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DEVELOPMENT OF THE MODEL TO EXAMINE THE IMPACT OF INFRASTRUCTURE ON ECONOMIC GROWTH AND CONVERGENCE

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Abstract. Core infrastructure, which covers transportation, information and communication (ICT), energy, water and sanitation systems, plays a significant role in economic growth. The development of core infrastructure – one of the European Union (EU) Cohesion Policy (CP) priorities – is heavily funded. However, it remains unclear whether these investments achieve the main aim, i.e. contribute to economic growth and convergence between EU countries and especially regions. A theoretical model addressing the identified issues is needed to assess the impact of infrastructure on economic growth and convergence comprehensively and as accurately as possible. To reach this aim, first, we have disclosed the definition of infrastructure and its structure. Also, we discussed different approaches to the relationship between infrastructure and economic growth. We developed a theoretical model for evaluating infrastructure impact on economic growth and convergence. Moreover, based on the neoclassical approach, we specified an econometric model that includes indicators of different types of infrastructure and assessed growth and convergence outcomes of infrastructure development. Even though we find that infrastructure positively affects growth and convergence, the estimated impact is not statistically significant except for some types of ICT and transport infrastructure.

Keywords: infrastructure, transport infrastructure, energy infrastructure, telecommunication infrastructure, water and sanitation infrastructure, economic growth, convergence.

JEL Classification: O11, O18, R11, R40.

Introduction

One of the areas in which all countries focus to achieve social and economic prosperity is the development of core infrastructure that covers transport, ICT, energy and water, and sanitation systems. Moreover, the development of core infrastructure is one of the EU's CP

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priorities. The development of core infrastructure in the least developed regions is expected to stimulate economic growth and reduce regional disparities. Infrastructure is heavily funded in the EU countries. Most infrastructure investments come from the EU funds and part from the state budgets. During the 2014–2020 period, over 14 billion euros were allocated to develop the ICT infrastructure in the EU countries from EU funds and 6 billion euros from national budgets. As much as 57 billion euros has been allocated from the EU budget to develop transport and energy infrastructure. Countries have provided an additional 12 billion euros from national budgets for this purpose.

The impact of infrastructure is receiving increasing attention in scientific literature. However, the effects of infrastructure investments remain controversial. For example, Canning and Pedroni (2004) investigate the impact of transport, energy and ICT infrastructure on economic growth using data of 67 countries for 1950–1992 and conclude that infrastructure positively influences economic growth in the vast majority of cases. European Commission (2014) assessed patterns of investments to transport and energy infrastructure in EU-28 for 1950–2012 and found a positive relationship between infrastructure development and economic growth. Toader et al. (2018) revealed positive effects of ICT on economic growth in EU-28 countries over 2000–2017. However, Apurv and Uzma (2020) evaluated the impact of transport, ICT, energy and water infrastructure on economic growth for 1980–2017 and found an insignificant relationship between infrastructure variables and per capita GDP in some BRIC countries. Moreover, the authors found evidence that telecommunication and transport infrastructure negatively affect economic growth in some countries. According to Ansar's et al. (2016) findings, "The question of whether infrastructure investment leads to economic growth must be answered in the negative".

Comparison of empirical results is difficult as the sampled countries and periods in the studies, and the applied methods differ.

Moreover, research usually assesses the impact of only one type of infrastructure on the economic growth in one or a few countries, ignoring the implications for convergence and not considering that the effect may occur with a lag. Another limitation identified in some previous studies is that the impact of infrastructure development is assessed without considering the effect of other factors. As Meersman and Nazemzadeh (2017) mention, it is difficult to determine the effect of infrastructure development on growth without considering investment demand for education, health care, social goals, and their impact on growth. A theoretical model addressing the identified issues is needed to comprehensively assess the impact of infrastructure on economic growth and convergence.

Considering the abovementioned, we aim to provide theoretical assumptions and develop a model to assess the impact of infrastructure on economic growth and convergence and empirically examine it. It is useful to disclose the infrastructure concept and identify its main types because the infrastructure term is multidimensional, vague, and different aspects are attributed to infrastructure in the scientific literature. This paper systematically analyses different approaches, features, and components if infrastructure and provides a generalized definition. In the next section, based on previous studies, we identify and discuss channels through which infrastructure can affect economic growth and convergence and develop a theoretical model of those chennels. Another section is devoted to analyzing previous studies to identify the applied methods, the indicators reflecting the infrastructure, the response and control variables. This analysis allows us to identify and summarise the essential aspects that need to be integrated into the specification of our model. The fourth section presents research models and data. The fifth section provides research results and discussion. The last section concludes the paper.

1. Definition of infrastructure: a comprehensive overview

Infrastructure – widely used term, but it has a variety of interpretations. Analysis of previous studies reveals that the description of infrastructure depends on the context of the field of science, application, the direction of possible effects. Stupak (2018) also mentioned that infrastructure could be described in several ways depending on the policy discussion. According to Fourie (2006), this term was first used to define war logistics. Nurkse (1952) defines infrastructure as large installations that are a basis for production capacity. He also notes other infrastructure features such as high costs and immobility. Hirschman (1958) identifies infrastructure as social overhead capital that provides public services and assigns transportation, health, education, communication, water and power, agricultural systems. He also highlighted that power and transportation are the main elements of the concept. According to Diamond and Spence (1989), infrastructure is "the collective and integrative basis for economic activity". These early definitions of infrastructure revealed certain features that deepen the concept of infrastructure. Rietveld and Bruinsma (1998) mentioned additional features of infrastructure: collective nature (publicness), indivisibility, non-substitutability, polyvalence, capitalnes, integrative role and support of economic activeness.

Noam (1994) distinguishes two essential aspects in defining the infrastructure term: i) it is a service used in most economic activities, ii) it generates positive externalities. The author attributes energy, transportation, education, communications, and protection to infrastructure. Torrisi (2009) defines infrastructure as government-provided input that promotes the production processes and has public goods characteristics in the sense of economic. According to this approach, infrastructure impacts outputs at the micro, mezzo, or national levels. The author additionally states that based on another approach, infrastructure could be considered as a cost-saving factor. It means that infrastructure indirectly affects the production process by increasing the efficiency of other production factors.

Frischmann (2012) also mentioned the publicness of infrastructure but additionally distinguished the physicality. He uses the term of traditional infrastructure and represents it as the system that is the basis for all other systems. According to the author, traditional infrastructure involves transportation system (railway, highway, road, ports, airline), communication systems (postal services and telephone networks), governance systems (court system), fundamental public facilities and services (schools, water systems, and sewers) and it is not an exhaustive list. The author points out that the publicness of infrastructure resources does not necessarily mean free access. It means that all entities can use infrastructure resources on non-discriminatory and equal terms.

