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Theses

**Physical capital accumulation and economic growth in the
Central Eastern European countries between 1995 and 2007**

Ákos Dombi

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Introduction

The Central Eastern European (CEE) countries, which joined the European Union in 2004 and 2007, have constituted a dynamic part of the world economy since the transformation took place. The CEE countries reviewed are Bulgaria, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, the Slovak Republic and Slovenia. The post-socialist growth path of these countries can be divided into three consecutive phases. The first phase is the crisis of transformation, which resulted in the severe contraction of GDP and employment. The background of the economic collapse is well documented in the literature (Antal, 2004). We can date this phase from 1990 to 1994. The end-date is not unambiguous. On the one hand, 1995 was the first year, when the free-fall in GDP stopped in each country and the dynamics switched from negative to positive sign. On the other hand, in some countries the economy already started to grow before 1995 (e.g., Poland, Hungary), while in other countries the economy slumped again into deep recession after 1995 (Romania, Bulgaria).

The second phase fell between 1995 and 2007, when these countries exhibited considerable economic growth compared to the developed world reducing thereby their relative backwardness. According to the Eurostat, the average annual GDP growth rates of these countries ranged from 3 to 7 percent in this period (figure 1.1), while the same rate was only 2.9, 1.1 and 2.2 percent for the USA, Japan and the former 15 countries of the European Union (EU-15) respectively.¹ The individual records disperse markedly with the Baltic countries being the fastest economies and with Bulgaria, Romania, the Czech Republic and Hungary being the slowest ones. As a result of this robust growth performance, the relative GDP per capita of the CEE countries improved significantly until 2007 (figure 1.2).

The third, recent phase has begun in 2008 and corresponds to the years of the global financial crises. Although the financial markets of the CEE countries were only marginally plagued by the CDO's and other structured financial assets, the crises hit some of them very seriously (Király, 2009). Especially the Baltic countries suffered.

Figure 1.1

Average growth rate of real GDP (1996-2007)

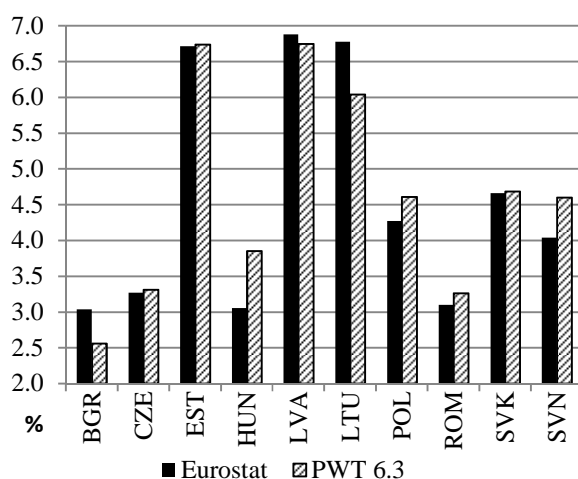
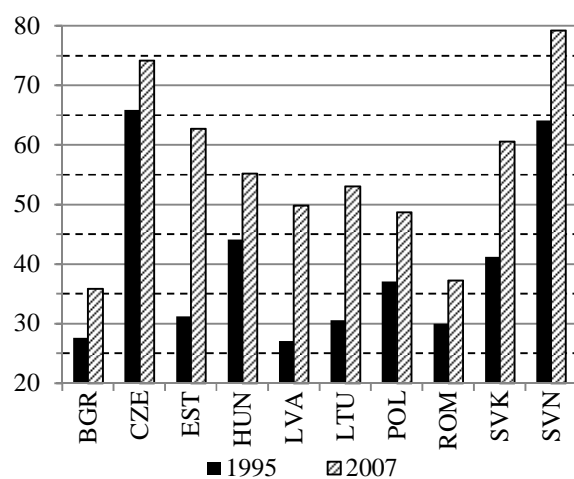


Figure 1.2

GDP per capita at PPP (EU-15=100, Eurostat)



¹ The country codes are the followings: Bulgaria (BGR), Czech Republic (CZE), Estonia (EST), Hungary (HUN), Latvia (LVA), Lithuania (LTU), Poland (POL), Romania (ROM), Slovak Republic (SVK) and Slovenia (SVN).

The tremendous literature on the CEE economies can be divided along the three phases of the post-socialist economic history. The first wave considers the crises of transformation and the challenges faced by economic policy during the transition from command to market economy.² The second wave considers the development of market institutions, the catching up process to the developed countries, the characteristics of the robust economic growth and the prerequisites of accelerating growth.³ The third wave deals naturally with the impact of the global financial crises and with the adequate responses with respect to economic policy.⁴

Goals

The dissertation contributes to the second wave of the CEE literature by investigating the main components of the robust economic growth between 1995 and 2007 with a special emphasis on the role of physical capital accumulation. In doing so, we base our work on the three major areas of growth empirics. These three areas are growth accounting, development accounting and conditional convergence. First, we perform the growth accounting and development accounting for the 10 CEE countries between 1995 and 2007 (chapter 2). The goal is to identify the contribution of the main production factors (i.e., physical capital, labor and multifactor productivity) to the economic growth and to the relative economic development of these countries. Secondly, we estimate the neoclassical speed of conditional convergence in the CEE countries during the referred period (chapter 3). It is widely known, that the neoclassical Solow model is a model of physical capital accumulation. Thus the speed of neoclassical convergence represents the dynamics of the economy emanating from physical capital accumulation.

