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INFRASTRUCTURE IN THE FRAMEWORK OF PRODUCTION FUNCTIONS: EVIDENCE OF EU MEMBER STATES AT THE REGIONAL LEVEL

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Abstract. Infrastructure development is seen as an essential tool for boosting economic growth. Infrastructure is funded under various programs to contribute to economic growth, and reduce regional disparities. Evaluations of the results achieved have to be carried out to develop efficient infrastructure development and investment allocation policy. This is highlighted in both the reports of policymakers and scientific publications. The main limitation of these studies is that they focus on assessing the return on infrastructure development at the national level, leaving the question of what outcomes were achieved at the regional level. This article aims to evaluate the economic outcomes of transport and ICT infrastructure development at the NUTS 2 regional level in the EU-28 countries, using 2000–2019 data. The research is based on the neoclassical production function complementing it with an infrastructure indicator. Based on previous research, it is hypothesized that economic outcomes may depend on the institutional environment of the region. Consequently, the research model specification is supplemented by government quality as a possible moderator. Research findings suggest just motorway and internet infrastructure are significantly positively related to production outcomes. Estimations show higher government quality and less corruption are related to the bigger production output of the infrastructure input.

Keywords: infrastructure, infrastructure development, transport infrastructure, telecommunication infrastructure, production function, economic outcomes.

JEL Classification: O11, O18, R11, R40.

Introduction

Infrastructure is one of the critical drivers of social and economic prosperity, job creation, and inclusive growth (European Commission [EC], n.d.). Core infrastructure covers transport, information and communication (ICT), energy, water and sanitation infrastructure

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(Palei, 2015). According to Global Gateway, the European Commission (EC) plans to invest 135 billion Eur in physical infrastructure over 2021–2027 (EC, 2021). However, a large part of these funds will not be allocated to the development of EU Member States (MS) infrastructure but to developing countries to increase connectivity in remote markets. EU MS infrastructure is funded under various funds. Most direct funding for infrastructure development goes from Cohesion Funds (CF), focusing on road transport networks, rail, public transport, and energy projects (Zachariadis, 2018). Infrastructure funding is also provided through Digital Europe Programme (DEP) and Connecting Europe Facility (CEF). The main aim of CEF is to finance the pivotal cross-border telecommunication, transport, and energy infrastructure links between EU MS (Zachariadis, 2018). According to Zachariadis (2018), the total CEF budget for 2021–2027 is 42.3 billion Eur: 7% would be allocated to the development of digital networks, 21% – to energy, and 72% – to transport infrastructure. In the last period, a lot of investments were also spent on infrastructure development. The question, therefore, arises: whether these investments have the desired effect?

The main aim of the Cohesion Policy is to reduce disparities between EU countries and regions. The DEP and CEF also set these goals. It means that infrastructure development must generate positive outcomes not only at the national but also at the regional level. However, most of the studies investigating infrastructure development outcomes evaluate effects at the national level, leaving the question of infrastructure development outcomes at the regional level. Moreover, there is a lack of research in the EU MS. Over the last five years, many infrastructure impact studies have been carried out in India (Maparu & Mazumder, 2017; Mitra et al., 2016), Sub-Saharian Africa (SSA) countries (Donou-Adonsou et al., 2016; Haftu, 2019), Middle East and North Africa (MENA) countries (Saidi et al., 2018), China (Lin & Chiu, 2018; Yang et al., 2020; Wang et al., 2020a) or cover BRIC (Brazil, Russia, China and South Africa) countries (Apurv & Uzma, 2020; Wang et al., 2020b). These studies reveal that core infrastructure development can positively and negatively impact a country's economic growth depending on countries' conditions, investment intensity, and type of infrastructure. The results of research in EU MS also differ. For example, Cigu, Agheorghiesei, Gavriluta, and Toader (2019) evaluated transport infrastructure impact on GDP per capita in EU-28 using 2000–2014 data and found a significant positive effect. As an independent variable, they used an index of transport infrastructure status. Therefore, these are not apparent effects of different transport infrastructure types (road, railway, etc.). Lenz, Skender, and Mirković (2018) found that in Central and Eastern Europe (CEE) MS road network development has a significant positive effect on GDP, but railways have a negative effect. Chen and Li (2021) conclude that the economic impact of transport infrastructure investments in the West and Central Europe is relatively minor.

