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Augmented Solow Model with Mincerian Education and Transport Infrastructure Externalities

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Abstract According to Crescezni and Rodríguez-Pose (2008) backward European states and regions should follow balanced strategies in which infrastructure development is coordinated with policies aimed at developing human capital and the innovative potential of regions. In order to assess their postulates we extend the analysis of Carstensen et al. (2009) further augmenting the neoclassical Solow Model to incorporate Mincerian schooling externalities and infrastructure externalities in a single theoretical framework. Infrastructure is introduced into the model in a manner similar to exogenous Hicks-neutral technological change, raising the overall efficiency of an economy. The theoretical model has been empirically tested for a panel of European economies in the period 1999–2010. Econometric estimates for a balanced panel data model bring interesting results. The overall fit of the model is considerable. In accordance with our expectations, the macroeconomic returns to human capital accumulation and infrastructure are positive and statistically significant for a full sample of countries. Externalities are stronger for CEE transition economies than for non-CEE countries. The infrastructure externality is positive and statistically significant for CEE states only when we control for the level of openness of an economy. Results obtained are robust when taken with the modifications of the baseline empirical model.

Keywords Economic growth, human capital, transport infrastructure, augmented neoclassical growth model, Mincerian schooling
JEL classification O41, H52, H54, C21, C23

1. Introduction

In a recent paper Crescenzi and Rodríguez-Pose (2008) point out in their policy implications that investment in transport infrastructure has to be efficiently coordinated with policies aimed at developing human capital and the innovative potential of regions (states) in order to efficiently stimulate economic development. This calls for implementation of balanced strategies which could maximize overall effects. This recommendation is of particular importance for EU Member States in Central and Eastern Europe (henceforth CEE) where the majority of structural funds are being spent on infrastructure projects and at the same time the allocation of funds to human capital accumulation is largely inefficient.

Using the framework of the augmented Solow model, we derive a specification that

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identifies an education externality as well as transport infrastructure externality within a single production function framework. We thus extend the analysis of Carstensen et al. (2009) which focuses on identifying the magnitude of macroeconomic return from education.

Infrastructure is frequently defined as a set of basic physical and organizational structures and facilities required for operation of an economy. It can be divided into (e.g. Wojewodzka-Krol and Rolbecki 2008): economic infrastructure (transport, telecommunication, energy provision and sewage) and social infrastructure (law enforcement, security provision, education and health system). Transport infrastructure is of particular significance as it affects the geographical distribution of economic activities while infrastructure investments generate significant externalities potentially leading to dynamic (or long-term) effects.

The role of infrastructure in economic growth has been analyzed along two main dimensions: effects on economic growth and effects on income inequality (Calderon and Serven 2004). The analyses are performed at both the national and regional levels. Most studies identify a positive and robust impact of infrastructure on aggregate output. However, in some studies (e.g. ESPON 2005) this impact is found either to be of limited magnitude or to be restricted to specific countries. Some studies find that public expenditure on transport and communications fosters long-term economic growth (e.g. Easterly and Rebelo 1993). However, the inefficiency of infrastructure provisions could reverse the impact (e.g. Ottaviano 2008). The results are hence more or less inconclusive.

At the regional level infrastructure is considered to constitute one of the key determinants of regional development (Brocker and Rietveld 2009). The problem is especially popular in the NEG literature which explicitly models the impact of infrastructure on spatial pattern of growth (e.g. Fujita et al. 2001; Fujita and Thisse 2002; Baldwin et al. 2003).[1] The impact is found to be asymmetric along several dimensions including e.g. the type of region (central or peripheral location, size), the phase of regional development, the type of transport infrastructure (intraregional or interregional, road versus railway network[2]) as well as network effects. The timing of infrastructure projects is of significance.

As Straub (2008) correctly points out, infrastructure can have an impact on economic growth through direct and indirect channels. The direct channel is due to pure productivity effect; the improvement in infrastructure stock raises the productivity of other factors. We have to note that in this case whether productivity-enhancing effects of infrastructure will result in a higher steady-state growth rate or not depends on the assumptions made about the nature of aggregate returns to scale. At the same time Straub (2008) discusses many potential indirect channels of impact including maintenance and private capital durability, adjustment costs, labor productivity, human capital

[1] For instance lower transport costs due to new infrastructure might lead to spatial deglomeration of activity, which in turn might enhance further development of the transport infrastructure and activate human capital which has stayed intact due to restricted labor mobility. However, the exact conditions necessary to that end are still unclear (e.g. Najman and Zaucha 2010).