Except development accounting, there is already a huge literature on the issues investigated in the dissertation. Here we present a short list. Growth accounting for the CEE countries or for a subset of them is performed in Doyle et al. (2001), Jongen (2004), Ganey (2005), Mourre (2009), Rapacki and Próchniak (2009), Salsecci and Pesce (2008), Vanags and Bems (2005), van Leeuwen and Földvári (2011). The real convergence of the CEE countries is investigated in Borys et al. (2008), Campos (2001), Cavenaile and Dubios (2011), Kutan and Yigit (2004), Matkowski and Próchniak (2007), Rapacki and Próchniak (2009), Szeles and Marinescu (2010), Borys et al. (2008). Despite this numerous literature, our results are real contributions to the empirics of the post-transition pre-crises economic growth of the CEE economies. We base this belief on the methodological accuracy with which the accounting decomposition of the growth rate and the relative development is performed and with which the neoclassical speed of convergence is estimated. Consequently, the dissertation adds value from both an empirical and a methodological standpoint.

Although the dissertation focuses on the pre-crisis growth path of the CEE countries, a small digression is devoted to the relationship of long run economic growth with population growth (chapter 4). The population of the CEE countries has stagnated or decreased since the transformation. The demographic processes are especially worrisome in the Baltic countries, Bulgaria and Romania. The question naturally arises: in what way decreasing population might affect the growth prospects of these countries? To find the answer, we review the related predictions of growth theory.

² See e.g., Blanchard and Kremer (1997), Veress (1994), Nagy (2003), Kornai (1993).

³ See e.g., Erdős (2000a, 2000b, 2004a, 2004b), Dedák (2000), Mellár (2001), Antal (2004).

⁴ See e.g., Darvas (2010, 2011), Atoyán (2010), Aslund (2010).

The dissertation is of methodological nature therefore we present the list of variables at the end of the theses. The source of the data is depicted after the individual variables in parenthesis. The choice concerning the source of GDP requires some comments. The growth accounting literature uses GDP at constant prices in national currency, while the development accounting literature uses GDP at current prices in purchasing power parity (PPP). The Eurostat provides both series for the CEE countries in the investigated period. However, the estimation of the speed of neoclassical convergence requires GDP at constant prices in purchasing power parity since growth theory neglects any monetary phenomenon. Consequently, we work with the GDP at constant prices in PPP throughout the dissertation so as to maintain consistency. Unfortunately, the Eurostat does not provide this series. The most qualified international database on GDP at constant prices in PPP is the Penn World Table (PWT), which has become the workhorse database for growth theorists. In figure 1.1, we present the growth rates of real GDP based on PWT 6.3 as well. Comparing these rates with those found in the Eurostat, we can conclude that the two series are broadly in line with each other.

New scientific results

Thesis 1.

The primary source of the rapid growth of the CEE countries between 1995 and 2007 was the accumulation of physical capital followed by the growth of multifactor productivity. Labor contributed only marginally. (Dombi, 2013a, 2013b)

We perform the growth accounting of the CEE countries in accordance with the following equation:

$$(1) \quad \Delta \ln Y_t = \Delta \ln MFP_t + \frac{s_{K',t} + s_{K',t-1}}{2} \Delta \ln K'_t + \frac{s_{L,t} + s_{L,t-1}}{2} \Delta \ln L_t,$$

where Y is the output (GDP), K' is the physical capital input, L is the labor input, MFP is the multifactor productivity, $s_{L,t}$ is the labor share, $s_{K',t}$ is the capital share and $s_{K',t} = 1 - s_{L,t}$. Physical capital input and labor input are calculated as the product of the quality dimension (Q^H , Q^K) and the quantity dimension (K, H) of these factors: $L = Q^H H$ and $K' = Q^K K$, where H is the total number of hours worked in the economy and K is the stock of physical capital.⁵

The accounting exercise is performed for each year in the investigated period and for two alternative measures of labor quality, that is for the growth theory approach of Q^H and for the growth accounting approach of Q^H as well. The annual results are presented in the appendix of the dissertation. In order to save place, we present here only the decomposition of the average GDP growth rate. Figure 2 investigates the average growth rate from 1996 to 2007 by following the growth theory approach of Q^H . On the contrary, figure 3 focuses on the average growth rate from 1999 to 2007 and has applied both the accounting approach and the growth theory approach of Q^H .

The decomposition of the average GDP growth rate (1996-2007), Q^H : growth theory approach

Figure 2.1 Percentage point contribution

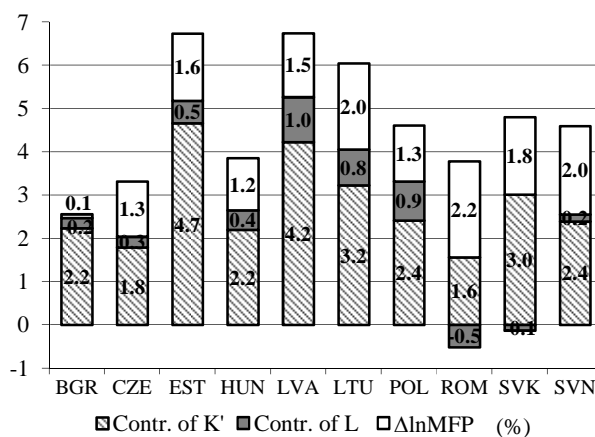
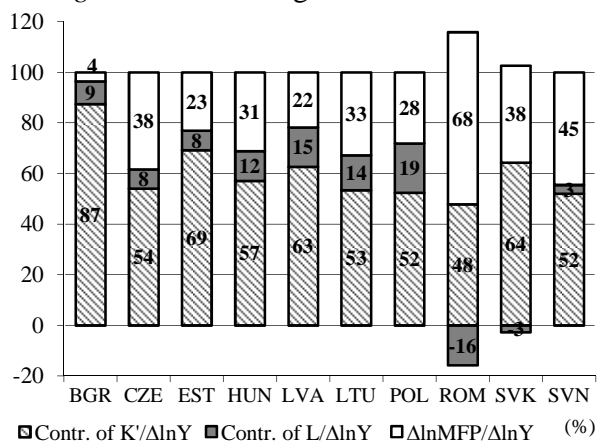


Figure 2.2 Percentage contribution



⁵ The calculation of Q^K faces difficulties in some CEE countries due to a lack of data availability. Therefore, we calibrate Q^K to 1. In other words, we ignore the compositional change in capital stock and its effect on quality. Although doing so worsens the accuracy of the accounting results, our calibration is in no way unusual. Many authors also utilize this aggregate concept of physical capital (e.g., Caselli and Tenreyro, 2005; Bosworth and Collins, 2003).