Toader, Firtescu, Roman, and Anton (2018) assessed the EU-28 MS ICT infrastructure impact on GDP per capita and found a significant positive effect. The same results were provided by Nair, Pradhan, and Arvin (2020) in the case of 36 OECD countries. The positive relation between infrastructure provision and GDP per capita was also revealed by the European Commission (2014) in the case of EU-28 MS, using 1950–2012 data. Maciulyte-Sniukiene and Butkus (2022) have conducted research covering all main infrastructure types (transport, ICT, energy, water, and sanitation), using 2000–2019 data of EU-28 MS. They found that only pipeline transport infrastructure, electricity production, and mobile cellular networks significantly affect economic growth. Effect of other indicators that proxy infrastructure development was insignificant. The inefficient infrastructure development can be related to government (institutional) quality. Kyriacou, Muinelo-Gallo, and Roca-Sagalés (2019) evaluated transport infrastructure investment economic outcomes in 34 countries (including 23 EU MS) and concluded that they depend on government quality. The same results were obtained by Maciulyte-Sniukiene and Butkus (2022), who found that the institutional environment (less corruption) positively affects the growth outcomes of infrastructure development. But are these results also typical at the regional level? To answer this question, the research aims to contribute to previous studies by evaluating core infrastructure development outcomes at EU-28 MS NUTS 2 regional level, using government quality as a possible moderator.

The rest of this paper is organized as follows. Section 1 provides a theoretical framework for core infrastructure relationships with economic growth. Section 2 presents the research methodology, model specification and data. Section 3 provides and discusses research results. The last section is dedicated to conclusions and policy implications.

1. Theoretical framework on the relationship between core infrastructure development and economic growth

Core infrastructure covers transport, information and communication (ICT), energy, water and sanitation infrastructure (Palei, 2015; Maciulyte-Sniukiene & Butkus, 2022). However, publicly available databases do not provide energy, water, and sanitation data at the NUTS 2 regional level. Therefore, this study focuses on transport and ICT infrastructure and its effects.

Transport infrastructure is an essential driver of economic growth (Wang et al., 2020b). According to EC (2014), transport infrastructure "play a vital role in the integration and efficiency of the EU's internal market". Transport infrastructure development facilitates economic growth through different channels: direct and indirect (Fourie, 2006; Meersman & Nazemzadeh, 2017; Wang et al., 2020a). Direct impact occurs through the increased contribution of the transport sector to GDP by providing more accessible and faster access to input and its cost reduction, which leads to an increase in economic activity (Meersman & Nazemzadeh, 2017). Proper transport infrastructure encourages logistic activities and reduces logistic costs (Oláh et al., 2018). The indirect impact is related to the contribution to other sectors. The developed transport network reduces costs and increases the productivity of other sectors by providing cheaper, faster, and more flexible transport services. Those positive externalities accelerate labour and capital flow and stimulate innovations (Wang et al., 2020a). As Fourie (2006) mentioned, transport infrastructure development also contributes to economic growth by creating jobs in the construction sector.

ICT covers software, hardware, networks, information creation, collection, processing, storage, transmission, and providing (data, text, voice, images) (Toader et al., 2018; Kallal et al., 2021). According to Pradhan, Mallik, and Bagchi (2018), ICT infrastructure includes fixed broadband, mobile networks, internet capability and services, and other technologies. The importance of ICT infrastructure to the economy is growing due to its expanding usage in the manufacturing, service, and public sector. Based on previous literature (Toader et al., 2018; Haftu, 2019; Kallal et al., 2021), few ICT effects on economic growth transmission channels can be distinguished. First of all, ICT infrastructure development directly influences the creation of value-added as ICT goods and services represent a significant share of GDP. In addition, the expansion of ICT infrastructure is increasing the volume of gross capital. ICT's indirect impact is manifested through more accessible information, knowledge, and human capital. This is especially relevant in the light of growing virtual organizations. ICT facilitates productivity and reduces production costs due to better and faster communication processes between companies. Advanced ICT and digital transformations enable access to new resources, products, services, labour markets and new business model creation, leading to increased operational efficiency (Olczyk & Kuc-Czarnecka, 2022). New generation networks (5G) will contribute to manufacturing by strengthening human-to-robot collaboration, creating smart factories, digital performance management, etc. (World Economic Forum, 2020).

Both types of infrastructure development directly affect economic output as production function input. Therefore, most authors investigate the impact of infrastructure development on economic growth based on neoclassic aggregate economic growth models. Authors provide modified Cobb-Douglas functions (see Table 1).

Table 1. Functions used in previous studies to justify infrastructure impact on economic growth (source: composed by the authors based on a literature review)

Author(-s)	Function	Explanation of the abbreviation	Type of infrastructure
Pohjola (2000)	$Y(t)=K_1(t)^{\alpha_1} K_2(t)^{\alpha_2} \ldots K_m(t)^{\alpha_m} * \left[A(t)L(t)\right]^{\left(1-\sum_{i=1}^{m}\alpha_i\right)}$	*Y* – total output, *K* – different type of capital, *L* – labour, *A* – state of technology.	ICT
Canning and Pedroni (2004)	$Y_t = A_t K_t^{\alpha} G_t^{\beta} L_t^{1-\alpha-\beta}$	*Y* – aggregate output, *A* – total factor productivity, *K* – capital, *G* – infrastructure capital, *L* – labour.	Total
Boopen (2006)	$Q_{it} = A_{it} L_{it}^{\beta 1} K_{it}^{\beta 2} G_{it}^{\beta 3} U_{it}$	*Q* – total output, *A* – total factor productivity, *K* – total physical capital, *G* – transportation capital, *L* – labour, *U* – an error term.	Transport
Zhang (2008)	$Y = Af(Kc, Kt, Kg, OK_t, L)$	*Y* – output, *Af* – total factor productivity function, *Kc*- local private-sector capital stock, *Kt* – transport infrastructure capital stock, *Kg* – local other public infrastructure capital stock, *OKt* – external transport infrastructure capital stock, *L* – local labour input.	Transport
Oyeniran and Onikosi-Alliyu (2016)	$Y(t)=A(t) f[K(t), L(t), FDIT(t), GOV(t)]$	*Y* – output, *A* – technology level, *K* – capital, *L* – Labour, *FDIT* – FDI in information and telecommunications, GOV –government investment in information and telecommunication.	ICT