According to Zhang and Jerome (2011), infrastructure can be distinguished into categories: "hard" infrastructure and "soft" infrastructure. The "hard" infrastructure is equated with physical capital or systems: transport (roads, railways, ports); energy (gas and pipelines, generations of electricity, electrical grids); telecommunications (internet, telephone); basic utilities (health and education, water supply, irrigations). This physical infrastructure supports the economy and society. According to Corporate Finance Institute [CFI] (2021), hard infrastructure is essential to running an industrialized, modern economy. The "soft" infrastructure comprises non-tangible infrastructure: institutional systems, policy and regulatory, governance mechanisms, social networks security, and other institutions that are essential to the well-being of an economy. This infrastructure supports the operation and development of physical infrastructure.

Fourie (2006) identifies these infrastructure categories as economic and social infrastructure. He describes economic infrastructure as infrastructure that stimulates economic activity. The economic infrastructure consists of telecommunications, transport infrastructure (roads, railroads, seaports, airports), electricity, water supply, and sanitation (Fourie, 2006; Arif et al., 2020). Fourie (2006) describes social infrastructure as infrastructure that contributes to society's education, health, and culture. Social infrastructure covers schools, universities, libraries, hospitals, clinics, theatres, museums, parks, playgrounds, and other institutions.

Palei (2015) notes that economists distinguish infrastructure capital and physical infrastructure. According to the author, the main elements of physical infrastructure are transport, water, telecommunication, and energy infrastructure.

Analysis of infrastructure definitions revealed that this term is multidimensional and covers three main elements: infrastructure features, elements, and outcomes for society. Researchers distinguish different characteristics and provide different infrastructure structures (components) but in unison state that infrastructure is a crucial factor for society's well-being. However, not all types of infrastructure play the same role in society.

One more concept related to infrastructure is the concept of critical (otherwise known as core) infrastructure. According to the National Research Council (2009), critical infrastructure is the basis for producing and delivering goods and services that are key to economic competitiveness, emergency response and recovery, and quality of life. National Research Council (2009) refers that critical infrastructure is transportation, power, water, and telecommunications systems. Stupak (2018) revealed that investments in core infrastructures (roads, railways, airports, and utilities) produce larger economic output than other types of infrastructure, such as schools, hospitals, etc. Given this insight, our paper aims to provide a theoretical model for assessing the effects of physical core infrastructure that covers transport, telecommunication, water, and energy systems.

Results of analysis of different approaches to infrastructure allow us to state that infrastructure is facilities and systems that are the basis for society's prosperity, provided by governments for public use, that can be distinguished to soft and hard – the latter consists of social and economic infrastructure. Economic infrastructure is essential for the economy and society and is treated as core infrastructure.

2. Relationship between infrastructure development, economic growth and convergence

The relationship between infrastructure and economic growth has been widely discussed in scientific literature utilizing different approaches. Based on previous studies, Torrisi (2009) distinguished four approaches explaining the mechanism of infrastructure that contributes to economic growth: production function approach, cost-function approach, growth-model approach, and causal relationship approach. Based on those approaches, we can identify channels through which infrastructure can boost economic growth. Kumo (2012) identified five effect transmission channels. First of all, based on the production function approach, infrastructure is one of the production factors that directly contribute to the production process and its outcomes. Secondly, infrastructure complements other production factors, and its improvement can reduce the cost of production. For example, road improvement can reduce the cost of production logistics. Thirdly, infrastructure can stimulate multifactor productivity since it provides facilities for other production factors, for example, human capital development.

Moreover, investment in infrastructure can enhance aggregate demand due to increased construction expenditure and maintenance operation. According to Kumo (2012), the development of infrastructure can influence industrial policy since the government may distribute investments to specific infrastructure projects and affect private-sector investment decisions. Torisi (2009) use a causal relationship approach based on Vector Autoregression (VAR) model, and the Granger causality test concludes that infrastructure development and economic growth can affect each other. Still, he stresses that "no study finds evidence to support the hypothesis of strict reverse causation from output to infrastructure".

Infrastructure can boost economic growth at the micro, regional or national level (Noam, 1994). Of course, infrastructure development does not guarantee favourable economic growth, but, as Nijkamp (1986) stated, "it creates the necessary conditions for achieving regional development objectives". Moreover, different types of infrastructure are interrelated and can generate positive externalities for each other. For example, ICT, transportations, and water supply systems depend on energy infrastructure (Wang et al. 2019): operation of the ICT systems without electric power is impossible; electric power system operates water pump stations; fuel networks also rely on the energy system. The development of transportation systems increases connectivity, and due to this, it can reduce the time and cost of ICT equipment delivery, as well as increase energy efficiency (Wang, 2020b). Management of all transportation, energy, and water supply services rely on ICT systems (Kallal et al., 2021). Moreover, upgrades or new infrastructure developments can reduce unemployment.

A theoretical model was developed based on theories about the relationship between infrastructure and economic growth, which identified impact transmission channels (see Figure 1).

Infrastructure investment increases the amount of total fixed capital and directly influences regional and national GDP growth. Infrastructure investments are usually directed to infrastructure construction or overhaul, leading to increased demand for construction workers and rising overall employment levels (Meersman & Nazemzadeh, 2017). Infrastructure investments increase the volume and quality of specific types of infrastructure.