[2] High speed rail (HSR) projects are said to have severely adverse effects for some regions due to the so-called straw effect (e.g. Ottaviano 2008).

channel, and economies of scale and scope.

The temporal dimension of potential effects of infrastructure projects has to be stressed. In the short run, aggregate demand is increased in the investment phase with associated negative fiscal effect depending on the particular financing scheme. In the long-run, the impact on the overall productivity will likely dominate with the associated adjustments in the organization and location of economic activity.[3]

In our approach we account for direct productivity effect only. We assume the infrastructure to have a general impact on the efficiency of an economic system. Its impact is as a result similar to exogenous Hicks-neutral technological progress. Assumption of constant returns to scale at aggregate level leads to a situation in which the infrastructure has an impact on the level of steady-state income per capita but not on the long-run growth rate. The long-run growth-rate in our model is positive and equal to the growth rate of technology which is assumed to be Harrod-neutral or labor-augmenting.

At the same time, there is a strong theoretical and empirical support for the positive impact of human capital accumulation on economic growth. According to Acemoglu (2009) human capital represents the stocks of skills, education, competencies and other productivity-enhancing characteristics embedded in labor.[4] Modern growth theory puts a great deal of emphasis on the role of human capital in explaining the observed variation in economic development levels—this applies both to augmented neoclassical growth models (e.g. Mankiw et al. 1992) as well as one-sector and multi-sector endogenous growth models (e.g. Lucas 1988).

In our model we exploit the so-called Mincerian approach to human capital accumulation. The approach attributed to Mincer (1974) gives a wage equation where the logarithm of hourly earnings is explained by schooling years, labor-market experience, and experience squared. The approach puts emphasis on education and learning-by-doing as two key factors in accumulation of human capital.

We expect the impact of infrastructure and human capital accumulation on the level of real income per capita, to be positive and statistically significant both for advanced market economies of Western Europe as well as the less developed transition CEE. We expect at the same time the macroeconomic returns to investment in infrastructure and human capital accumulation to be higher at least for the time being for converging CEE economies.

The remainder of this paper is organized as follows. Section 2 presents the theoretical model. The empirical model is developed and the utilized data are developed and described in Section 3. Empirical results are presented and discussed in Section 4. The final section concludes and discusses some important research and policy implications.

[3] Please refer to Lakshamanan and Chatterje (2005) for an extended overview of effects.

[4] These could include health status of soft hard-to-measure determinants such as enthusiasm or entrepreneurship.

2. Theoretical model

We start with a simple Cobb-Douglas production function with physical capital K and labor L as the two basic inputs. We assume the labor input to be conditioned for the average level of education. In order to simplify notation, we drop the notation i for countries/regions. The general production function is given by:

$$Y = I^{\gamma} K^{\alpha} (B_L)^{1-\alpha}, \tag{1}$$

where Y is the aggregate output of country/region, B an index of the level of technology that is exogenous to individual firms within countries, I is an index of the quality of infrastructure that is also exogenous to individual firms, K the stock of aggregate physical capital, and L the labor force. Infrastructure externality could be positive, negative or neutral. Thus we do not set any restrictions on parameter γ. The general production function shows constant returns to scale as long as we treat infrastructure as a simple, exogenous efficiency-adjusting parameter.

Accumulation of human capital through education system generates an externality given by:

$$B = Ah^{\lambda}, \tag{2}$$

where h the average level of education and λ represents educational externality. A is a country-specific technology that grows exponentially over time at an exogenous and positive rate g common to all the countries/regions. Technology is labor-augmenting (of Harrod-neutral type). In other words we allow for heterogeneity of countries along technological sophistication due to the initial level of technology as given by $A(0)$.

$$A = A(0)\, e^{gt}, \tag{3}$$

where g is some positive constant.

In accordance with Mincerian tradition the average level of education may be specified as a function of average schooling years and average years of experience (Bils and Klenow 2000).[5] For simplicity we omit the potential non-linear impact of experience. Accordingly:

$$h = \mu e^{\beta AYS + \chi AYE}, \tag{4}$$

where μ is a positive constant, AYS gives average years of schooling and AYE represents average years of working experience in a given country/region. Parameters β and χ represent average individual private returns to schooling and experience respectively.