End of Table 1

Author(-s)	Function	Explanation of the abbreviation	Type of infrastructure
Meersman and Nazemzadeh (2017)	$GDPCAP = f(TREND, KCAP, INFCAP, HUM, EMP, INV, POPG, OPEN)$	*GDPCAP* – GDP per capita, *TREND* – a time trend to capture technological change, *KCAP* – capital stoch per capita, *INFCAP* – total transport infrastructure p capita, *HUM* – human capital, *EMP* – employment, *INVGDP* – the rate of investment, *POPG* population growth, *OPEN* – level of openness.	Transport
Saidi et al. (2018)	$Y = \theta TIN_t^{\delta} K^{\alpha} RTEC^{\beta} L^{1-\alpha} e^{\mu}$	θ – time-invariant consnt, *TIN* – transport infrastructure, *K* – capital, *RTEK* – road transport energy consumption, *L* – labourorce, e^u – the error term.	ansport
Lenz et al. (2018)	$EG = f(POP, GFCF, OPEN, RAIL, ROAD)$	*EG* – economic growth, *POP* – population growth, *GFCF* – infrastructure investment, *OPEN* – trade openness, *RAIL* – railway transport infrastructure, *ROAD* – road transport infrastructure.	Total + Transport
Toader et al. (2018)	$Y_t = A_t f(C_t, K_t, H_t, L_t)$ $Y = AC^{\alpha_c} K^{\alpha_k} H^{\alpha_h} L^{\alpha_l}$	*Y* – aggregatevalue-added, *A* – level of technology, *f* – function, *C* – input from ICT capital, *K* – non-ICT physical capital, *H* – hum capital, *L* – labour.	ICT
Elburz and Cubukcu (2021)	$Y_{it} = AK_{it}^{\alpha} H_{it}^{\beta} T_{it}^{\gamma}$	*Y* – output per capita, *A* – level of technology, *K* – private capital per capita, *H* – human capital, *T* – transport infrastructure stock.	Transport
Nair et al. (2020)	$PEG_{it} = A_0 R\&D_{it}^{\beta 1i} ICT_{it}^{\beta 2i} e^{\varepsilon it}$	*PEG* – economic growth, *A* – level of technology, *R&D* – R&D expenditure, *ICT* – ICT infrastructure, *e* – error term.	ICT
Wang et al. (2020a)	$C = A^{-1} Tra^{-\theta} Agg^{-1}$ $P_K^{\alpha_K} . P_L^{\alpha_L} P_E^{\alpha_E} Q$	*A* – total factor productivity, *Tra* – transportation infrastructure, *Agg* – industrial agglomeration, *Q* – degree of transport infrastructure depending on its scale, P_K – price of capital, P_L– price of labour, P_E – price of energy.	Transport
Kallal et al. (2021)	$VA_{it} = (TFP)_{it} (ICTD)_{it}^{\beta_2} (K)_{it}^{\beta_3} (L)_{it}^{\beta_4} e^{\varepsilon_{it}}$	*VA* – real value-added, *TFP* – total factor productivity, *ICTD* – ICT diffusion, *K* – stock of capital, *L* – labour, ε – disturbance term.	ICT

Note: *i* denotes region or country, *t* – time, α, β, γ,…– constant or elasticity of input, *e* – an error term.

As can be observed from Table 1, the authors complement typical neoclassic aggregate economic growth models by infrastructure (ICT, transport, or total) and other growth factors such as innovation (R&D expenditure), openness, human capital or level of technology.

However, the standard production function expanded by the infstructure component does not allow for evaluating how infrastructure outcomes are depdent on government quality. Moreover, it ignores the heterogeneity of the labour force and the diminishing marginal effect of capital investment. Addressing these limitations, we augmented the Cobb-Douglas production function to catch the diminishing marginal effect of capital and possible different effects of labour on production outcomes dependi on the accumulated human capital. To assess the moderating effect of government quality on infrastructure outcomes, we augmented model specification with the multiplicative term. The comprehensive specifications are consistently described in the 2nd section. Our methodological approach makes it possible to achieve new rests on infrastructure development outcomes, which are essential in shaping the allocation policy of the infrastructure funds at the regional level.

