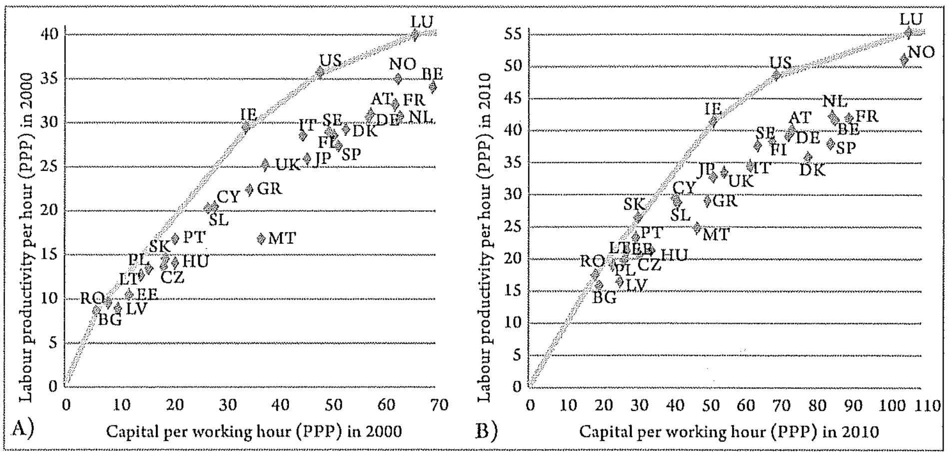
Therefore, the adjusted level of labour productivity was calculated as:

$$\gamma_{it}^{*} = \frac{y_{it} \cdot (1 - e_{it} - m_{it} - f_{it})}{S_{it}} \tag{13}$$

where γ and γ^{*} – unadjusted and adjusted labour productivity, respectively;
e, m, and *f* – energy rent, mineral rent and forest rent, respectively (% of GDP).
i and *t* – country and period, respectively.

Given the large impact of assumption with regard to initial capital to output ratio on the input variable at the beginning of the period, results are discussed for the 2000-2010 period.

The *world production frontier*, estimated by DEA method, consists of four countries observed in both 2000 and 2010: Romania, Ireland, the USA and Luxembourg (see figure 4A and 4B). The other countries are not efficient. For instance, Latvia has a lower labour productivity than the U.S. not only due to relatively low capital to labour ratio, but also due to its backwardness relative to the *world production frontier*. Ireland and Luxembourg are the only two countries considered to be efficient in either particular year and irrespective of the data set.



Source: author's construction

Fig. 4. **World Production Frontier (adjusted k and y values): A) 2000; B) 2010**

Note also, that, although in 2000 the Eastern European economies were lagging their Western counterparts in terms of efficiency (73.3% vs. 82.9%; see Table 1), the efficiency differentials almost vanish up to 2010 (81.4% vs. 82.1%). The efficiency catch-up by EU-12 countries was accompanied by a rapid capital accumulation as compared to the advanced economies (70% vs. 41% growth in capital stock per working hour). While the difference in capital endowment decreased in relative numbers, it still increased in absolute numbers over the decade. In the Baltic states, the capital formation was particularly fast, but the efficiency catch-up was somewhat slower as compared to other EU-12 economies.

Under the traditional neoclassic growth accounting framework relying on a Cobb-Douglas production function, the contribution of capital accumulation to labour productivity growth is estimated to be between 40% and 50% depending on the data set (the respective figure for variance of labour productivity growth is between 44% and 66%). Taking the average number of the four data sets, capital accumulation accounts for about 45% of labour productivity growth (the average of the countries sample) whereas cross-country differences in the speed of capital accumulation explain about 55% of labour productivity growth cross-country differentials (see Table 2). This means that about half of the economic growth is not explained by a standard Cobb-Douglas framework, thus mirroring a large role of TFP. Although the average result of the four data sets lacks *real-world* interpretation, it may still be useful in assessing the relevance of the *appropriate technology* view given the imprecision of capital stock estimates for the Eastern European countries. The usage of the non-parametric DEA method in measuring the sources of economic growth substantially increases the role of capital – to about 95–100%. Thus, a relaxing of the Cobb-Douglas assumptions suggests that capital accumulation is (very) nearly the only source of economic growth within a particular sample of countries.