The decomposition of the average GDP growth rate (1999-2007): percentage point contribution

Figure 3.1 Q^H: growth theory approach

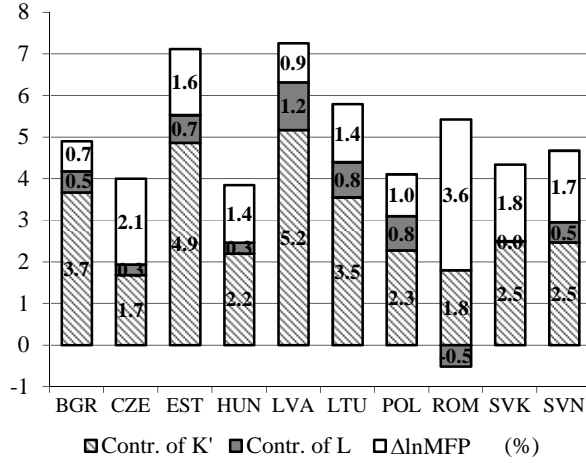
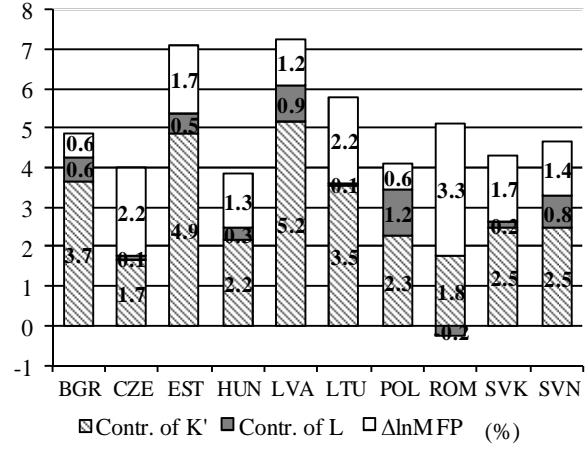


Figure 3.2 Q^H: accounting approach



Notes to figures 2 and 3: The results are presented in percentage form (*100).

$$\text{Contr. of } K' = \frac{\sum_{t=\lambda}^{2007} \frac{s_t^{K'} + s_{t-1}^{K'}}{2} \Delta \ln K_t}{2007 - (\lambda - 1)}, \quad \text{Contr. of } L = \frac{\sum_{t=\lambda}^{2007} \frac{s_t^L + s_{t-1}^L}{2} \Delta \ln L_t}{2007 - (\lambda - 1)}, \quad \Delta \ln MFP = \frac{\sum_{t=\lambda}^{2007} \Delta \ln MFP_t}{2007 - (\lambda - 1)}, \quad \Delta \ln Y = \frac{\sum_{t=\lambda}^{2007} \Delta \ln Y_t}{2007 - (\lambda - 1)},$$

where 'Contr.' is contribution. For figure 2, $\lambda = 1996$, whereas in figure 3, $\lambda = 1999$.

Thesis 2.

In the investigated period (1995-2007) the primary reason for the lower GDP/hours worked of the CEE countries compared with Germany is the lower capital intensity followed by the lower MFP at second place. Concerning the labor quality, the CEE countries are at the same level as Germany. (Dombi, 2013a, 2013b)

We perform the development accounting of the CEE countries in accordance with the following equation:

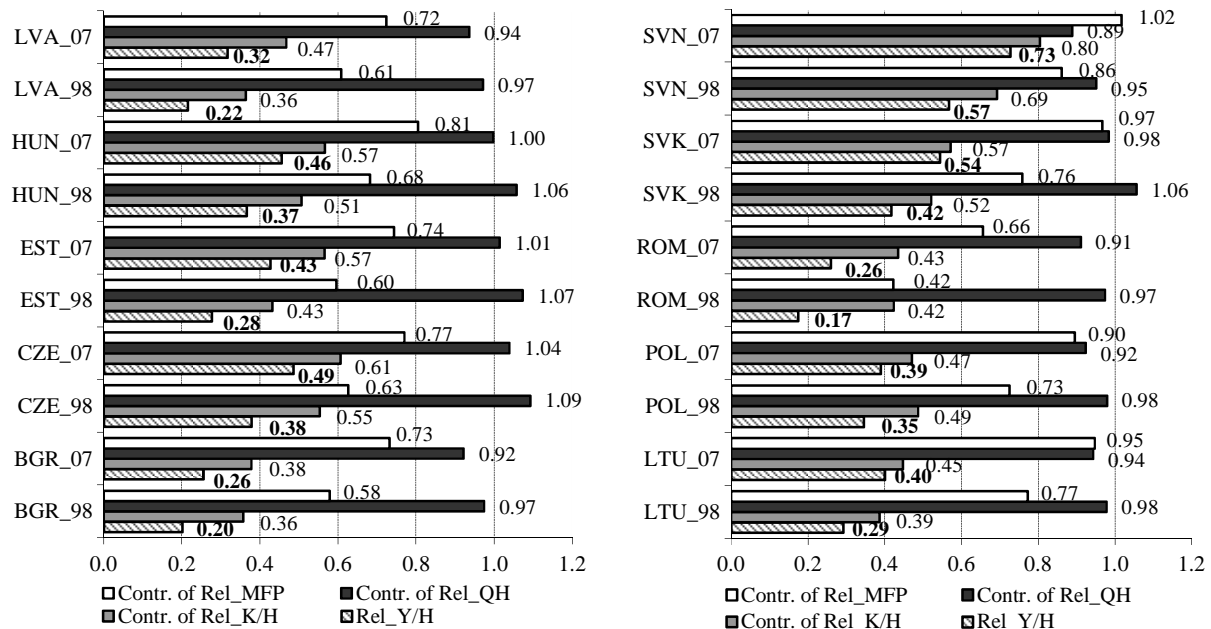
$$(2) \quad \ln \frac{Y_t}{Y_t^R} = \ln \frac{MFP_t}{MFP_t^R} + \frac{s_{K',t} + s_{K'',t}^R}{2} \ln \frac{K'_t}{K_t^R} + \frac{s_{L,t} + s_{L,t}^R}{2} \ln \frac{L_t}{L_t^R},$$