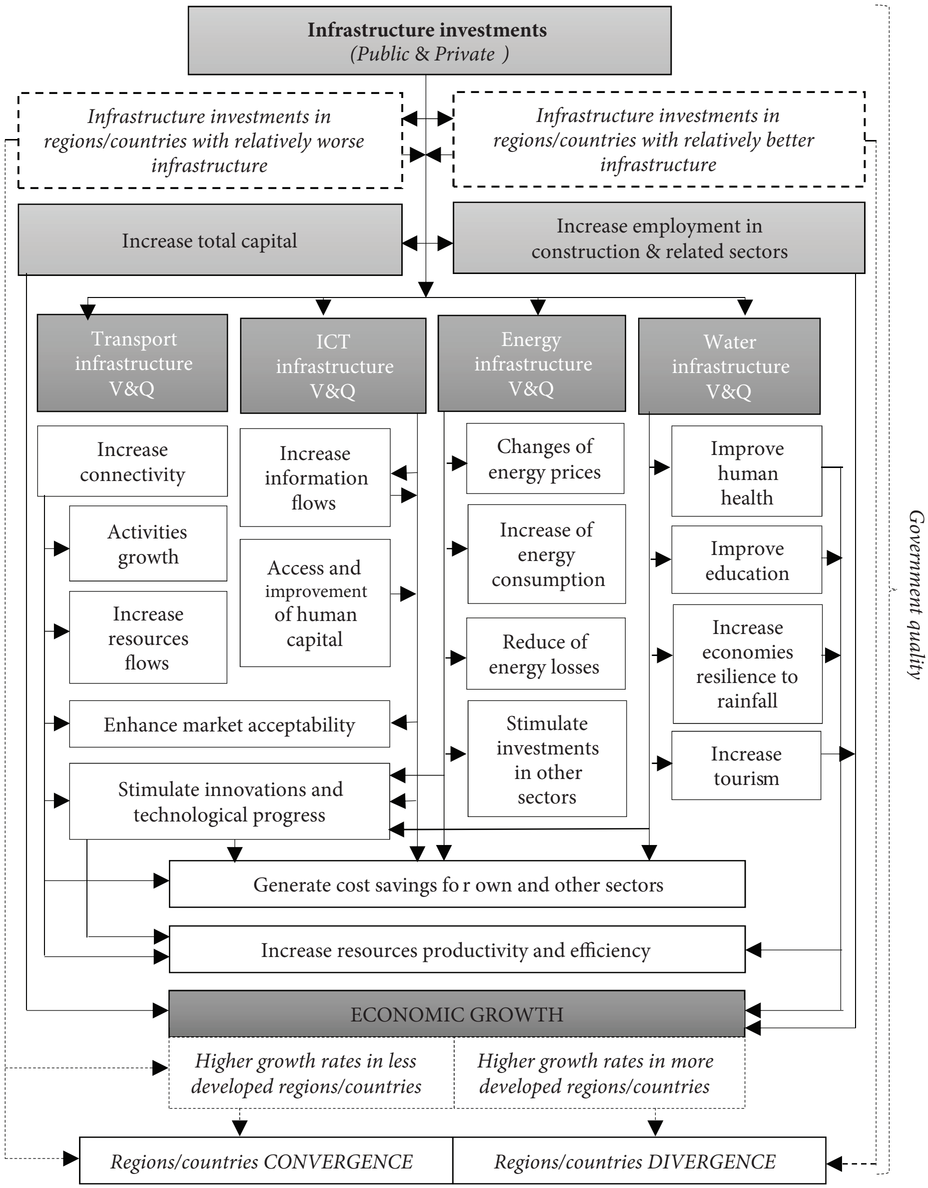

Figure 1. The theoretical model for infrastructure impact on economic growth and convergence (source: composed by the authors based on Sanctuary et al., 2005; Azevedo, 2014; Meersman & Nazemzadeh, 2017; Toader et al., 2018; Kyriacou et al., 2019; Elysia & Wihadanto, 2020; Wang et al., 2020b; Kallal et al., 2021, etc.)

Transport infrastructure development increases connectivity, and this, in the long run, leads to growth of economic activities, increases resource flows, enhances market acceptability, and stimulates innovations and technological progress (Wang et al., 2020b). An increase of connectivity directly and via cost-saving for other sectors raises the productivity and efficiency of resources. Wang et al. (2020b) emphasize transport infrastructure's impact on energy efficiency. Transport infrastructure development promotes industrial agglomeration that leads to technological spillover and raises competition and economies of scale, which positively influence energy and other resources efficiency.

Energy efficiency directly depends on energy infrastructure conditions. Improvement of energy infrastructure, first of all, reduces energy losses. Energy losses directly raise energy efficiency and can indirectly lead to lower energy prices that positively influence energy consumption (Azevedo, 2014). Increasing energy consumption in the household and business sectors raises regional and country GDP. Moreover, a decrease in energy prices generates saving in all sectors. Those savings can become investments in innovations that are also the source of cost-saving and resource productivity and efficiency. Some authors (Pandey, 2020; Wang et al., 2019) consider energy infrastructure essential among other critical infrastructure types since all economic activities depend on energy. Moreover, energy infrastructure can be treated as a political intermediary and cause countries political independents or vice versa (Bridge et al., 2018). But political aspects of energy infrastructure are not a field of interest for this paper and will not be discussed further.

The development of water and sanitation infrastructure positively influences economic growth mainly due to its impact on human health, leading to the improvement of education (Sanctuary et al., 2005, Palei, 2015). Improved safe water supply and sanitation facilities reduce the illness of the population, and in the long run, it benefits education and labour productivity due to lower morbidity (Sanctuary et al., 2005). Other positive externalities of improved water and sanitation infrastructure are related to the increase of the economy's resilience to rainfall variability and tourism (Elysia & Wihadanto, 2020).

ICT infrastructure development increases information flows and knowledge creations and flow, facilitates access to new markets and human capital, and ensures its improvement, stimulates innovation and technological progress (Toader et al., 2018; Kallal et al., 2021). Nowadays, almost all businesses, the public sector, and households use ICT services. Moreover, innovative business management systems and production equipment are also based on ICT technologies and solutions, generating cost savings and increasing resource productivity and efficiency (Haftu, 2019). Internet and mobile networks allow companies to adapt more quicly to turbulent economic conditions and ICT development becomes an essential elements of business and national socio-economic development strategies (Ortiz et al., 2020; Olczyk & Kuc-Czarnecka, 2022).

In general, since the performance of all economic sectors (service, industry, agriculture) relies on transport, ICT, energy, and water services and products, the development of core infrastructure has to lead to regional and national economic growth. But according to Kyriacou et al. (2019), infrastructure investment outcomes depend on government quality. The government accepts the distribution of national public investment and EU Structural funds support and takes part in the selection of infrastructure projects. The government, for political reasons, may divert investments, not to regions with the worst infrastructure situation but those with the highest number of potential voters. In this case, the country's economy can grow, but regional disparities will widen, and the convergence objectives will not be achieved. The allocation of funds to inefficient projects is also associated with corruption. In general, infrastructure development outcomes in all stages of effect – from investment to economic growth – depend on government quality. This aspect has to be taken into consideration, evaluating infrastructure development outcomes.

The main limitation of our model is the interaction between the development of all types of infrastructure and the interrelationships of the impact channels, which are challenging to represent in one model. Therefore, the model is simplified by depicting only the fundamental relationships.

3. Identification of elements for model specification

Analysis of literature revealed that most of the research bases the impact of infrastructure on economic growth on public investment theory and neoclassic aggregate economic growth models. Studies (Oyeniran & Onikosi-Alliyu, 2016; Meersman & Nazemzadeh, 2017; Saidi et al., 2018; Toader et al., 2018; Nair et al., 2020; Wang et al., 2020b; Elburz & Cubukcu, 2021; Kallal et al., 2021) provide differently modified Cobb-Douglas production functions. Modified functions covers traditional factors such us capital, labour, level of technology and integrates specific factors related to infrastructure such us foreign direct investment in ICT (Oyeniran & Onikosi-Alliyu, 2016), government investment in ICT (Oyeniran & Onikosi-Alliyu, 2016), ICT infrastructure (Nair et al., 2020), ICT diffusion (Kallal et al., 2021), transport infrastructure capital or stock (Meersman & Nazemzadeh, 2017; Saidi et al., 2018; Elburz & Cubukcu, 2021; Wang et al., 2020a). Toader et al. (2018) capital devided into ICT and non-ICT capital. The main limitation in modified growth functions is that they do not implement some types of infrastructure.