The idea that government quality affects the growth or the growth factors is not new. However, the moderating effect of government quality on infructure development outcomes has been little studied in the EU. Low government quality can reduce infrastructure development returns due to the lack of managerial capabilities or corruption. According to Fazekas and Tóth (2018) findings, corruption casteer infrastructure investments toward high-value investments and increase the cost of projects. Kyriacou et al. (2019) and Maciulyte-Sniukiene and Butkus (2022) empirically confirmed that lower government quality and higher levels of corruption limit the potential benefits of infrastructure development at the macro level. However, whether this effect holds considering regional-level governance remains unclear.

2. Research methodology and data

Based on the available research methodologies in the selected field of study, our research is based on the neoclassical production function:

$$Y = f\left(K, L\right), \tag{1}$$

where Y is the output, and K and L are inputs (production factors), such as capital and labour. We modify this function to account for the fact that K and L usually are used as complementary rather than substituting inputs in the production process. In this scenario, more important becomes the ratio between K and L, i.e. k, which shows the amount of capital per labour unit. Also, we consider infrastructure ($INFR$) as one of the production factors, and thus our production function utilizes additional input:

$$Y = f\left(k, L, \ INFR\right). \tag{2}$$

We apply a standard form for the Cobb-Douglas production function:

$$Y = Ak^{\beta_1} L^{\beta_2} INFR^{\beta_3}, \tag{3}$$

where Y is the real value of production (goods and services produced in a year). L is a labour input (number of people worked in a year), and k is capital input (value of capital used in a year per one labour unit, i.e. K/L). *INFR* is the infrastructure input (the amount of infrastructure available and used for the production of goods and services). *A* is the total factor productivity. $\beta_{(.)}$ are the output elasticities of inputs, whose values are constants and determined by available technology.

Assuming that *k* is subject to diminishing marginal effect on *Y*, the trans-log form of the Cobb-Douglas production function specified for a panel data can be expressed as:

$$\ln Y_{i,t} = \ln A + \beta_{11} \ln k_{i,t} + \beta_{22} \ln k_{i,t}^2 + \beta_2 \ln L_{i,t} + \beta_3 \ln INFR_{i,t} + \mu_i + \theta_t + \varepsilon_{i,t}, \quad (4)$$

where *i* is the cross-sectional unit, i.e. region, and *t* is the time period, i.e. year. μ_i is the term that stands for unobserved time-invariant and region-specific factors. θ_t is the time-dummies.

Based on previous research (Kyriacou et al., 2019; Maciulyte-Sniukiene & Butkus, 2022), we can assume that the effect of infrastructure on production depends on the quality of the infrastructure, which, in turn, is highly related to the institutional environment in the region. Our next and final specification will be used to test this assumption by interacting infrastructure variables with government quality, i.e.:

$$\ln Y_{i,t} = \ln A + \beta_{11} \ln k_{i,t} + \beta_{22} \ln k_{i,t}^2 + \beta_2 \ln L_{i,t} + \beta_3 \ln INFR_{i,t} + \\ \delta \ln INFR_{i,t} \cdot GQ_{i,t} + \beta_4 GQ_{i,t} + \mu_i + \theta_t + \varepsilon_{i,t}, \quad (5)$$

where δ_3 shows how government quality moderates the effect of infrastructure on production outcomes.

Table 2 presents data of our research.

All variables in euros are at constant (2015) prices. Since there is no data at NUTS 2 level on capital depreciation, i.e. the decline in value of capital assets, which proxy the value of the capital consumed during the production process, we use Gross fixed capital formation, i.e. the investment in capital assets which we assume are made to compensate the depreciation over a year. Since not all capital assets are homogeneous in terms of their effect on production, we separate these investments into R&D (Ka) and the rest of the investments (Kb). Considering the human capital theory, we can assume that the effect of labour on production output differs depending on the amount of accumulated human capital. Based on that, we separate employed people with (La) and without (Lb) tertiary education. Since the data on infrastructure is rather scarce, we include just two types of infrastructure, i.e. transportation and ICT.

Pesaran CD test of initial estimations of Eq. (4) indicated cross-sectional dependency in our data. It is not surprising since interactions between the regions within the country are intense. To minimize the possibility of this cross-sectional correlation affecting our results, we included variable *W*, which proxy the relative importance of a region in a country's economy. Here we assume that regions with relatively bigger economies have more relations with other regions and have more impact on other regions in the county.

Our unbalanced panel data set covers 256 EU28 NUTS 2 level regions over the period of 2000 – 2019. Data for all variables, except for *EQI*, was collected from Eurostat. Data for *EQI* was collected from The Quality Of Government Institute (Charron et al., 2021).