Substituting (2) and (4) into (1) and dividing both sides by L we obtain the formula for real income per capita y:

$$y = I^{\gamma} K^{\alpha} \left(Ah^{\lambda}\right)^{1-\alpha} L^{-\alpha} \tag{5}$$

[5] In another paper we develop a similar model adopting a typical augmented neoclassical model (Mankiw et al. 1992) which incorporates a separate low of motion for human capital per effective unit of labor introduced in a similar manner to accumulation of physical capital. The model has a unique and globally-stable steady-state equilibrium affected by the exogenously given infrastructure endowment. Here for clarity we utilized a simple Mincerian approach.

Following the tradition in neoclassical growth literature we introduce the level of output per effective unit of labor ($\tilde{y} \equiv Y/AL$) and stock of capital per effective unit of labor $\left(\tilde{k} \equiv K/AL\right)$.

We know that by definition the growth rate of income per capita is equal to the growth rate of income per effective unit of labor, plus the rate of growth of technology g:

Dividing (5) by A and using the definition of stock of capital per effective unit of labor, we obtain the formula for income per effective unit of labor as given by:

$$\tilde{y} = I^{\gamma}\tilde{k}^{\alpha}h^{(1-\alpha)\lambda} = I^{\gamma}\tilde{k}^{\alpha}\left(\mu e^{\beta AYS+\chi AYE}\right)^{(1-\alpha)\lambda} \tag{6}$$

Adopting the Solowian rule of physical capital accumulation (the so-called perpetual inventory method) as well as assuming that a constant fraction of output s is saved and invested ($s > 0$) and a constant fraction of physical capital δ decays every period ($\delta > 0$), it follows that an increase in the stock of physical capital is given by

$$\dot{K}_t = sY - \delta K_t. \tag{7}$$

From the chain rule of differentiation we can show that evolution of capital per effective unit of labor over time is governed by:

$$\dot{\tilde{k}} = s\tilde{y} - \tilde{k}\left(g+n+\delta\right), \tag{8}$$

where n is the exogenous rate of population growth.

Substituting (6) into (8) we can show that

$$\dot{\tilde{k}} = sI^{\gamma}\tilde{k}^{\alpha}h^{(1-\alpha)\lambda} - \tilde{k}\left(g+n+\delta\right). \tag{9}$$

Dividing both sides by $\tilde{k}$ we obtain the growth rate of income per effective unit of labor

$$g_{\tilde{k}} = sI^{\gamma}\tilde{k}^{\alpha-1}h^{(1-\alpha)\lambda} - \left(g+n+\delta\right). \tag{10}$$

In the steady state, the rate of growth of capital per effective unit of labor must be equal to zero. Setting (10) to zero we can solve for steady-state level of capital per effective unit of labor. It is given by

$$\tilde{k}^{*} = I^{\frac{\gamma}{1-\alpha}}h^{\lambda}\left(\frac{s}{g+n+\delta}\right)^{\frac{1}{1-\alpha}}. \tag{11}$$

The steady state level of capital per effective unit of labor is a function of exogenous parameters of the model as well as of infrastructure index I and endowment of human capital h.

We know that the steady-state level of capital per effective unit of labor implies a given level of income per effective unit of labor in the steady-state. Consequently plugging (11) into (6) we obtain:

$$\tilde{y}^{*} = I^{\frac{\gamma}{1-\alpha}}h^{\lambda}\left(\frac{s}{g+n+\delta}\right)^{\frac{\alpha}{1-\alpha}} \tag{12}$$

From definition of income per effective unit of labor we know that the steady-state level of income per capita is equal to steady-state level of income per effective unit of labor times the level of technology. Taking account of it we obtain the level of income per capita in the steady state as given by

$$y^* = AI^{\frac{\gamma}{1-\alpha}} \left(\mu e^{\beta AYS + \chi AYE}\right)^{\lambda} \left(\frac{s}{g+n+\delta}\right)^{\frac{\alpha}{1-\alpha}}. \tag{13}$$

Finally taking logs of both sides we obtain the crucial structural equation of the model:

$$\ln y^* = \ln A + \frac{\gamma}{1-\alpha}\ln I + \lambda \ln \mu + \lambda\left(\beta AYS + \chi AYE\right) + \frac{\alpha}{1-\alpha}\ln\left(\frac{s}{g+n+\delta}\right) \tag{14}$$

Knowing that α is positive but smaller than 1, it can be easily shown that the only rate of growth of capital per effective unit of labor in the equilibrium consistent with the steady-state criterion is exactly equal to zero. However, income per capita in the steady-state grows at a positive rate equal to the rate of labor-augmenting technological progress g.