Hence, before specifying the model, first of all, the output variable has to be chosen. For this reason, output variables used in related literature have been identified. Analysis revealed that authors used different output variables for estimation infrastructure development economic outcomes: labour productivity and/or total factor productivity (Farhadi, 2015; Mitra et al., 2016; Arif et al., 2020; Kallal et al., 2021), Gini coefficient (Untari et al., 2019), Global competitiveness index (Palei, 2015), GDP, GDP growth, GDP per capita or GDP per capita growth (Canning & Pedroni, 2004; Calderón & Servén, 2004; Crescenzi & Rodríguez-Pose, 2012; European Commission, 2014; Donou-Adonsou et al., 2016; Oyeniran & Onikosi-Alliyu, 2016; Cigu et al., 2019; Lin & Chiu, 2018; Pradhan et al., 2018; Saidi et al., 2018; Toader et al., 2018; Haftu, 2019; Untari et al., 2019; Apurv & Uzma, 2020; Arif et al., 2020; Batool & Goldmann, 2020; Yang et al., 2020; Maneejuk & Yamaka, 2020; Muvawala et al., 2020; Nair et al., 2020; Wang et al., 2020a, etc.). We agree that infrastructure development can influence all mentioned phenomena. Still, the ultimate result is expressed by the total output growth in the economy, as other factors directly or indirectly affect it. Thus, economic growth has to be used as an output variable specifying a research model for infrastructure impact.

In the next step, we have identified and systemized control variables used in the research. It enables us to identify other growth factors and integrate them into the specification. Analysis revealed that research uses traditional economic growth factors as control variables in econometric specifications: *capital* (Donou-Adonsou et al., 2016; Oyeniran & Onikosi-Alliyu, 2016; Lenz et al., 2018; Toader et al., 2018; Haftu, 2019; Arif et al., 2020; Apurv & Uzma, 2020; Yang et al., 2020; Maneejuk & Yamaka, 2020; Muvawala et al., 2020; Wang et al., 2020a; Kallal et al., 2021), *population or/and employment* (Farhadi, 2015; Meersman & Nazemzadeh, 2017; Lenz et al., 2018; Haftu, 2019; Muvawala et al., 2020), *labour force* (Oyeniran & Onikosi-Alliyu, 2016; Cigu et al., 2019; Pradhan et al., 2018; Untari et al., 2019; Maneejuk & Yamaka, 2020; Wang et al., 2020a; Apurv & Uzma, 2020; Arif et al., 2020; Kallal et al., 2021), *human capital* (Crescenzi & Rodríguez-Pose, 2012; Farhadi, 2015; Meersman & Nazemzadeh, 2017; Untari et al., 2019; Maneejuk & Yamaka, 2020; Elburz & Cubukcu, 2021; Arif et al., 2020), *economic openness* (financial: Toader et al., 2018; Yang et al., 2020; trade: Donou-Adonsou et al., 2016; Mitra et al., 2016; Meersman & Nazemzadeh, 2017; Cigu et al., 2019; Lenz et al., 2018; Toader et al., 2018; Apurv & Uzma, 2020; Muvawala et al., 2020; Wang et al., 2020a). However, some authors, evaluating infrastructure outcomes, took into account *innovation development* (Crescenzi & Rodríguez-Pose, 2012; Farhadi, 2015; Mitra et al., 2016; Maneejuk & Yamaka, 2020; *urbanization level* (Wang et al., 2020a), *industry size* (Mitra et al., 2016), *inflation* (Toader et al., 2018; Haftu, 2019; Muvawala et al., 2020; *government size* (Donou-Adonsou et al., 2016; Cigu et al., 2019; Toader et al., 2018; Haftu, 2019), and other factors. All those factors can be used to develop the model, but they must not duplicate the impact on the outcome variable. Initial real per capita GDP allows to capture infrastructure effect on the convergence between regions and countries (Yang et al., 2020), and it has to be included in the econometric specification.

Another step in developing a research model is identifying and selecting indicators that proxy infrastructure development. Analysis of literature revealed that there are few ways for examining the impact of infrastructure on economic growth and convergence i) to analyze infrastructure investment returns (IIR) (European Commission, 2014; Oyeniran & Onikosi-Alliyu, 2016; Kyriacou et al., 2019; Untari et al., 2019; Muvawala et al., 2020); ii) to identify infrastructure development effects, using physical infrastructure indicators (Lenz et al., 2018; Maparu & Mazumder, 2017; Meersman & Nazemzadeh, 2017; Saidi et al., 2018; Batool & Goldmann, 2020; Elburz & Cubukcu, 2021; Wang et al., 2020a, 2020b; Apurv & Uzma, 2020; Arif et al., 2020; Elysia & Wihadanto, 2020); iii) to analyze infrastructure impact, using aggregate infrastructure index (Palei, 2015; Mitra et al., 2016; Cigu et al., 2019; Nair et al., 2020; Yang et al., 2020; Kallal et al., 2021).

We also found that research uses different estimators to study the impact of infrastructure on growth. Most authors used GMM (Donou-Adonsou et al., 2016; Mitra et al., 2016; Saidi et al., 2018; Toader et al., 2018; Haftu, 2019; Yang et al., 2020), OLS (Farhadi, 2015; Mitra et al., 2016; Cigu et al., 2019; Lenz et al., 2018; Toader et al., 2018; Apurv & Uzma, 2020; Arif et al., 2020; Elburz & Cubukcu, 2021), FE (Farhadi, 2015; Donou-Adonsou et al., 2016; Cigu et al., 2019; Lenz et al., 2018; Apurv & Uzma, 2020), and RE (Cigu et al., 2019; Lenz et al., 2018; Apurv & Uzma, 2020) estimators and their variations to assess the impact of infrastructure on economic growth.

Cigu et al. (2019) provided the analysis and discussion on previous studies that evaluate transport infrastructure outcomes using different estimators. Based on their analysis, regardless of the estimator applied, the research results reveal similar trends, but the elasticity coefficients reflecting the effects differ. It can be stated that the research results are more influenced by the countries/regions and periods covered, research strategies applied, and the indicators used, but not by the estimator applied. All main econometric methods can be used to assess the impact of infrastructure on growth and convergence, as each has some limitations that can be identified using additional testing.