where R is the reference country, which is Germany in our case. To eliminate the distorting effect of size differences, we investigate the GDP per hours worked instead of GDP. The additive decomposition of equation (2) is inadequate in our case. The underlying reason is that the log-differences ($\ln x - \ln x^R$) are only a poor approximation for the relative differences ($x/x^R - 1$) due to the substantial differences between the related variables of the CEE countries (x) and Germany (x^R). Therefore, we perform multiplicative decomposition by taking the exponent of equation (2).

The accounting exercise is performed for each year in the investigated period and for the two alternative measures of labor quality as well. The results are publicized in the appendix of the dissertation. We present the case of the growth theory approach of Q^H for the year 1998 and 2007 in figure 4. The depicted relative GDP/hours worked equals the product of the contribution of relative capital intensity, the contribution of relative labor quality and the contribution of relative MFP.

We have to note, that the results of development accounting according to the growth accounting approach of Q^H differs significantly from those in figure 4 with respect to the contribution of relative labor quality and to the contribution of relative MFP. However, the latter does not affect thesis 2, because the contribution of relative capital intensity is the same at both cases of Q^H .

Figure 4. The multiplicative decomposition of the relative GDP/Hours worked according to the growth theory approach of Q^H



Notes: $Rel_Y/H = (Y_t/H_t) / (Y_t^G/H_t^G)$, $Contr. of Rel_K/H = \left((K_t/H_t) / (K_t^G/H_t^G) \right)^{\frac{s_{K,t} + s_{K,t}^G}{2}}$, $Contr. of Rel_QH = \left(Q_t^H / Q_{t,G}^H \right)^{\frac{s_{L,t} + s_{L,t}^G}{2}}$, $Contr. of Rel_MFP = \frac{MFP_t}{MFP_t^G}$, where $G = \text{Germany}$. The calculations were performed according to a converted version of equation (2). At the conversion, we first subtracted $\ln(H/H^G)$ from both sides of (2), and then we took its exponent.

Comments on thesis 1 and thesis 2

The formula of growth accounting (eq.1) and the formula of development accounting (eq.2) are theoretically well established and widely known in the literature (see e.g., O'Mahony and Trimmer, 2009; Inklaar and Timmer, 2008). Thus the central issue in growth accounting and development accounting is the accurate measurement of factor shares and inputs. The latter is very problematic at the CEE countries partly because of the lack of data and partly because of the short time-series. Consequently, each study involved in the growth accounting and/or in the development accounting

of the CEE countries which improves the measurement of factor inputs and factor shares contributes to the empirics of the post-transition growth of these economies. The dissertation contributes to the measurement issue in two respects. First, we consider two alternative indicators of the labor quality. Second, we provide a thorough estimation of the initial (1995) capital-output ratio (i.e., K_{1995}/Y_{1995}) by considering all the relevant methods known in the literature.

The first approach of measuring the Q^H quality factor is related to the accounting literature and focuses on the compositional differences of labor (Mourre, 2009). More precisely, we calculate the following index: $Q_t^H = \sum_j (E_t^j / E_t) (\overline{p_{j02}^H / p_{p02}^H})_{CEE}$, where j is the labor category, E is the employment and p_j^H is the rental price of labor hour j . Labor is divided into three categories based on the highest level of education: labor with primary education ($j = p$), labor with secondary education ($j = s$) and labor with tertiary education ($j = t$). According to this *accounting approach of Q^H* , the composition of labor improves if the shares of the more productive (i.e., expensive) categories within the labor force rise. The indicator is calculated only from 1998 because disaggregated employment data are not available for some countries before 1998. The evolution of the indicator is depicted in figure 5.

The second approach of the Q^H quality factor relies on the human capital concept of growth theory and tries to measure the average level of qualification within the labor force. In the literature the average human capital is usually calculated according to the following log-linear function: $Q^H = e^{r \cdot sy}$, where sy is the average years of schooling for the labor force and r is the return to schooling (Caselli, 2005). However, the level of human capital depends not only on the years of schooling but also on the quality of the educational system. Therefore we calculate the quality-adjusted years of schooling (sy_{adj}) based on Hanushek and Woessmann's (2009) cognitive index, which is actually the average score achieved by the students of a given country on the International Student Achievement Tests in math and science. Utilizing this quality-adjusted years of schooling, we calculate the *growth theory approach of Q^H* as follows: $Q^H = e^{r \cdot sy_{adj}}$. Based on the results of Psacharopoulos (1994), many studies calibrate the returns to schooling in the following manner: $r=0.134$ if $sy \leq 4$; $r=0.101$ if $4 < sy \leq 8$; and $r=0.068$ if $8 < sy$ (e.g., Hall and Jones, 1999; Caselli, 2005). Therefore, we also utilize these values. The evolution of indicator is depicted in figure 6.