3. Empirical model and data

Assuming the actual level of GDP per capita to be close to the steady-state level, we are going to estimate a panel data version of the empirical model with individual effects for countries in order to take into account unobserved country-specific factors and potential bias in the data. The above assumption seems to be pretty strong, and suitable only for a group of advanced economies only. It seems, however, that transitional economies of Central and Eastern Europe converge at an accelerated pace to the mean of the group, consequently closing the initial developmental gap.[6]

Starting from the afore-developed structural equation (14), assuming that $\lambda \ln \mu = const$, allowing for differences in technology to be given by A_i and knowing the average investment rate $\overline{s}_i$ and average population growth rate $\overline{n}_i$ we can show that:

$$\begin{aligned} \ln y_i \quad = \quad & const + \ln A_i + \frac{\gamma}{1-\alpha}\ln I_i + \lambda\left(\beta AYS_i + \chi AYE_i\right) + \\ & + \frac{\alpha}{1-\alpha}\ln\left(\frac{\overline{s}_i}{g+\overline{n}_i+\delta}\right) + \varepsilon_i, \quad i = 1,\ldots,N \end{aligned} \tag{15}$$

Equation (15) predicts that the coefficient on the investment share equals in absolute value the coefficient on labor force growth (conditioned by g and δ). For a typical capital share α in income of one-third as suggested by proponents of neoclassical growth theory, the size of this coefficient is predicted to be exactly 0.5. We are nonetheless not going to impose any restrictions on its size.

[6] From a global perspective Europe constitutes a roughly homogenous group of states potentially sharing a common steady-state level of income per capita.

The panel data version of the empirical model with individual effects for countries takes the following form:[7]

$$
\begin{aligned}
\ln y_{i,t} \quad = \quad & const + \ln A_{i,t} + \frac{\gamma}{1-\alpha} \ln I_{i,t} + \lambda \left(\beta AYS_{i,t} + \chi AYE_{i,t} \right) + \\
& + \frac{\alpha}{1-\alpha} \ln \left(\frac{\bar{s}_{i,t}}{g + \bar{n}_{i,t} + \delta} \right) + \eta_i + u_{i,t}, \quad i = 1, \ldots, N, \; t = 1, \ldots, T
\end{aligned} \tag{16}
$$

As can be seen from the empirical equation above, fixed individual effects seem to be our preferred choice; however, in the estimation we are not going to assume fixed effects a priori, but we will perform a standard Hausman test which gives a generally accepted way of choosing between fixed (FE) and random effects (RE).[8] The null hypothesis of the test states that the RE estimator is consistent and thus outperforms FE estimator.

From the estimates of the coefficient on $\ln(s/(g+n+\delta))$ we will be able to calculate the implied value of α. We expect it to be close to one-third. Knowing α and the coefficient on the infrastructure index will allow us to calculate the implied value of γ. We expect it to be positive and in the range of 0 to 10 percent. We will obtain implied macroeconomic return on education λ directly from the coefficient on the fourth term on the RHS of the estimated empirical equation. We expect λ to be positive and statistically significant.

In line with the related empirical growth literature, we assume a constant rate of labor-augmenting technological progress $g = 0.02$ and a constant decay of physical capital $\delta = 0.03$. Thus $g + \delta = 0.05$. In accordance with the theoretical model we allow for variation in the level of technological sophistication of countries/regions. A large number of variables have been suggested in the literature as proxies for international differences in technology including continental dummy-variables in heterogeneous global samples. As we are dealing with a continental sample of European countries the use of continental dummies is not feasible. We have decided to utilize a measure of institutional quality instead. This is the rule of law index (*ROL*) calculated on a yearly basis by World Bank (Kaufman et al. 2010). As it could be considered by some as an inadequate proxy for technological sophistication we also utilize a more standard variable—log of patent applications per 1 million population as provided by the United States Patent and Trademark Office (*USPTO*).[9] The rule of law index in these specifications will approximate institutional quality.

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[7] The regionalized version of the model would have to take into account the modifiable area unit problem (MAUP). A recent paper by Resende (2009) clearly shows that growth models applied to the regional level have to take into account agglomerative processes and potential spatial autocorrelations between bordering regions. Different spatial interaction models can be considered such as SAR/SEM, SMA or SEC. The choice of optima spatial weighting matrix requires the use of sophisticated spatial econometrics techniques.

[8] The fixed effect estimation assumes to some extent that human capital and infrastructure stock are exogenous while they might in fact be endogenous. In other words, advanced countries could have better education systems, better institutions in general, and superior infrastructure than less developed economies. The use of more sophisticated estimation methods such as system GMM could take out potential bias.