For example, the autocorrelation of errors is highly probable using OLS. To avoid this, variable differentiation and lagged dependent variable in the specification is used. The FE calculate a vast number of coefficients. In addition, it is not possible to include time-invariant factors or factors that change at a constant rate. Multicollinearity is expected between fixed effects and independent variables that slowly change over time. Estimates of the RE may be inconsistent if random effects correlate with other independent variables. In this case, compatibility must be checked using the Hausman test.

The choice of a specific method for estimating the impact of independent factors on dependent variables depends on the research strategy. The research questions and choosing a research strategy that allows answering those questions is essential. In general, the analysis revealed that the main questions that have to be answered in research evaluating outcomes of infrastructure development to address the shortcomings of previous studies are: What is the impact of infrastructure development on convergence? What impact does the government quality have on the outcomes of infrastructure development? How much do the outcomes differ between countries with relatively high and low quality of government? What are the effects of different types of infrastructure development?

4. Econometric specification for assessing the impact of infrastructure development on growth and convergence

The econometric specification to examine the impact of infrastructure on growth and convergence between EU-28 countries is based on neoclassical growth specification for a panel of countries, which is conventional in the literature related to the analysis of beta convergence, i.e. β-convergence:

$$\frac{1}{T-1}\ln\left(\frac{Y_{i,t+T}}{Y_{i,t}}\right)=\alpha+\beta\ln\left(Y_{i,t}\right)+c_1 inst_{i,t}+c_2\Delta\ln\left(pop_{i,t}\right)+$$

$$c_3\ln\left(dens_{i,t}\right)+c_4\ln\left(urb_{i,t}\right)+c_5\Delta\ln\left(lf_{i,t}\right)+c_6 gcf_{i,t}+c_7 gcf_{i,t}^2+c_8\ln\left(opn_{i,t}\right)+$$

$$c_9\ln\left(gov_{i,t}\right)+c_{10}\ln\left(r\,\&\,d_{i,t}\right)+c_{11}\Delta\ln\left(cpi_{i,t}\right)+c_{12}\ln\left(hc_{i,t}\right)+\theta_t+\mu_i+\varepsilon_{i,t}, \quad (1)$$

where i stands for the country and t for the period. The dependent variable is the average per capita GDP (Y) growth rate. Variables used to control growth sources, included in the right-hand side of the equation, are presented in Table 1. θ_t and μ_i are time- and country-specific effects, respectively, modelled including time dummies and estimating Eq. (1) using within (FE) estimator. $\varepsilon_{i,t}$ is the idiosyncratic error term. α, β and $c_{(.)}$ are parameters to be estimated. Negative and statistically significant estimated β would suggest that initially (at period t) less developed countries (in terms of per capita GDP) were growing (over the period $t \rightarrow T$) faster and catching up with more developed ones.

A variable *INFR* that represents infrastructure as a usual growth factor is added to the right-hand side of the Eq. (1):

$$\frac{1}{T-1}\ln\left(\frac{Y_{i,t+T}}{Y_{i,t}}\right) = \alpha + \beta\ln\left(Y_{i,t}\right) + \gamma INFR_{i,t} + c_1 inst_{i,t} + \ldots + \theta_t + \mu_i + \varepsilon_{i,t}. \quad (2)$$

This research assumes that infrastructure affects the speed of convergence, i.e infrastructure works as the mediator that speeds up the convergence process between EU-28 countries:

$$\frac{1}{T-1}\ln\left(\frac{Y_{i,t+T}}{Y_{i,t}}\right) = \alpha + \beta\ln\left(Y_{i,t}\right) + \gamma INFR_{i,t} + \varphi\ln\left(Y_{i,t}\right) \times INFR_{i,t} + c_1 inst_{i,t} + \ldots + \theta_t + \mu_i + \varepsilon_{i,t}, \quad (3)$$

where multiplicative term $ln(Y_{i,t}) \times INFR_{i,t}$ allows examining whether bigger infrastructure leads to faster convergence and vice versa. Eq. (3) could be slightly rearranged to show that introducing a multiplicative term, i.e. $\ln(Y_{i,t}) \times INFR_{i,t}$ allows modelling the conditional relationship between $\ln(Y_{i,t})$ and growth, which depends on the amount of infrastructure:

$$\frac{1}{T-1}\ln\left(\frac{Y_{i,t+T}}{Y_{i,t}}\right) = \alpha + \left(\beta + \varphi INFR_{i,t}\right)\ln\left(Y_{i,t}\right) + \gamma INFR_{i,t} + c_1 inst_{i,t} + \ldots + \theta_t + \mu_i + \varepsilon_{i,t}, \quad (4)$$

where $\beta + \varphi INFR_{i,t}$ is the composite slope of growth on an initial per capita GDP. The estimated negative coefficient on φ would give empirical evidence of infrastructure's convergence outcome. Still, γ shows the effect of infrastructure on growth. With the introduction of the multiplicative term, not only does the slope coefficient become conditional, but also the standard error associated with the coefficient. It implies that a certain level of infrastructure could be needed for the convergence even to start. In the present research, the formulas developed by Brambor et al. (2006) will be applied in order to calculate standard errors.

Estimating the equations, it is necessary to select the span of the growth episode (T). Research that uses $T = 1$ (i.e., annual per capita GDP growth) maximizes the sample size (Donou-Adonsou et al., 2016; Muvawala et al., 2020). Still, this strategy might lead to estimates that are highly affected by the cyclical patterns of economic fluctuations and endogeneity (since *INFR* is lagged only by one period with respect to growth). These issues will be addressed by setting T equal to 3, aiming to estimate the effect of the current level of infrastructure (and the other left-hand-side variables) on the 3-year forward-looking average per capita GDP growth rate. Having a relatively short period under investigation, instead of non-overlapping growth episodes, as an alternative, it is considered to use 3-year overlapping growth periods even though the usage of overlapping growth rates as the dependent variable creates a moving average structure in the error term. Following Panizza and Presbitero (2014), the Huber–White Sandwich correction is used, which yields almost identical results as Newey and West's (1987) estimator, which allows modelling the autocorrelation in the error term.

Our unbalanced panel data covers 28 EU countries from 2000 through 2019. Data is collected from Eurostat, Our World in data and World Bank databases. Table 1 presents summary statistics of the research variables.