Table 2. Summary statistics of the variables

Variable		Descriptive statistics					
Abbreviation	Full name, description and measurement unit	Mean	Median	Min.	Max.	Std. Dev.	No of Obs.
Y	Gross domestic product, mil. Eur	45641	27491	0.0000	733910	61088	5375
K	Gross fixed capital formation, mil. Eur	10009	6152	−3.8932	173470	13179	5250
Ka	Gross domestic expenditure on R&D, mil. Eur.	748.09	232.42	0.0000	18348	1565.6	2875
Kb	K–Ka, mil. Eur.	8792.3	5216.6	−1022.8	130500	11819.	2868
L	Number of people aged from 15 to 64 years employed, thousands	775.77	594.70	13.200	5406.3	671.33	4770
La	Number of people with tertiary education (ISCED levels 5–8) employed, thousands	199.97	137.66	2.9436	2915.3	225.80	4710
Lb	L–La, thousands	584.17	461.55	8.5848	3606.2	485.98	4710
k	K/L	13292	13872	864.46	109600	6899.9	4770
ka	Ka/La	3009.4	1899.4	0.0000	30522	3220.0	2813
kb	Kb/Lb	15496	14947	1036	84916	9937.2	2813
INFRa	Passengers carried by air transport, thousands	7.3248	7.5000	0.0000	11.590	2.0023	3217
INFRm	Motorways, kilometres	5.3211	5.3910	2.2225	7.8739	0.95292	2626
INFRr	Total railway lines, kilometres	6.5680	6.8093	4.2127	8.0647	0.85740	2343
INFRi	Households with access to the internet at home, %	4.2910	4.3820	2.8332	4.6052	0.26841	1991
INFRb	Households with broadband access, %	4.2008	4.3307	2.1972	4.6052	0.38512	1983
EQI	European Quality of Government Index	−0.0354	−0.0450	−2.6930	2.8180	1.0003	4142
CORR	The sub-index of European Quality of Government Index to estimate corruption level at regional level	−0.0359	−0.0650	−2.6690	2.5600	1.0003	4158
W	Size NUTS 2 region's economy compared to national. Ratio between regional and national GDP, i.e. weight of regions economy	0.1055	0.0490	0.0000	1.0000	0.0014	5375

3. Research results and discussion

Panel diagnostics of Eq. (4) PLS estimates revealed that regional-specific factors exist and are quite persistent. Since the number of cross-sections is quite large, instead of modelling unobserved regional heterogeneity using LSDV estimator, we applied within transformation to our data to eliminate the possible effect of all observable and unobservable time-constant effects. Results are presented in Table 3.

Our results (see Estimation (1)) suggest that amount of capital per one labour unit is linked with the output in an inverted U-shaped form. It means that additional investment in the capital having a fixed amount of labour has a diminishing marginal effect on output. Considering R&D related investments per employee with tertiary education, this rule is not applicable. It seems that these investments are not subject to diminishing returns contrary to all other investments per one employee with below tertiary education (see Estimations (2)–(5)). Considering labour, the effect of highly educated labour on production is roughly twice bigger than one with a relatively lower educational attainment level. These findings are in line with previous studies on the interaction between human capital development (longer years of schooling, higher education, etc.) and labour productivity (or general economic outputs), which reveals a positive relationship (Hou et al., 2020; Ogbeinfun & Shobande, 2021).

Our findings suggest that just motorway and internet infrastructure are significantly positively (as inputs) related to production outcomes. An increase of these inputs by 10 per cent, other factors being fixed, would result in higher output by 0.5 and 1.3 per cent, respectively. Our results are in line with Crescenzi and Rodríguez-Pose's (2012) investigation, which revealed a positive and significant relationship between the length of motorways and GDP per capita growth in EU-15. Meersman and Nazemzadeh (2017) also found significant positive relationships between those variables in the case of Belgium and Lenz et al. (2018) in the case of CEE MS. Surprisingly, the impact of the development of the railway networks at the regional level is insignificant. Many regions do not have railway networks, and their development and improvement do not directly impact the region's economic growth.

Comparing the results of the evaluation of the return on ICT infrastructure development with the results of other investigations in the case of the EU, it should be noted that Toeader et al. (2018) found a significant positive relationship between GDP growth and not only internet but also fixed-broadband and mobile networks. The development of a broadband network at the regional level generates positive but insignificant economic output. De Clercq, D'Haese, and Buysse (2021) examined fixed broadband coverage in European rural areas and concluded that rural areas, in comparison with urban, are still falling behind in broadband infrastructure. Moreover, they found that the impact of broadband coverage on economic output in rural areas is weaker. De Clercq's et al. (2021) findings explain our results and suggest that to achieve economic convergence between EU regions is necessary to direct investment for the ICT infrastructure development to less developed regions.

Unfortunately, due to the lack of data on mobile network development at the NUT 2 regional level, it was impossible to assess its economic output.

Our results are not robust if we include all infrastructure variables since, due to missing observations, our sample size decreases significantly. Thus in the analysis of the moderating effects of institutional quality (see Table 4), we will include just two infrastructure variables, i.e. transport infrastructure (motorways) and ICT infrastructure (availability of the internet).