[9] Due to inadequate data availability we did not utilize a preferred database from the European Patent Office (EPO).

We do not adjust schooling years for differences in schooling quality which could potentially bias our results. In order to obtain implied macroeconomic return from human capital accumulation (λ) similarly to Carstensen et al. (2009), we impose restrictions on private returns to schooling, thus setting $\beta = 0.1$ and private return on experience $\chi = 0.03$. The assumed values are based on the results of microeconometric research. In reality the values of parameters vary between states at different level of development and across time. Lacking desired estimates even for a relatively homogenous group of European states we make this strong simplifying assumption.[10]

In order to obtain average years of experience (*AYE*), we follow Mincer and calculate it as an average age of the cohort (ages 15 to 65) minus the average years of schooling and further deduce 6 years (presumed age of entry into education system). The data on population come from EUROSTAT.

The empirical analysis is carried out for a group of 32 European countries (EU-27 as well as Iceland, Norway, Switzerland, Croatia, Macedonia and Turkey) within the period 1999 to 2009. We utilize several data sources. The majority of data comes from Penn World Tables Mark 7.0 provided by Heston et al. (2011). These are supplemented by data on human capital accumulation from a recent Barro-Lee data-set (Barro and Lee 2010). EUROSTAT data have been utilized in construction of several infrastructure-related variables as well as the calculation of average years of experience, which has been already mentioned. Institutional quality data have been taken from World Bank study by Kaufmann et al. (2010). Our explained variable will be real GDP per capita as provided by PWT 7.0 which is given in constant USD.

Construction of the crucial infrastructure quality index measuring overall quality of infrastructure is based on the methodology proposed by Careijo et al. (2006). The index of corrected infrastructure quality *CIIQ* relativizes the infrastructure endowment by taking into account both population size and land area and compares it to a benchmark. In the case of the present study we treat the EU-27 mean as a benchmark. This, at least to some extent, takes out the impact of observed heterogeneity in sizes and populations of states/regions. *CIIQ* is calculated according to the following formula:

$$CIIQ_r = \left(\frac{\frac{X_r}{N_r}}{\frac{X_{EU}}{N_{EU}}}\right)^{0.5}\left(\frac{\frac{X_r}{S_r}}{\frac{X_{EU}}{S_{EU}}}\right)^{0.5}, \tag{17}$$

where X_r and X_{EU} gives the infrastructure endowment of a given state and the EU, whereas N and S represents respectively population (in thousands) and land area (in squared kilometres). We consider two types of infrastructure stock as key determinants of an overall accessibility and competitiveness of regions and states: motorway system and railway network.[11] These are key elements shaping international (interregional) accessibility. Indices have been calculated separately for both (*IQM* and *IQR*

[10] Ideally the values of parameters should vary between advanced and converging economies. We lack access to necessary microeconomic cross-sectional studies carried on comparable basis. Still, Psacharopoulos and Patrinos (2004) in their review provide for large variation between countries and between different time periods.

[11] In accordance with the growing NEG literature, if the analysis was conducted at the regional level, it would

respectively) as well as an overall index *CIIQ* has been calculated (as a simple arithmetic mean of two aforementioned indices).[12]

The quality of the proposed index could obviously be questioned by economic geographers or spatial planners who utilize much more elaborate spatial techniques in order to construct regional accessibility indices. We have to first stress that the use of accessibility indices is more suitable for regional than country-level setting and second, the required data are unavailable for our balanced panel.

Apart from variables described above, we will utilize a conditioning set of variables suggested by empirical literature on growth to test the robustness of the obtained results, including a log of openness (*OPEN*) or the size of government (*KG*). All utilized variables are presented together with their summary statistics in Table 1. We have to note, that the exploitation of different data sources, despite of their standard use in the empirical growth literature, could potentially bias the obtained results.[13] Still, we consider them compatible to each other.

Table 1. Summary statistics

Variable	Data source	Mean	Std.Dev.	Min	Max
$\ln y$	PWT 7.0	9.991	0.58	8.675	11.406
$\beta AYS+\chi AYE$	Based on BL 2010 with restrictions	1.674	0.114	1.199	1.985
ROL	Kaufman et al. 2010	1.081	0.676	−0.634	1.964
IQM	Own calcul. based on EUROSTAT	1.099	1.227	0	6.741
IQR	Own calcul. based on EUROSTAT	0.978	0.892	0	5.195
CIIQ	Own calcul. based on EUROSTAT	1.039	0.896	0	5.222
$\ln(s/(g+n+\delta)$	PWT 7.0	1.436	0.209	0.894	2.016
KG	PWT 7.0	9.448	2.374	4.75	16.682
OPEN	PWT 7.0	4.527	0.421	3.578	5.782
EU	–	0.636	0.482	0	1
CEE	–	0.303	0.46	0	1

Note: 363 observations.