Table 1. Research variables and summary statistics

Notation	Variable	Average	Min.	Max.	S. D.
Y	GDP per capita (constant 2010)	3.22×10^4	3.98×10^3	1.12×10^5	2.11×10^4
pop	Population, total	1.79×10^7	3.90×10^5	8.31×10^7	2.27×10^7
dens	Population density (people per sq. km of land area)	174	17	1.51×10^3	242
urb	Urban population (% of total)	72.2	50.8	98.0	12.5
lf	Labour force, total	8.61×10^6	1.56×10^5	4.39×10^7	1.10×10^7
gcf	Gross capital formation (% of GDP)	22.9	11.9	46.0	4.56
opn	Trade (% of GDP)	117	45.4	408	64.9
gov	Total general government expenditure (% of GDP)	44.7	24.5	64.8	6.55
r&d	Researchers in R&D (per million people)	2.90×10^3	321	8.00×10^3	1.62×10^3
cpi	Consumer price index (2010 = 100)	96.8	32	124	13.5
hc	Tertiary educational attainment age group 30–34 (%)	33.5	7.4	58.8	11.8
inst	Control of Corruption: Estimate	1.03	–0.491	2.47	0.792
INFR – core infrastructure					
ict – ICT infrastructure					
ict_ft	Fixed telephone subscriptions (per 100 people)	39.8	4.86	72.1	13.9
ict_fb	Fixed broadband subscriptions (per 100 people)	21.1	0.0119	46.0	12.6
ict_mc	Mobile cellular subscriptions (per 100 people)	107.	9.23	172.	29.6
ws – water and sanitation infrastructure					
ws_sf	Share of the population with access to safely managed sanitation facilities (%)	81.8	24.7	99.7	14.6
ws_dwf	Share of the population with access to safely managed drinking water facilities (%)	95.6	67.2	100.	5.68
t – transport infrastructure					

End of Table 1

Notation	Variable	Average	Min.	Max.	S. D.
t_rw	Railway tracks (kilometres per 1000 sq. km of land area)	88.9	21.2	258.	60.9
t_r	Roads (kilometres per 1000 sq. km of land area)	1.48×10^3	112.	9.68×10^3	1.52×10^3
t_ww	Navigable inland waterways (kilometres per 1000 sq. km of land area)	18.2	3.58	187.	33.7
t_pl	Pipelines operated (kilometres per 1000 sq. km of land area)	10.7	0.411	24.5	5.56
t_ap	Air passenger transport (passengers on board per 1000 inhabitants)	2.77×10^3	80.0	1.45×10^4	2.17×10^3
e – energy infrastructure					
e_epc	Electricity production capacities (megawatts per one mil. of GDP)	0.0678	0.000	0.363	0.0469

5. Results of the evaluation infrastructure development impact on convergence

We estimated our specification using three alternative estimators, i.e. pooled OLS, FE and RE. Panel diagnostics revealed that country fixed effects are present and thus have to be omitted or modelled. We decided to estimate our model using FE estimator, which controls time-invariant effects by applying within transformation, instead of LSDV, which yields the same coefficients but additionally estimates country-specific constant. Annex 1 (Table 2) presents FE estimation results of Eq. (3).

Results are largely consistent with previous literature analyzing growth factors. We find that a better institutional environment (in our case, less corruption) is positively and, in most cases, statistically significantly related to growth. The estimated coefficient on institutions (as well as on other growth controls) varies across estimations mainly due to non-constant sample size, which is primarily constrained by data on infrastructure variables. Those results are in line with Cigu's et al. (2019) findings. They investigated transport infrastructure's impact on economic growth and "the role of policy makers in explanation cross-country differences in EU" and found that corruption negatively affects economic growth.

The estimated coefficient on population growth is negative and marginally statistically significant, while the growing labour force is positively related to economic growth. Arif et al. (2020) also revealed a significant and positive relationship between labour force and economic output. We did not find a significant effect of population density and urbanization, and the sign of the coefficient varies, indicating that there is no clear link with growth. Although according to Urban Economic theory, urbanization leads to economic growth, this is not always the case (Bertinelli & Strobl, 2007). Wang et al. (2020) used urbanization as a control variable examinating transport infrastructure impact on economic growth in the Belt and Road Initiative (BRI) countries and found a significant negative effect in Central and

Eastern Europe. Urbanization impact on economic growth in East Asia and Commonwealth of Independed States (CIS), South Asia, Weast Asia and North Africa was insignificant. Maparu and Mazumder (2017), did not found significant relationship between urbanization and economic growth in post-liberalization era in India.

We find a significant and positive relationship between growth and gross capital formation and a negative with the squared term. That is a sign of the diminishing marginal effect of capital investments on output, which is predicted by neoclassic growth theory. We estimated that the tipping point above which capital has a negative marginal effect is at about 23–24 per cent of GDP. Our results reveal that trade openness has a significant positive effect on growth, while government size slow down economic growth. Those results are in line with results from Fetahi-Vehapi et al. (2015), Dritsakis and Stamatiou (2016), who revealed a positive trade openness impact on economic growth in EU countries, and Alfonso and Jalles (2011), who found a negative relationship between government size and economic growth. Some authors (Nouira & Kouni, 2021; Zungu & Greyling, 2021) identified a threshold (10–30 per cent depending on the country) above which the government size negatively related to economic growth.

A negative and significant relationship is also found between inflation and growth. We find no significant effect of R&D and human capital on growth. We believe that is mainly because we use an input approach to proxy R&D and the 3-year episode is too short of capturing the effect of human capital stock on growth.

Our findings (the negative and statistically significant estimated coefficient on β) suggest that β-convergence between countries is present in the EU28. It is in line with Siljak and Nagy (2019), Butkus et al. (2018). Negative coefficients on interaction terms (i.e. φ) between initial per capita GDP and infrastructure show that infrastructure development boosts convergence. Still, results suggest that this is not happening at a scale that would be statistically significant. We find that only the development of ICT infrastructure (fixed broadband connectivity) and transport infrastructure (network of pipelines) boost convergence significantly (see Figure 2).

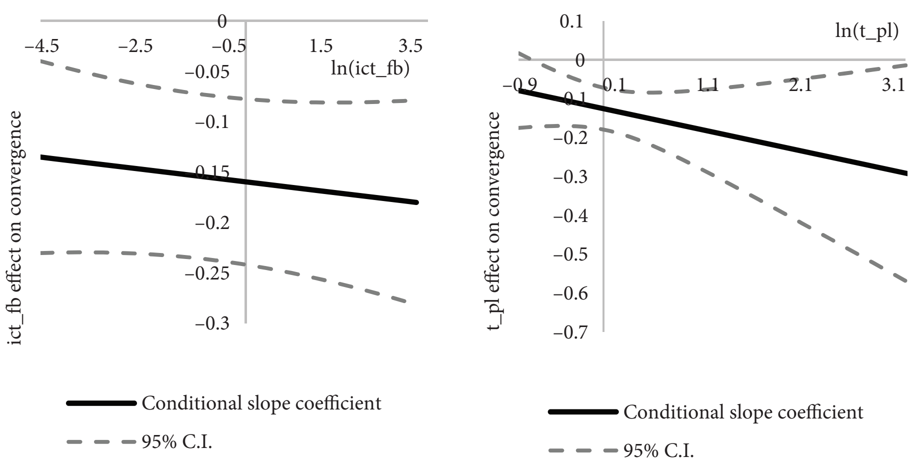

Figure 2. Effect of fixed broadband subscriptions (left side) and pipeline network (right side) on convergence

Estimated coefficients on γ indicate the effect of infrastructure development on growth. As in the case of convergence, we find that the development of all types of infrastructure is positively related to growth. Still, the significant effect we observe is just in the case of fixed broadband subscriptions and pipeline networks.