Figure 5. The efficiency multiplier of labor: accounting approach

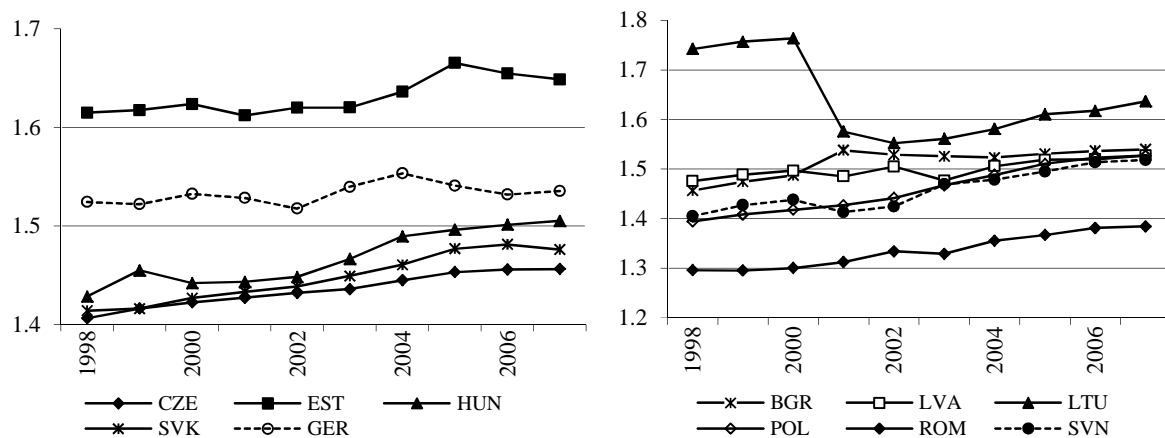
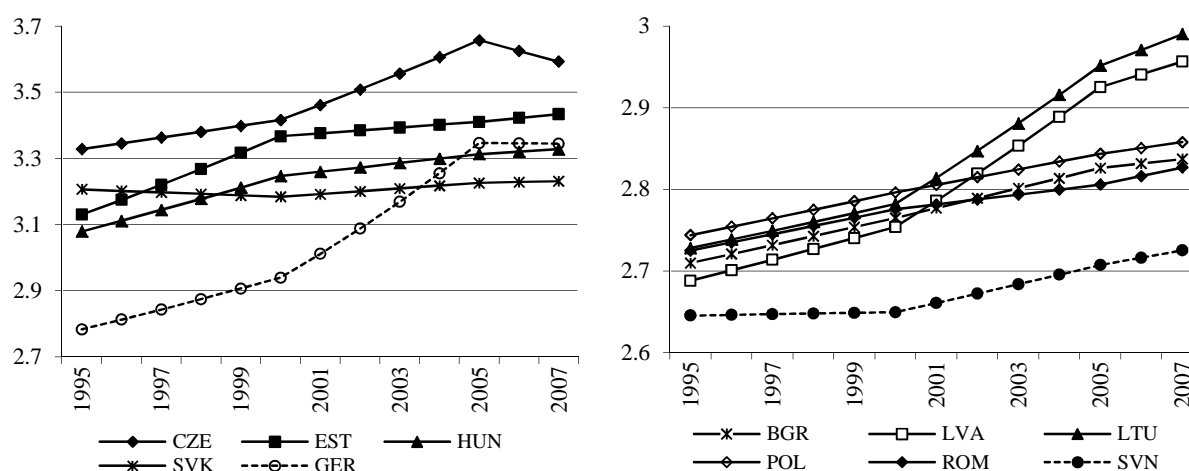


Figure 6. The efficiency multiplier of labor: growth theory approach



We calculate the aggregate capital stock (K) by the standard perpetual inventory method from 1995. The choice of initial year is governed by necessity. On the one hand, reliable investment data are only available for a few CEE countries before the transformation process. On the other hand, we only have loose assumptions about the one-off drop in capital stock during the transformation process (Doyle et al., 2001; Pula, 2003). However, the proximity of the initial year induces a severe problem in that the calculated capital stock will be sensitive to the initial capital stock (K_0). The latter renders the usually unimportant question of which method to choose for estimating K_0 highly relevant in the case of the CEE countries. Thus, in the dissertation a thorough overview of the possible techniques present in the literature is provided. Six major techniques are identified: 1. *Naive Approach* (Nehru and Dhareshwar, 1993), 2. *Harberger Approach* (Iradian, 2007; King and Levine, 1994), 3. *Quasi-Harberger Approach* (Young, 1995), 4. *Profit-maximization Approach* (Jongen, 2004; IMF, 2010), 5. *Regression Approach I.* (Nehru and Dahreshwar, 1993; King and Levine, 1994; IMF, 2008), 6. *Regression Approach II.* (Rööm, 2001; Nehru and Dahreshwar, 1993). We calculate the initial (1995) capital stock of CEE countries by utilizing each method. Supposing that the depreciation rate (δ) is 10 percent, the results are the followings:

Table 1. The initial (1995) capital-output ratio according to the individual methods

K_{1995} / Y_{1995}	Naive	Harberger	Quasi-Harberger	Profit Max.	Regr. I.	Regr. II.	Own estimation
Bulgaria	1.47	-2.77	0.18	0.93	1.45	1.50	1.47
Czech Rep.	1.81	2.21	2.19	1.91	1.89	2.24	2.04
Estonia	1.96	1.95	1.22	5.49	1.25	1.42	1.56
Hungary	1.69	2.10	1.50	2.66	2.34	1.84	1.78
Latvia	1.69	1.30	0.64	0.78	1.69	1.57	1.56
Lithuania	1.25	0.95	0.62	1.71	0.78	1.09	1.35
Poland	1.48	1.44	1.24	1.86	1.88	1.53	1.57
Romania	1.52	1.64	1.39	1.76	1.82	1.84	1.66
Slovak Rep.	1.66	1.85	1.77	1.98	1.77	1.51	1.76
Slovenia	2.24	2.29	1.65	3.26	2.48	1.86	2.01

Notes: Calculations are performed with $\delta=0.1$. Rounded data. 'Own estimation': arithmetic average of the gray fields.