4. Empirical results and discussion

The results of estimation of our empirical model are provided in Table 2. In choosing between fixed and random effects, we used the Hausman test. The null hypothesis was rejected and thus the FE estimator was chosen.

be necessary to discriminate between intraregional and interregional infrastructure (e.g. Ottaviano 2008). Furthermore, potential spatial autocorrelation should be taken into account not mentioning the modifiable area unit problem (MAUP).

[12] The raw data for infrastructure endowment was taken from the EUROSTAT and supplemented in the case of missing data by information provided by national Ministries of Infrastructure.

[13] It has been shown in the empirical literature for instance that the use of different versions of Penn World Tables alone could significantly modify the obtained results.

Table 2. Estimation results for alternative model structures and samples

	M1	M2	M3	M4	M5 (CEE)	M6 (non-CEE)	M7	M8 (CEE)	M9 (non-CEE)
const	5.838	5.81	5.837	5.798	1.96	7.798	6.603	4.441	7.258
	(28.93)***	(28.95)***	(28.37)***	(28.83)***	(4.30)***	(28.83)***	(36.88)***	(8.18)***	(35.00)***
IQM		0.023							
		(2.38)***							
IQR			0.001						
			−0.01						
CIIQ				0.045	0.141	0.041	0.048	0.068	0.045
				(2.35)**	−1.16	(2.52)**	(3.05)***	−0.67	(2.90)**
ROL	0.201	0.2	0.201	0.198	0.204	0.101	0.112	0.181	0.065
	(4.67)***	(4.67)***	(4.62)***	(4.62)***	(3.10)***	(2.15)**	(3.10)***	(3.26)***	−1.4
$\beta AYS+\chi AYE$	1.878	1.876	1.878	1.874	3.883	1.383	1.469	2.46	1.338
	(15.22)***	(15.31)***	(15.17)***	(15.29)***	(13.63)***	(12.30)***	(13.77)***	(7.60)***	(12.14)***
$\ln(s/(g+n+\delta))$	0.589	0.593	0.589	0.591	0.487	0.363	0.494	0.437	0.426
	(13.42)***	(13.60)***	(13.21)***	(13.55)***	(8.20)***	(5.83)***	(13.38)***	(8.68)***	(6.76)***
EU							0.15	0.12	0.099
							(12.13)***	(6.45)***	(3.61)***
Obs.	352	352	352	352	110	242	352	110	242
N	32	32	32	32	10	22	32	10	22
R^2	0.658	0.664	0.658	0.664	0.863	0.482	0.771	0.904	0.512
F-test	204.01	156.66	152.53	156.58	151.65	50.39	212.62	180.86	45.17
Hausman test	45.17	42.02	42.01	35.01	#	16.35	119.7	48.17	15.04
Implied α	0.371	0.372	0.371	0.371	0.328	0.266	0.331	0.304	0.299
Implied λ	1.878	1.876	1.878	1.874	3.883	1.383	1.469	2.46	1.338
Implied γ	–	0.014	0	0.028	0.095	0.03	0.032	0.047	0.032

Table 2 cont. Estimation results for alternative model structures and samples

	M10	M11	M12 (CEE)	M13 (CEE)	M14 (non-CEE)	M15 (non-CEE)
const	6.205	5.494	3.373	3.551	7.418	6.793
	(29.30)***	(27.89)***	(7.03)***	(8.81)***	(34.07)***	(25.97)***
CIIQ	0.041	0.04	0.107	0.197	0.039	0.037
	(2.22)**	(2.49)***	−1	(2.18)**	(2.47)***	(2.39)**
USPTO	0.033	0.02	0.074	0.048	0.014	0.01
	(4.87)***	(3.29)***	(5.39)***	(3.94)***	(2.12)**	(1.67)*
OPEN		0.426		0.355		0.27
		(10.13)***		(6.40)***		(4.02)***
ROL	0.168	0.164	0.167	0.235	0.087	0.064
	(4.00)***	(4.49)***	(2.85)***	(4.68)***	(1.86)*	−1.39
$\beta AYS+\chi AYE$	1.62	0.961	3.117	1.973	1.281	0.959
	(12.47)***	(7.37)***	(10.81)***	(6.56)***	(10.59)***	(6.76)***
$\ln(s/(g+n+\delta))$	0.557	0.504	0.375	0.376	0.376	0.381
	(12.72)***	(13.11)***	(6.66)***	(7.96)***	(5.84)***	(6.12)***
Obs.	351	351	110	110	241	241
N	32	32	10	10	22	22
R^2	0.688	0.765	0.895	0.927	0.493	0.529
F-test	138.69	170.1	162.52	199.32	41.61	39.83
Hausman test	38.26	98.35	#	#	14.25	18.13
Implied α	0.358	0.335	0.273	0.273	0.273	0.276
Implied λ	1.62	0.961	3.117	1.973	1.281	0.959
Implied γ	0.026	0.027	0.078	0.143	0.028	0.027