Table 3. Fixed effects estimates of Eq. (4)

Full name of the regressor	Abbreviation	Parameter	(1)	(2)	(3)	(4)	(5)
Total factor productivity	TFP	A	2.775**	2.291**	2.246**	2.618***	2.752***
			(0.9536)	(0.8960)	(0.9710)	(0.9570)	(0.9480)
Capital	k	β_{11}	1.1750***				
			(0.1874)				
	k^2	β_{12}	–0.0502***				
			(0.0105)				
	ka	β_{11a}		0.0858**	0.0757**	0.0714**	0.0790**
				(0.0335)	(0.0340)	(0.0302)	(0.0360)
	ka^2	β_{12a}		0.0019	0.0020	0.0022	0.0026
				(0.0025)	(0.0047)	(0.0032)	(0.0039)
	kb	β_{11b}		0.6044***	0.5302***	0.5999***	0.6152***
				(0.1967)	(0.1703)	(0.1748)	(0.2385)
	kb^2	β_{12b}		–0.0217**	–0.0152**	–0.0186**	–0.0231**
				(0.0107)	(0.0089)	(0.0084)	(0.0114)
Labour	L	β_2	0.4954***				
			(0.0501)				
	La	β_{2a}		0.3623***	0.3849***	0.3331***	0.3476***
				(0.0459)	(0.0659)	(0.0514)	(0.0769)
	Lb	β_{2b}		0.1835***	0.1726***	0.1743***	0.1862***
				(0.0253)	(0.0374)	(0.0300)	(0.0441)
Infrastruc-ture	INFRa	β_{3a}			0.0088		0.0064
					(0.0095)		(0.0105)
	INFRm	β_{3m}			0.0482***		0.0508***
					(0.0160)		(0.0155)
	INFRr	β_{3r}			0.0057		0.0287
					(0.0186)		(0.0273)
	INFRi	β_{3i}				0.1320***	0.0906
						(0.0399)	(0.0657)
	INFRb	β_{3b}				0.0472	0.0456
						(0.0294)	(0.0340)
Weight	W	β_4	3.547***	3.591***	3.118***	3.554***	3.712***
			(0.6215)	(0.5741)	(0.6701)	(0.6736)	(0.5500)
Number of observations			4770	2809	983	1416	616
Number of regions			239	210	87	141	70
The average number of observations per region			20.0	13.4	11.3	10.0	8.8
Within R^2			0.7416	0.7965	0.8083	0.7128	0.7446
Test for differing group intercepts$^{(1)}$ [p-value]			[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]
Breusch-Pegan $^{(2)}$ [p-value]			[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]
Hausman test$^{(3)}$ [p-value]			[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]

End of Table 3

Full name of the regressor	Abbreviation	Parameter	(1)	(2)	(3)	(4)	(5)
Wooldridge test(4)[p-value]			[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]
Wald test for heteroscedasticity(5) [p-value]			[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]
Pesaran CD test(6) [p-value]			[0.0573]	[0.0741]	[0.0629]	[0.0906]	[0.0788]
Wald joint test on time dummies(7) [p-value]			[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]

Notes: All estimations include time dummies since null on joint insignificance of time dummies was rejected. Since the presence of heteroscedasticity and serial correlation in the error term was detected, heteroscedasticity and serial correlation robust standard errors are presented in parentheses. *, **, *** indicate significance at the 10, 5 and 1 per cent levels, respectively.

(1) A low p-value counts against the null hypothesis that the pooled OLS model is adequate in favour of the fixed effects alternative.

(2) A low p-value counts against the null hypothesis that the pooled OLS model is adequate in favour of the random effects alternative.

(3) A low p-value counts against the null hypothesis that the random-effects model is consistent in favour of the fixed-effects model.

(4) A low p-value counts against the null hypothesis: no first-order serial correlation in error terms.

(5) A low p-value counts against the null hypothesis: heteroscedasticity is not present.

(6) A low p-value counts against the null hypothesis: cross-sectional independence.

(7) A low p-value counts against the null hypothesis: no time effects.

Table 4. Fixed effects estimates of Eq. (5)

Full name of the regressor	Abbreviation	Parameter	(1)	(2)	(3)	(4)	(5)
Total factor productivity	TFP	A	7.279***	6.110***	7.561***	6.254***	7.734***
			(0.8301)	(1.2010)	(0.8861)	(1.2390)	(0.8651)
Capital	ka	β_{11a}	0.0684***	0.0660***	0.0635***	0.0721***	0.0737***
			(0.0161)	(0.0214)	(0.0193)	(0.0189)	(0.0221)
	ka^2	β_{12a}	0.0036	0.0022	0.0042	0.0026	0.0034
			(0.0030)	(0.0046)	(0.0045)	(0.0043)	(0.0039)
	kb	β_{11b}	0.5410***	0.5045***	0.5171***	0.5700***	0.5860***
			(0.1622)	(0.1401)	(0.1740)	(0.1487)	(0.1734)
	kb^2	β_{12b}	–0.0241***	–0.0231***	–0.0273***	–0.0244***	–0.0196**
			(0.0088)	(0.0093)	(0.0095)	(0.0830)	(0.0094)
Labour	La	β_{2a}	0.3024***	0.3117***	0.3176***	0.3027***	0.3143***
			(0.0430)	(0.0504)	(0.0477)	(0.0472)	(0.0444)
	Lb	β_{2b}	0.0916***	0.1107***	0.0967***	0.1124***	0.0932***
			(0.0271)	(0.0265)	(0.0282)	(0.0263)	(0.0289)
Infrastructure	INFRm	β_{3m}	0.0446***	0.0371***	0.0347***	0.0244**	0.0365***
			(0.0114)	(0.0129)	(0.0125)	(0.0117)	(0.0120)
	INFRi	β_{3i}	0.0160	0.0272	0.0726***	0.0276	0.0799**
			(0.0275)	(0.0294)	(0.0265)	(0.0299)	(0.0306)