Table 1

Efficiency Estimation for Selected Countries (2000 and 2010)

Period:	2000				2010			
Variable:	k_{it}	y_{it}	$y_t(k_{it})$	$y_{it}/y_t(k_{it})$	k_{it}	y_{it}	$y_t(k_{it})$	$y_{it}/y_t(k_{it})$
Unit:	euro PPP				euro PPP			
Estonia	12.2	10.5	15.2	0.688	31.2	20.8	28.0	0.742
Latvia	10.1	8.9	13.2	0.675	25.7	16.5	23.5	0.701
Lithuania	14.4	12.7	17.2	0.738	26.9	19.8	24.5	0.807
EU-15 and USA	50.1	29.4	35.5	0.829	70.6	38.8	47.3	0.821
EU-12	18.1	13.6	19.2	0.733	30.8	21.8	27.2	0.814

Source: author's calculations based on GGAD, World Bank and Eurostat data

Table 2

Sources of labour productivity growth and its cross-country variance in 2000-2010 using Cobb-Douglas and DEA decompositions separately, %

Variable:	**Labour productivity growth**				**Variance of labour productivity growth**			
Method:	**Cobb-Douglas**		**DEA**		**Cobb-Douglas**		**DEA**	
Growth factor: / Data used:	**Capital**	**TFP**	**Capital**	**Efficiency**	**Capital**	**TFP**	**Capital**	**Efficiency**
No adjustments	48.1	51.9	91.9	8.1	59.3	40.7	140.3	-40.3
Y adjustment	50.1	49.9	107.7	-7.7	66.3	33.7	121.1	-21.1
K adjustment	39.6	60.4	91.2	8.8	44.2	55.8	71.9	28.1
K & Y adjustment	41.3	58.7	88.7	11.3	49.1	50.9	67.1	32.9
Average:	**44.8**	**55.2**	**94.9**	**5.1**	**54.7**	**45.3**	**100.1**	**-0.1**

Source: author's calculations based on GGAD, World Bank and Eurostat data

To clarify whether the difference in results is due to the indirect impact of capital to technology in line with an *appropriate technology* view, the Cobb-Douglas and DEA frameworks were combined. Note that in some cases (depending on data set) the indirect effect of capital accumulation is even more important than the direct effect (see Table 3). Taking the average result of the four data sets, both effects of capital accumulation are similarly important sources of labour productivity growth: V'_{F_i} and V'_{T_i} are close to 45% each. However, when measuring why labour productivity growth in some countries is faster than in others, direct effect is somewhat more important: V''_{F_i} and V''_{T_i} are estimated to be about 50% and 37% respectively. Thus, the results confirm the *appropriate technology* view that rapid capital accumulation, by increasing the capital to labour ratio, allows a country to employ a more productive technology which, in its turn, has a positive impact on labour productivity.

Table 3

Sources of labour productivity growth and its cross-country variance in 2000-2010 using a combination of Cobb-Douglas and DEA decompositions, %

Variable:	Labour productivity growth			Variance of labour productivity growth		
Growth factor: / Data used:	Capital	Technology	Efficiency	Capital	Technology	Efficiency
No adjustments	50.0	36.6	13.4	46.4	64.8	-11.2
Y adjustment	50.1	62.4	-12.5	64.0	42.6	-6.6
K adjustment	39.6	43.7	16.7	43.3	37.1	19.6
K & Y adjustment	41.3	40.1	18.6	47.8	2.6	49.6
Average:	**45.3**	**45.7**	**9.0**	**50.4**	**36.8**	**12.8**

Source: author's calculations based on GGAD, World Bank and Eurostat data

The indirect effect of capital accumulation on labour productivity is ignored by a standard Cobb-Douglas decomposition. While the Cobb-Douglas assumes that TFP is not related to k, in reality, however, there is a strong positive relation between these variables. In using data with both input and output adjustments, about 71% of the cross-country differences in TFP can be explained by the difference in capital to labour ratio (when none of the adjustments is used, the relation is even stronger with $R^2 = 0.83$). The results prove that the technology available to a country is crucially dependent on its capital endowment ($k = K/L$). Given the direct and indirect effects of capital accumulation, investments have a greater role in economic growth than is derived from standard (Cobb-Douglas) growth-accounting practices.