Conclusions

The term infrastructure has a variety of interpretations. Analysis of literature revealed that this term is multidimensional and covers three main components: infrastructure features, elements (structure), and outcomes for society.

Infrastructure has the following main characteristics: immobility, the high level of cost, publicness, non-substitutability, and indivisibility. Based on an analysis of infrastructure definitions provided in previous studies, it can be stated that infrastructure covers facilities and systems that are the basis for society's prosperity, provided by governments for public use. Most of the authors distinguish infrastructure into i) soft (non-tangible) infrastructure and ii) hard (physical) infrastructure. Soft infrastructure covers institutional system, policy and regulatory, governance mechanism, etc. Hard infrastructure integrates i) social infrastructure that covers schools, universities, hospitals, clinics, theatres, museums, parks, etc.; ii) economic infrastructure that consists of transport, ICT, energy, water, and sanitation systems. Social, physical infrastructure facilitates education, health, and cultural services. Economic infrastructure stimulates economic activity and is treated as core infrastructure.

From the theoretical point of view, relationships between infrastructure and economic growth are based on four approaches: production function approach, cost-function approach, growth-model approach, and causal relationship approach. Although the relationship between infrastructure and economic growth is mostly based on production function extended by implementing infrastructure component, it often has limitations since it does not separate different types of infrastructure. We provided a modified function that has a few novelties: i) it separates different types of infrastructure capital; ii) infrastructure capital does not duplicate total capital, iii) it includes other growth factors.

After evaluating all mentioned approaches, a new theoretical model of the impact of infrastructure development on economic growth and convergence has been developed, integrating all the main infrastructure components (transport, ICT, energy, water, and sanitation) and the channels of direct and indirect impact transmission and their interrelationships.

Investment in infrastructure development increases the total capital of a country or region and increases employment, which directly affects economic growth. The increasing volume and quality of individual types of infrastructure stimulate economic growth by shaping the availability of resources and markets, reducing resource losses, and improving human capital. It can be achieved by knowledge creation and flows, improvement of human health and education, stimulation innovation and technological progress, generating cost-saving, resources productivity, and efficiency of own and other sectors). One of the novelties of the model is that it includes a component of government quality. The infrastructure development outcomes, especially convergence, highly depend on the government since government management abilities, priorities (economic prosperity and regions convergence or political bonuses), level of corruption influence the effectiveness of distribution infrastructure investments between geographical areas and projects.

Analysis of literature revealed that most of the research grounds the impact of infrastructure on economic growth on public investment theory and neoclassic aggregate economic growth models. The main limitations of those functions are the following: infrastructure capital duplicates total capital; different types of infrastructure are not separated; just a few growth factors are included; lagged effects are not considered. Those shortcomings have been solved by providing a modified growth specification that can be the basis for empirical research. Control variables used by research in econometric specifications were also systemized. It allows us to identify and select growth factors that have to be integrated into the growth function and empirical model. Analysis revealed that most authors integrate traditional factors such as capital, population or/and employment, labour force, human capital, and economic openness (trade and financial). However, innovation development, urbanization level, industry size, size of government, and inflation can affect economic growth and have to be integrated into the specification. Moreover, the research model has to implement initial real GDP per capita since it allows catching infrastructure effect on the convergence.

Based on the analysis of previous studies, we can conclude that there are a few ways to investigate the infrastructure impact on economic growth and convergence: to explore infrastructure investment returns; to analyze infrastructure development effects using physical infrastructure indicators; to investigate infrastructure impact using aggregate infrastructure index. Most appropriate is to use infrastructure investments and physical infrastructure indicators that proxy infrastructure development since the usage of aggregate infrastructure index does not allow to assess the effects of individual types of infrastructure and effectiveness of distribution of investment. That is very important if authors seek that research would have practical value and provide recommendations for policymakers.

Literature analysis allows us to conclude that different econometric models can examine infrastructure development outcomes. Still, considering the limitations of previous studies, econometric models have to be able to assess lagged effects and evaluate the impact not only on growth but also on convergence. The effects of individual infrastructure development have to be assessed as well. These aspects have been taken into consideration while developing an econometric specification that has been empirically tested assessing the impact of infrastructure development on convergence and growth in the EU. It covers not only standard variables but also additional like initial per capita GDP, innovation development, urbanization level, size of government, inflation, control of corruption.

Even though we find that infrastructure positively affects growth and convergence, the estimated impact is not statistically significant except for some types of ICT and transport infrastructure.

Also, we found a positive relationship between labour force, gross capital formation (up to the threshold of 23–24 per cent of GDP), trade openness, and government size.

Nevertheless, the research has some limitations. First of all, the study evaluated infrastructure growth and convergence outcomes at the national level, leaving the question of what impact is at the regional level. Another limitation is that the research was performed using only one type of variable (physical indicators) to proxy infrastructure development. Thus, future research could include an assessment of the infrastructure development outcomes at the NUTS 2 regional level. In addition, a study could be carried out using infrastructure investments as an indicator of its development.

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Author contributions

VD conceived the study and was responsible for the analysis design, general conclusions. AMS was responsible for material collection, systematization, analysis, interpretations, theoretical model formulation, data collection and systematization. MB conducted and implemented research model, discusses results. AMS wrote the first draft of the article. VD revise and corrected the article.

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The authors do not have any competing financial, professional, or personal interests from other parties.