Examining table 1, we can determine that the capital-output ratios calculated with the individual methods disperse throughout a wide range for each country. This observation remains true even when we concentrate only on those values, which appear to be realistic. These values are colored gray in table 1. There are two reasons for the inconsistent results: the initial assumptions of the analytical methods are not fully realized, and the methodological difficulties in the regressions can only be partially addressed. Therefore, each method provides an imperfect approximation for the capital stock. Unfortunately, we cannot set up an unambiguous order of preferences for the different methods because each method has its own deficiency. Therefore, as a golden mean, we work with the arithmetic average of the realistic (i.e., gray-colored) values. This average is our own estimation of the K_{1995} / Y_{1995} ratio. Although we have no methodological argument for relying on the average, the calculated capital-output ratios are quite reasonable and consistent with those of previous studies.⁶

We base the calculation of the physical capital stock and the calculation of the growth theory approach of Q^H on some severe restrictions. As regards to the former, we set the depreciation rate to 10 percent and proceed from an initial capital-output ratio, which is derived as the average of the ratios calculated by the relevant methods. As regards to the latter, Q^H is calculated according to the quality-adjusted years of schooling and according to the rates of returns to education found in Psacharopoulos (1994). Consequently, we perform the sensitivity analyses of the basic growth accounting and development accounting results with respect to the depreciation rate, to the initial capital-output ratio, to the adjustment of the years of schooling to the quality of the educational system and to the rates of return to education. The conclusion of the sensitivity analyses is, that the concrete contribution of the individual production factors to the growth rate and to the relative development are sensitive to the assumptions utilized in the calculation of the physical capital stock, but are not sensitive to the calculation of the growth theory approach of Q^H . However, thesis 1 and thesis 2 still hold in each sensitivity scenario.

⁶ Doyle et al. (2001), IMF (2003, 2008, 2010), Jongen (2004), Pula (2003), Rööm (2001), Vanags and Bems (2005)

Thesis 3.

The speed of convergence (λ) calculated from the beta-regression is not the instant, but the average speed of convergence ($\bar{\lambda}$). The formula for the speed of convergence averaged over the period $[0,t]$ is :

$$(3) \quad \bar{\lambda} = - \frac{\int_0^t \frac{d(\ln \hat{y}_\tau - \ln \hat{y}^*) / d\tau}{\ln \hat{y}_\tau - \ln \hat{y}^*} d\tau}{t} = - \frac{\left[\ln \left| \ln \frac{\hat{y}_\tau}{\hat{y}^*} \right| \right]_0^t}{t} = - \frac{\ln |\ln Y_t| - \ln |\ln Y_0|}{t},$$

where $\hat{y} = Y / AL$, A is technology, the asterisk denotes the steady-state value and $Y_t = \hat{y}_t / \hat{y}^*$ is the relative income position. (Dedák-Dombi, 2009)

The speed at which a stationary $\ln \hat{y}_t$ variable converges to its balanced growth path (BGP) value ($\ln \hat{y}^*$) is by definition $\lambda_t = -(d \ln \hat{y}_t / dt) / (\ln \hat{y}_t - \ln \hat{y}^*)$. This formula is a first-order differential equation in $\ln \hat{y}_t$ with a varying coefficient, and its solution is as follows:

$$(4) \quad \ln \hat{y}_t = \beta \ln \hat{y}_0 + (1 - \beta) \ln \hat{y}^*, \text{ where } \beta = e^{-\xi} \text{ and}$$

$$(5) \quad \xi = \int_0^t \lambda_\tau d\tau = \frac{\int_0^t \lambda_\tau d\tau}{t} t = \bar{\lambda} t.$$

Adding an error term to equation (4), we arrive at the beta regression, with which one usually estimates the speed of convergence. The calculation runs indirectly, based on $(-\ln \beta / t)$. The interpretation of the result remains an open question whose solution lies in eq.(5). If the speed of convergence is a constant, that is, $\lambda_\tau = \lambda$, then $(-\ln \beta / t)$ equals the constant, instantaneous speed of convergence. On the contrary, if the speed of convergence is not a constant, then $(-\ln \beta / t)$ equals the average speed of convergence over the $[0,t]$ period. The related empirical works arrive at eq.(4) exclusively by the log-linear approximation of the Solow model around the steady-state. Therefore, in their interpretation, $(-\ln \beta / t)$ is the constant, instantaneous speed of convergence (see, e.g., Caselli et al., 1996; Hauk and Wacziarg, 2009; Islam, 1995; Mankiw et al., 1992).⁷ However, the speed at which an economy converges to its BGP varies over time and across economies under both the neoclassical model (Temple and Mathunjwa, 2006) and endogenous models (see, e.g., Eicher and Turnovsky, 2001; Steger, 2007). Therefore, what we calculate from the beta regression is not the instant but the average speed of convergence.

The formula for the speed of convergence averaged over the period $[0,t]$ (eq.3) can be derived easily by substituting the expression for the instant speed of convergence into eq.(5). Note, that eq.(3) is a general expression, which is not model specific. The underlying growth model enters the formula only through the assumed evolution of the relative income position. Assume that the

⁷ It is well-known that by log-linearizing the equation of motion of the Solow model around the steady-state we arrive at the notorious formula of the speed of convergence near the balanced growth path: $\lambda = (1 - \alpha)(n + g + \delta)$. Note, that the latter is constant.

production function takes the following Cobb-Douglas form: $Y = K^\alpha (AL)^{1-\alpha}$, where $0 < \alpha < 1$. Then in the neoclassical case, the time path of the relative income position is as follows:

$$(6) \quad Y_t = \frac{\hat{y}_t}{\hat{y}^*} = \left[(1 - e^{-t(1-\alpha)(n+g+\delta)}) + Y_0^{\frac{1-\alpha}{\alpha}} e^{-t(1-\alpha)(n+g+\delta)} \right]^{\frac{\alpha}{1-\alpha}},$$

where n is the growth rate of labor and g is the growth rate of technology. Calibrating the parameters in eq.(6), we are able to calculate the average speed of convergence according to eq.(3) and eq.(6) in terms of the Solow model.