Note that the role of efficiency in economic growth is not robust (results are not stable and depend on the data set used). This could reflect data measurement error since capital stock data are the least precise in almost all growth accounting literature. The absence of robust relation between efficiency increase and labour productivity growth could be interpreted as fast growing economies experience with only modest efficiency catch-up. While the rapid rise of capital stock not only increases labour productivity directly, but also allows these countries to use a more productive technology, their backwardness compared to the *world production frontier* remains rather stable. Earlier research suggests that the contribution of efficiency to economic growth could even be negative (for instance, Jerzmanowski, 2007), i.e., fast growing economies tend to deviate from the *world production frontier* over time. Although this is not the case with regard to Eastern European economies in general, the efficiency catch-up was particularly slow in the Baltic states, especially in Latvia (see table 1.). Still, given the possible imprecision of capital estimates and unstable efficiency numbers depending on the data set, a caveat should be made before linking efficiency measures to any fundamental (i.e., institutional) factors.

It should be noted that this paper uses a narrow definition of the term *capital* that includes physical capital stock but disregards Human capital. While some growth accounting papers consider Human capital as well (for instance, Hsieh, Klenow, 2010; Jerzmanowski, 2007), all of these use the broad country sample (including both the world's richest and poorest countries) in which there is a strong positive correlation between the Human capital variable and income level. In contrast, the Eastern European economies are not lagging behind their Western counterparts with regard to quantitative Human capital data (years of schooling etc.), thus, there is no statistically significant correlation between these indicators and labour productivity. Despite a possible lack of Human capital quality, this cannot be concluded, for example, via "mincerian equations" both due to the unavailability of data and since the "age" of employee's education matters for its value in some countries (as documented by (Hazans, 2005) in the case of Latvia). Given that (Melihovs, Davidsons, 2006) have not found any Human capital variable that would improve the accuracy of Latvia's production function, the finding of a precise Human capital proxy that would be useful for cross-country growth accounting research becomes a real challenge that is left for further research efforts.

CONCLUSIONS, PROPOSALS, RECOMMENDATIONS

The main findings of this paper are summarised as follows:

1. In accord with the observation that capital depreciation rates are generally higher in developing countries than in developed economies, the annual depreciation rate of physical capital is found to be substantially higher in Eastern European countries than in Western European countries (14.9% and 10.2% respectively).

2. The initial capital to GDP ratio (in 1995) in the Eastern European countries was found to be somewhat lower than in the Western European countries (1.44 and 1.69 respectively). This is in line with a common observation that the capital marginal product is relatively higher in Eastern Europe.
3. Using a standard neoclassical growth accounting framework relying on the Cobb-Douglas production function, the contribution of capital accumulation to labour productivity growth (average in a country sample that consists of all 27 EU countries, Norway, the USA and Japan; during 2000-2010) is about 45%. Similarly, the cross-country differences in the speed of capital accumulation accounts for about 55% of labour productivity growth differentials. This reflects the direct effect of capital accumulation on output: the increase of capital to labour ratio increases labour productivity given the same level of technology.
4. The usage of non-parametric DEA methodology allows for increasing the contribution of capital in assessing the sources of economic growth to 95–100%. In line with the *appropriate technology* model (Basu, Weil, 1998), capital accumulation has an indirect effect on output ignored by the neoclassical framework: the increase of capital to labour ratio allows a country to use a more productive technology. When accounting for the sources of labour productivity growth, both effects of capital accumulation are similarly important. In its turn, when evaluating why labour productivity growth in some countries is faster than in others, the direct effect of capital accumulation seems to be somewhat more important.
5. The conclusion regarding the presence of an indirect effect of capital accumulation is robust, subject to the usage of alternative assumptions of capital formation as well as an adjustment of labour productivity in respect to the employment structure by sectors and natural resource endowment.
6. Although the neoclassical growth model assumes that the capital to labour ratio and TFP are independent of each other, empirical data points to the strong positive relation between these variables.
7. Further research efforts on multi-county growth accounting in the EU should focus on the usage of other methods to estimate the *world production frontier*, alternative to DEA (for instance, SFA: stochastic frontier analysis). An additional challenge is to find a precise Human capital approximation that would be suitable for growth accounting in each of the EU economies.

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