End of Table 4

Full name of the regressor	Abbreviation	Parameter	(1)	(2)	(3)	(4)	(5)
Interactions	INFRm·EQI	δ_{me}		0.0101			
				(0.0082)			
	INFRm·CORR	δ_{mc}				0.0113	
						(0.0071)	
	INFRi·EQI	δ_{ie}			0.0326*		
					(0.0173)		
	INFR·CORR	δ_{ic}					0.0357**
							(0.0170)
Government quality	EQI	β_{4e}		0.0815**	0.0912**		
				(0.0361)	(0.0455)		
	CORR	β_{4c}				0.0853**	0.0914**
						(0.0377)	(0.0451)
Weight	W	β_4	4.593***	4.198***	4.390***	4.088***	4.362***
			(1.047)	(1.053)	(1.034)	(1.049)	(1.047)
Number of observations			1137	1037	1037	1037	1037
Number of regions			118	108	108	108	108
The average number of observations per region			9.6	9.6	9.6	9.6	9.6
Within R^2			0.7708	0.8023	0.7853	0.8081	0.7900
Test for differing group intercepts(1) [p-value]			[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]
Breusch-Pegan (2) [p-value]			[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]
Hausman test(3) [p-value]			[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]
Wooldridge test(4) [p-value]			[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]
Wald test for heteroscedasticity(5) [p-value]			[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]
Pesaran CD test(6) [p-value]			[0.0813]	[0.0728]	[0.0724]	[0.0917]	[0.0970]
Wald joint test on time dummies(7) [p-value]			[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]

Note: All estimations include time dummies since null on joint insignificance of time dummies was rejected. Since the presence of heteroscedasticity and serial correlation in the error term was detected, heteroscedasticity and serial correlation robust standard errors are presented in parentheses. *, **, *** indicate significance at the 10, 5 and 1 per cent levels, respectively.

(1) A low p-value counts against the null hypothesis that the pooled OLS model is adequate in favour of the fixed effects alternative.

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(4) A low p-value counts against the null hypothesis: no first-order serial correlation in error terms.

(5) A low p-value counts against the null hypothesis: heteroscedasticity is not present.

(6) A low p-value counts against the null hypothesis: cross-sectional independence.

(7) A low p-value counts against the null hypothesis: no time effects.

Estimations show that a better institutional environment (higher government quality, less corruption) in the region is related to a more considerable production output of the infrastructure input. It could mean that better institutions create higher quality and more accessible infrastructure, which, having the same amount of it, produces more output. We also have evidence (see Figure 1) that institutions must reach a certain level of quality for the effect of infrastructure on production to become statistically significant. These results align with the results obtained by Kyriacou et al. (2019) and Zergawu, Walle, and Giménez-Gomez (2020) at the country level. Kyriacou et al. (2019) examined transport infrastructure investment efficiency using a data set of 34 countries over the period 1996 to 2010. Zergawu et al. (2020) investigated infrastructure capital's impact on economic growth in 99 countries from 1980 to 2015. Both research specifications cover institutional (government) quality as a possible moderator for infrastructure outcomes. Results reveal that infrastructure development effectiveness (economic returns) depends on institutional quality. These results were robust to a variety of alternative institutional quality measures. Therefore, it can be argued that achieving the maximum returns from infrastructure development is essential to improving government quality both at the national and regional levels.