In table 2, we present calculations of the average speed of the neoclassical convergence at different parameter values considered to be reasonable for the CEE economies. We set $t=12$ in accordance with the investigated period. The share of physical capital (α) is calibrated to 0.425, 0.45 and 0.475. This magnitude is in line with the regression results and with the statistics on the CEE economies. The value of $(n + g + \delta)$ is set to 0.07, 0.08, 0.09 and 0.1, which corresponds to the benchmark values of n (0-0.01), g (0.02) and δ (0.05-0.07). The initial relative income position is set between 0.3 and 0.7.

Table 2. The average speed of the neoclassical convergence

t=12	α	0.425				0.45				0.475			
	n+g+ δ	0.07	0.08	0.09	0.1	0.07	0.08	0.09	0.1	0.07	0.08	0.09	0.1
Y_0	0.3	0.072	0.080	0.088	0.096	0.066	0.074	0.081	0.089	0.061	0.068	0.075	0.082
	0.4	0.064	0.071	0.079	0.086	0.059	0.066	0.073	0.080	0.054	0.061	0.068	0.075
	0.5	0.057	0.065	0.072	0.079	0.053	0.060	0.067	0.074	0.050	0.056	0.063	0.069
	0.6	0.053	0.059	0.066	0.073	0.049	0.056	0.062	0.068	0.046	0.052	0.058	0.064
	0.7	0.049	0.055	0.062	0.068	0.046	0.052	0.058	0.064	0.043	0.049	0.055	0.061

Note: Own calculations according to equations (3) and (6).

Assuming that the parameter calibration in table 2 delineates a reasonable range for Y_0 , α and $(n+g+\delta)$ for the CEE economies, we can conclude that according to the theory the average speed of the neoclassical converge was between 4.3 and 9.6 percentage points in these countries over the time period of 1995 to 2007. This range is far too wide, therefore we attempt to reach a more precise range by estimating the beta regression (eq.(4)) on the panel of the CEE countries.

According to our OLS estimations, the average speed of the neoclassical convergence was in the range of 5.7 and 7.2 percent in the CEE countries between 1995 and 2007 (chapter 3). These estimation results are supported by the auxiliary statistics of the regressions, the sensitivity analyses and the Monte Carlo simulations as well. Moreover, the improvements in the applied methodology with regard to the estimation of the beta regression render our results not just well funded, but even better funded than those found in other papers. Specifically, we treated the technology level properly in the beta regression and addressed the issue of finding the proper proxy for the unobservable steady-state output per effective labor (\hat{y}^*).

The results of growth accounting and development accounting and the estimation of the speed of neoclassical convergence are consistent with each other and provide the following story about the post-transformation pre-crisis growth path of the CEE economies:

1. Concerning the production factors, the gap compared to Germany was highest in the stock of physical capital.
2. The low relative capital intensity made the rapid accumulation of physical capital possible.
3. The rapid accumulation of physical capital induced robust economic growth and fast neoclassical convergence.

Thesis 4.

If third-generation idea-based growth models incorporate inter-firm knowledge spillovers into the R&D process, their predictions become inconsistent with the empirical observations. This calls severely in question the relevance of third generation idea-based growth models. (Dombi, 2013c)

The effect of population size on steady-state output per capita growth is a long debated issue in endogenous growth theory. Idea-based growth models, which consider technological change as an outcome of the entrepreneurs' innovative activity, can be ordered into free strata according to their related predictions. In order to highlight the distinguishing features of the three strata of idea-based growth models, assume that the firm-level technology production function (R&D function) is as follows:

$$(7) \quad \dot{A}_i = L_{A,i} A_i^\phi, \text{ where } i \text{ is the index for firm } i \text{ and } L_{A,i} \text{ is labor (i.e. the number of researchers).}$$

In the first-generation models of Romer (1990) and Aghion and Howitt (1992) population size positively affects the steady-state growth rate of the economy, thus there is a *scale-effect*. The underlying intuition comes from the non-rival nature of technology according to which innovation costs can be incurred only once and, that after success, the discovered new idea can be used for the production of infinite units. Because technology is partly exclusive, as well, the innovator earns a certain monopoly mark-up on each unit of product. Therefore, when a successful innovator is able to sell more products, its aggregate profit will be greater, spreading to a greater extent the usually high innovation costs. However, the demand for the innovator's product is ultimately determined by the size or, put differently, the scale of its market. Therefore, the larger scale of the market implies greater incentives for R&D. From that point into the future, the form of the technology production function alone determines whether the resulting larger firm-level R&D inputs ($L_{A,i}$) increase the rate of technological advance in the long run.

In first-generation models, the relevant scale of the market for a firm is identified with the population size. According to the factors mentioned above, this association leads to higher returns on R&D when population is larger and thus to larger firm-level R&D intensity as well. Larger firm-level R&D intensity leads to faster steady-state growth in technology and in output per capita, because the technology function is characterized by perfect intertemporal knowledge spillovers ($\phi = 1$). Consequently, economic growth explodes in first-generation models in case of growing population, which contradicts the empirics.

The second-generation idea-based growth models of Jones (1995) and Segerstrom (1998) eliminate the scale effect by assuming imperfect knowledge spillovers in the R&D process ($0 < \phi < 1$). Although these models continue to link the scale of the market for a given firm to the population size, the change in the ϕ parameter cancels any relationship between the population size and the long run growth rate.⁸ To show the latter, divide both sides of eq.(7) by A_i and take the logs and the time-derivatives: $\dot{g}_i/g_i = n - (1 - \phi)g_i$. The latter formula is a stable differential equation; therefore, the steady-state growth rate of technology is

$$(8) \quad g_i^* = n / (1 - \phi).$$

⁸ 'Long run growth rate/economic growth' and 'steady-state growth rate/economic growth' are synonymous.