Source: Estimation carried out in STATA.11 (xtreg).

Notes: Value of t-statistic in brackets. Significant at 1% ***, 5 % ** , 10% * level. Hausman procedure applied. N – no. of groups (countries). All estimates given with FE estimator. # – negative value of Hausman test due to group-size. FE chosen for direct comparability with other results.

Several different specifications of the model are tested. Model M1 is a simplified version, as it does not include any proxy for infrastructure quality. In models M2 to M4 we investigate different proxies for infrastructure quality: focusing on motorways (*IQM*, M2), railway network (*IQR*, M3) and finally the overall index of infrastructure quality (*CIIQ*, M4) which is variable of our choice. Our baseline specification estimated for the full sample of countries is given in model M4. In models M5 and M6 we split the sample into CEE countries and non-CEE countries. In M7 and the following two specifications, we include an additional dummy variable for membership in the European Union (*EU*). In specifications M10 to M16 we test an extended version of the baseline model incorporating the traditional proxy for technological sophistication as proxied by the number of patent applications in the USPTO per 1 million population (*USPTO*) and retaining rule of law—here representing the overall quality of institutions which could be considered an extra determinant of the quality of the national innovation systems. In specifications M11, M12, M15 we include the level of openness of a country (*OPEN*) which by definition is a ratio of total trade to GDP. Openness is obviously a negative function of the size of an economy. *USPTO* and *OPEN* enter the model in logs.

Overall our empirical model seems to fit the data pretty well. We obtain several important and noteworthy results. First of all, we obtain a statistically significant and positive education externality with a magnitude ranging from 0.96 to 3.88 (the magnitude depending on the sample of countries considered). The estimated externality (λ) is likely to be biased upward, however, we do not control for schooling quality. It is worth pointing out nonetheless that the macroeconomic education externality is significantly higher for the CEE than non-CEE group by nearly three times or nearly two times when we include EU membership dummy. The inclusion of infrastructure externality does not seem to have an impact on the magnitude of the education externality. This is an interesting result as it goes contrary to some arguments in the theoretical literature indicating a two-sided relation between the two. Furthermore, the size of implied education externality is lower when we properly control for the level of technological sophistication (*USPTO*) and when we control for outward orientation of an economy (*OPEN*).

The implied infrastructure externality (γ) is positive and close to 3% in most cases, however, it is not always statistically significant. It is in particular the case in samples restricted to the CEE group (specifications M5 and M8). Taken at face value, this result would suggest that the CEE countries should subsidize human capital accumulation to a larger extent—in most cases infrastructure investments co-financed from EU cohesion policy have become their overriding structural policy objective since accession. The impact for the non-CEE group is clearly positive. But, we have to note that if we control for the level of openness, even in the case of the CEE group, the impact of infrastructure quality becomes statistically significant (M13). This result is quite robust. Infrastructure externality when we control for outward orientation (and indirectly if we control for the size of the economy) becomes positive and is significantly higher for the CEE group (implied γ for the CEE group equal to 0.143 in comparison to 0.027

for the non-CEE group).[14] The size of the infrastructure externality increases when the openness ratio is taken into account. Better accessibility seems to be of particular importance for outward-oriented economies.

It is interesting to note that the impact railway network quality alone (IQR) is not statistically significant (M3). At the same time, the impact of motorway network quality seems to be significant and noteworthy (M2). Still, the overall index of infrastructure quality (CIIQ) seems to be the desired proxy for infrastructure quality as it takes both types of infrastructure into account.

The coefficient on $\ln(s/(g+n+\delta))$ is always statistically significant at 1% level and close to one-half which implies physical capital shares (α) close to one-third as postulated by the neoclassical growth theory (it lays in the range form 0.266 to 0.371).