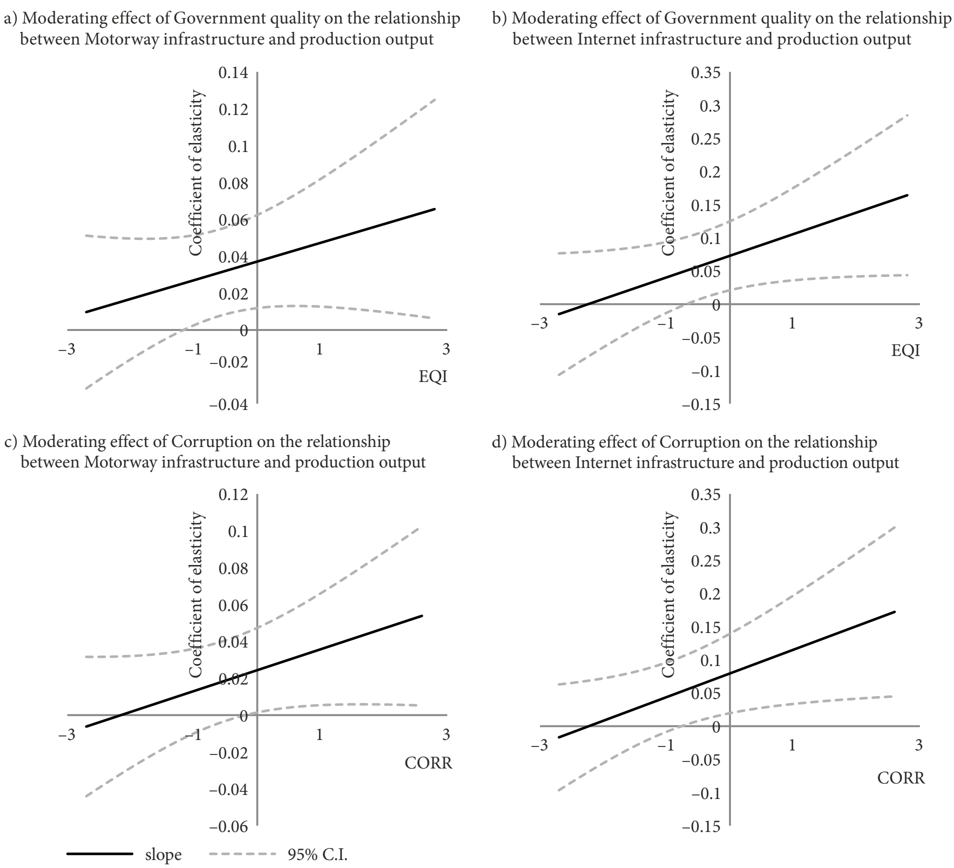

Figure 1. Moderating effect of institutions on the relationship between infrastructure and production output

Conclusions

The economic returns from core infrastructure development are given considerable attention in both scientific publications and the reports of policymakers. Nevertheless, they focus on assessing the impact of infrastructure development at the national level. The economic outcomes of infrastructure development at the regional level remain unassessed. However, this is important as one of the infrastructure development objectives is to reduce regional disparities and bring regions closer to international markets.

This paper contributes to previous studies of infrastructure development's impact on economic growth in the EU, evaluating economic outcomes of infrastructure development at the NUTS 2 regional level and moderating the effect of government quality. The study's main limitation is the concentration on two types of core infrastructure – transport and ICT, although core infrastructure also covers water and sanitation and energy infrastructure. Unfortunately, data for the latter two types of infrastructure are not provided in databases. The European Commission, which manages EU structural funds, recommends to collect and publish statistics on infrastructure development not only at the national but also at the regional level.

Assessment of the regional level's transport and ICT infrastructure economic outputs suggests that just motorway and internet generate significant results. However, the development of broadband networks at the regional level generates positive but insignificant production output. Based on the study results, it can be stated that the funds allocated to road and internet infrastructure should be directed to the regions where this infrastructure is less developed. It would boost economic growth in these regions, alongside social welfare, and reduce the gap with the economically strongest regions. This observation may lead to managerial implications of importance for policy makers on different levels of public government.

Estimations revealed that higher government quality and lower level of corruption in the region are related to a bigger production output of infrastructure input. Maximizing outputs from infrastructure development requires improvement of government quality and reduction of corruption at the national and regional levels. Regions need to adopt a policy to improve public administration capacity and ensure operational and infrastructure fund allocation transparency. That policy would ensure that funds are transferred to the regions with the worst infrastructure and where infrastructure upgrades are most needed to impact business development. It would also provide the transparency of public tenders for the construction and renovation of infrastructure, and it, in turn, would reduce the project's implementation costs and increase the return on infrastructure development.

The methodological contribution of the paper is stemmed in proposing a research methodology based on the neoclassical production function, which is modified to account for possible different effects of labour depending on the amount of accumulated human capital and possible diminishing marginal effect of capital investment. The proposed research methodology could be tested in other countries to get some insights into its validity and applicability. Such studies would build the basis for future international comparative analysis. Once the impact of infrastructure development on production output has been identified, further studies of the effects on convergence at the regional level could be carried out. Moreover, it would be appropriate to determine whether a diminishing marginal effect of infrastructure investments occurs. Having evidence of the diminishing return, it is possible to set the threshold level above which infrastructure development does not generate positive marginal outcomes. It would have an essential practical value, as it would help to direct infrastructure investments to those regions where they are most needed and not waste funds. Previously, such studies were not carried out at the EU regional level.

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Author contributions

Conceptualization, M.B. & M.S.; methodology and software, M.B.; validation, A.M.-S. and M.B.; formal analysis and investigation, A.M.-S. and M.B.; resources, A.M.-S & M.S.; data curation, A.M.-S.; writing, original draft preparation, A.M.-S.; review and editing, M.B. & M.S., visualization A.M.-S. and M.B. All authors have read and agreed to the published version of the manuscript.

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