According to eq.(8), steady-state growth is semi-endogenous because its determinants, that is the population growth rate and the knowledge spillover parameter (n, ϕ), are generally regarded as being exogenous to economic policy in the short run. Another important feature of second-generation models is that steady-state growth is zero in the absence of population growth (i.e. $n = 0$).

Third-generation idea-based growth models preserve the perfect intertemporal spillovers in the firm-level technology function ($\phi=1$), but they completely separate the scale of the market from the size of the population thereby eliminating the scale effect (Aghion-Howitt, 1998; Dinopoulos-Thompson, 1998; Peretto, 1998). The main idea is the incorporation of the entry of new firms. In these models entry perfectly dilutes the positive effect of the population rise on the size of the market for the representative firm. For this reason, the decision of the representative firm with regard to R&D is not influenced by any change in the population, contrary to the case of the first- and second-generation models. Firms continue to employ the same number of researchers, even in the presence of population growth, which keeps the rate of technological advance constant.

The debate on the scale effect (i.e., the positive affect of population size on long run growth) appears to have been settled recently, thanks to empirical observations that are more in line with the predictions of third-generation models than with the predictions of the second-generation models (Laincz-Peretto, 2006; Ha-Howitt, 2007). However, third-generation models use a fragile framework because they severely restrict the knowledge spillover space by omitting the inter-firm knowledge spillovers (Dombi, 2013c). This restriction is a crucial component of the elimination of the scale effect. There are two types of potential inter-firm knowledge spillovers: intertemporal spillovers and contemporary spillovers. The former corresponds to Romer's (1990) original concept of "standing on each other's shoulders" in R&D, that is, the concept of benefiting from the accumulated technology and thus from the past research efforts of other firms. Contemporary spillovers are productivity gains in the R&D process originating from other firms' current research effort. The presence of these spillovers can result in explosive growth as their potential sources grow parallel to the number of firms. To realize the latter, consider the following firm-level technology function augmented with the inter-firm knowledge spillovers:

$$(9) \quad \dot{A}_i = L_{A,i} A_i^\phi (N\bar{A})^\eta (N\bar{L}_A)^\mu ; \quad \phi, \eta, \mu \geq 0 ; \quad N, \bar{L}_A, \bar{A} > 0;$$

where N is the number of firms – except firm i –, \bar{A} is the average technology level of the other firms, η is the intertemporal spillover parameter (i.e. the intensity of "standing on others' shoulders"), \bar{L}_A is the average R&D employment of the other firms and μ is the measure for contemporary spillovers.

We can conclude from eq.(9) that if $\phi = 1$ and $\eta > 0$, the intensity of "standing on its own and the others' shoulders" is large enough to lead to accelerating technology growth. This parameter setting implies that if the number of firms grows parallel to the population, scale-effect is present. In third-generation models, the two knife-edge conditions of $\eta=0$ and $\mu=0$ entail that externalities are absent in R&D. This assumption would be true only if firms involved in similar technologies were totally separated from each other, which is not the case in the context of globalization. The empirical literature also underpins the presence of inter-firm knowledge spillovers (see, e.g., Varga, 2009).

The knife-edge conditions and the consequences of their relaxation call into question the relevance of third generation idea-based growth models. This means that the debate between the second and the third generation models is not over yet. Scale-effect is still on agenda (Dombi,

2013c). Thus we cannot draw any strict conclusion on the ‘population – economic growth’ relationship according to idea-based growth models.

Although the scrutiny of idea-based growth models suggests that population growth might be crucial for positive steady-state growth, the demographic processes of the CEE countries are probably not relevant from this point of view since the predictions of idea-based growth models are more adequate for large countries – or regions – than for small, open ones. Consequently, we can conclude, that neither the neoclassical growth model nor the endogenous idea-based growth models alarm against the demographic catastrophe toward which some CEE countries are approaching.⁹ However, this does not mean that decreasing population cannot harm economic growth in the long run. As the share of working age population diminishes due to the ageing of population, both the investment rate and the saving rate are expected to decrease because of the probable rise of taxes and the lower saving propensity of the elderly. The latter induces slower capital accumulation and hence slower technology development at the same time. Consequently, there is an indirect negative feedback from population decrease to steady-state growth (output).

⁹ In the neoclassical Solow model, the steady-state output per capita increases with the decrease of the population.

List of variables (data source)

A : technology level (own calculation)

δ : depreciation rate (calibration)

E : employment (Eurostat)

g : growth rate of technology (calculation according to A)

H : total number of hours worked in the economy (TED)

h : human capital (own calculation)

K : aggregate capital stock (own calculation)

K' : physical capital input / service of physical capital

L : labor / labor input

$L_{A,i}$: the number of researchers at firm i

MFP : multifactor productivity (own calculation)

n : growth rate of labor force/population (PWT 6.3)

Q^H : efficiency multiplier of labor (own calculation)

Q^K : efficiency multiplier of capital (own calculation)

r : return to schooling (calibration)

$s_{K'}$: share of physical capital ($1 - s_L$)

s_L : labor share (AMECO)

sy : average years of schooling for the labor force (Barro and Lee (2010) database)

sy_{adj} : quality-adjusted years of schooling (own calculation)

Y : output, real GDP at PPP (PWT 6.3)

y : real GDP per capita at PPP (rgdpl, PWT 6.3)

λ_t : instantaneous speed of convergence

$\bar{\lambda}$: average speed of convergence

\hat{y} : output per effective labor $\hat{y} = Y / (AL)$

Υ : relative income position ($\Upsilon_t = \hat{y}_t / \hat{y}^*$)

* : steady-state value of the respective variable

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