Rule of law (*ROL*) showing the quality is statistically significant in all specification and has a positive impact on the level of real GDP per capita. However, it's role, as could have been expected, is more important for transition economies of Central and Eastern Europe. Our desired proxy for the level of technological sophistication—patent applications to the USPTO per 1 million inhabitants (*USPTO*)—has a positive and statistically significant impact on the explained variable.

The results are robust to the inclusion of other potential explanatory variables suggested by the literature of the subject such as the size of the government (government spending to GDP, *KG*).[15]

We have to note, however, one important caveat of our results. They may be, at least to some extent, biased due to measurement error in key variables. We have to acknowledge that *CIIQ* is just an imperfect measure of infrastructure quality/endowment. Schooling and experience may be at the same time imperfect proxies for a true measure of educational capital. More effort is therefore required in this field.

5. Conclusions

The aim of the paper was to empirically identify the existence, the sign and magnitude of macroeconomic education and infrastructure-related externalities for a subset of European states. In order to do so we developed an augmented neoclassical growth model incorporating a Mincerian approach to human capital accumulation, as well as assuming infrastructure to have a direct effect on overall productivity of an economic system. We derived a specific structural equation of the theoretical model which, after inclusion of stochastic element, became our empirical model. The panel version of the model was estimated with FE estimator. The initial results are very promising.

Overall, the macroeconomic return to accumulation of human capital through education and experience is statistically significant, robust and positive with estimates of its magnitude similar to other macroeconomic studies. It is worth highlighting, how-

[14] In specifications M12 and M13 we obtained a negative value of the Hausman test due to limited size of the CEE group-size. FE has been nonetheless chosen for the sake of comparability with other specifications of the model. We would like to stress that even if the RE estimator was chosen the coefficients on CIIQ would be of similar magnitude and statistically significant at least at 5% level.

[15] The results, not shown here, can be obtained upon a request.

ever, that educational externality is significantly larger, at least for the time-being, for the CEE group of countries.

The macroeconomic infrastructure externality in accordance with our expectations is positive with a magnitude close to 3%. The impact of infrastructure externality, however, is not statistically significant for Central and Eastern European countries, if we do not control for the level of openness of an economy. Taken at face value, this result could have significant policy implications. Overriding priority should be given to fostering further accumulation of human capital over investments in the transport infrastructure that have been recently emphasized in most of the transition countries. Good quality of basic interregional infrastructure is a fundamental determinant of growth. In order to boost economic growth further, when an economy goes from extensive (resource and efficiency-driven) to intensive (innovation-driven) growth (converges to world technology frontier) phase, requires accelerated accumulation of human capital as well as increasing gross expenditures on R&D. The central role of capital-deepening is replaced by human capital accumulation and knowledge creation (e.g. Aghion and Howitt 2009).

We see several limitations of our analysis. First of all, more microeconometric research is necessary in order to properly discriminate private returns from education in transition and advanced economies. Secondly, our theoretical model should preferably incorporate both direct and indirect effects of infrastructure on economic growth. There are, however, obvious limits to its capacity. We strongly agree with Straub (2008) that modern models of new economic geography could outperform economic growth models in this respect, as they allow for agglomeration effects, non-linear impact of infrastructure development due to reduction of transport costs, and the role of sequencing and infrastructure types (interregional and intraregional). Last but not least, there could be a significant measurement error in key variables which could potentially bias the estimates.

At the same time we see several potential extensions. First of all, more effort has to be given to constructing better indices of infrastructure quality including various types of infrastructure (e.g. ICT infrastructure said to be of prime importance for a knowledge-based economy). The use of more elaborate accessibility indices could bring interesting results. Secondly, the robustness of our results should be further tested on a broader set of countries. Thirdly, our analysis, as was pointed out before, should be carried out on finer levels of spatial agglomerations—preferably NUTS2/NUTS3 regions of the European Union, which would force us to include agglomeration-related aspects.. In this framework, we could include spatial weighting matrices to test potential spatial autocorrelation between bordering regions within panel spatial error/spatial autoregressive models or more elaborate panel spatial autoregressive and spatially autocorrelated models (SARAR) and estimated with dedicated econometric techniques.[16] Last but not least, other potential theoretical frameworks could be utilized including more elaborated multi-sector growth models as well as dynamic NEG models.

[16] Anselin (1988) provides a thorough overview of potential spatial weighting matrices that could be considered in the extended analysis. Different econometric methods are discussed e.g. in Elhorst (2003).

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