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Table 2. Fixed-effects estimates. Dependent variable is 3-year overlapping forward-looking average per capita GDP growth rate

Variable	Coefficient	ict_ft	ict_fb	ict_mc	ws_sf	ws_dwf	t_rw	t_r	t_ww	t_pl	t_ap	e_epc
Intercept	α	1.1630	0.8626	0.7375	0.4549	–0.8574	1.0280	1.9140	3.9090***	3.1720***	1.0670	1.0790
		(1.2920)	(1.0790)	(1.0900)	(0.9954)	(4.2540)	(1.7110)	(1.3280)	(1.0180)	(0.8993)	(1.7500)	(1.2500)
inst	c_1	0.0178**	0.0190**	0.0209**	0.0173**	0.0147**	0.0152	0.0135*	0.0200*	0.0222***	0.0210**	0.0153*
		(0.0072)	(0.0072)	(0.0089)	(0.0074)	(0.0070)	(0.0133)	(0.0075)	(0.0102)	(0.0054)	(0.0080)	(0.0074)
pop	c_2	–1.2900*	–1.3060*	–1.3080*	–1.2460*	–1.1640	–1.7910**	–1.4020	–1.1660**	–0.5292	–1.1740*	–1.4680**
		(0.6961)	(0.7066)	(0.6679)	(0.6754)	(0.7040)	(0.7387)	(0.8211)	(0.4869)	(0.3978)	(0.6491)	(0.7009)
dens	c_3	0.1039	0.1459	0.1224	0.1095	0.1208	0.1042	0.0693	–0.1203	–0.1187	0.1149	0.0703
		(0.0871)	(0.0904)	(0.0935)	(0.0914)	(0.0850)	(0.0993)	(0.0824)	(0.0945)	(0.0860)	(0.0962)	(0.1003)
urb	c_4	0.0037	–0.0461	0.0274	0.0278	0.0201	–0.0336	–0.0293	–0.3147***	–0.4184**	–0.0051	0.0271
		(0.1038)	(0.1143)	(0.1214)	(0.1095)	(0.1074)	(0.1620)	(0.1280)	(0.1066)	(0.1434)	(0.1201)	(0.1075)
lf	c_5	0.2133**	0.1907**	0.1922**	0.1906**	0.1956**	0.1969	0.2283**	0.0679	0.0194	0.2919***	0.2195**
		(0.0846)	(0.0871)	(0.0814)	(0.0914)	(0.0941)	(0.1177)	(0.0901)	(0.0716)	(0.0962)	(0.1031)	(0.0946)
gcf	c_6	0.0067**	0.0062*	0.0074**	0.0070**	0.0071**	0.0088*	0.0056	0.0029	–0.0013	0.0064	0.0078*
		(0.0031)	(0.0032)	(0.0032)	(0.0030)	(0.0031)	(0.0044)	(0.0033)	(0.0043)	(0.0039)	(0.0040)	(0.0040)
gcf^2	c_7	–0.0001**	–0.0001**	–0.0002**	–0.0001**	–0.0001**	–0.0002**	–0.0001*	–0.0001	0.0000	–0.0001*	–0.0002**
		(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
opn	c_8	0.1113***	0.1119***	0.1148***	0.1141***	0.1157***	0.1066***	0.1141***	0.1342***	0.1266***	0.1124***	0.07612***
		(0.0222)	(0.0232)	(0.0228)	(0.0232)	(0.0246)	(0.0202)	(0.0234)	(0.0354)	(0.0331)	(0.0263)	(0.0198)
gov	c_9	–0.0716**	–0.0786***	–0.0769**	–0.0695**	–0.0741**	–0.0844**	–0.0612*	–0.0338	–0.0103	–0.0715*	-0.0773**
		(0.0303)	(0.0235)	(0.0303)	(0.0331)	(0.0300)	(0.0369)	(0.0355)	(0.0239)	(0.0173)	(0.0407)	(0.0339)
r&d	c_{10}	0.0016	0.0022	0.0076	0.0055	0.0054	–0.0175*	–0.0036	–0.0163	–0.0312*	0.0071	–0.0020
		(0.0143)	(0.0124)	(0.0140)	(0.0145)	(0.0151)	(0.0096)	(0.0136)	(0.0154)	(0.0177)	(0.0149)	(0.0121)
cpi	c_{11}	–0.1901**	–0.1669**	–0.1577**	–0.1926**	–0.2036***	–0.1577**	–0.2181**	–0.2405***	–0.3644***	–0.3205**	–0.1604**
		(0.0697)	(0.0716)	(0.0686)	(0.0794)	(0.0692)	(0.0732)	(0.0809)	(0.0731)	(0.0737)	(0.1292)	(0.0747)

End of Table 2

Variable	Coefficient	ict_ft	ict_fb	ict_mc	ws_sf	ws_dwf	t_rw	t_r	t_ww	t_pl	t_ap	e_epc
hc	c_{12}	–0.0048	–0,0000	–0.0038	–0.0032	–0.0100	–0.0046	–0.0079	–0.0019	0.0099	–0.0095	0.0036
		(0.0108)	(0.0101)	(0.0110)	(0.0129)	(0.0090)	(0.0142)	(0.0129)	(0.0138)	(0.0155)	(0.0154)	(0.0115)
Y	β	–0.1920**	–0.1596***	–0.1903***	–0.1172***	–0.0304	–0.1477*	–0.2473**	–0.2336***	–0.1257***	–0.1909	–0.1688**
		(0.0718)	(0.0419)	(0.0585)	(0.0417)	(0.4848)	(0.0817)	(0.1117)	(0.0529)	(0.0275)	(0.1330)	(0.0625)
INFR	γ	0.1104	0.0473**	0.0041	0.0009	0.3352	0.0402	0.1088	0.0811	0.5600***	0.0383	0.1093
		(0.1453)	(0.0207)	(0.0991)	(0.0014)	(1.0050)	(0.1610)	(0.1900)	(0.2555)	(0.1380)	(0.2030)	(0.1503)
Y×INFR	φ	–0.0101	–0.0055**	–0.0032	–0.0077	–0.0291	–0.0034	–0.0122	–0.0106	–0.0518***	–0.0040	–0.0083
		(0.0137)	(0.0022)	(0.0111)	(0.0055)	(0.1105)	(0.0142)	(0.0192)	(0.0249)	(0.0138)	(0.0215)	(0.0157)
Sample size		342	339	342	342	332	237	294	201	166	320	312
Within R^2		0.7513	0.7573	0.7557	0.7524	0.7546	0.7773	0.7740	0.8343	0.8388	0.7462	0.7435
Pesaran CD test(1) [p-value]		[0.1356]	[0.111]	[0.1539]	[0.1696]	[0.1478]	[0.1682]	[0.1611]	[0.1861]	[0.1287]	[0.1688]	[0.1353]
Test for differing group intercepts(2) [p-value]		[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]
Wald test (3) [p-value]		[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]
Hausman test(4) [p-value]		[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]	[<0.001]
Wooldridge test(5) [p-value]		[0.0889]	[0.0649]	[0.0985]	[0.0952]	[0.0929]	[0.0907]	[0.0909]	[0.0713]	[0.0871]	[0.0864]	[0.0691]

Note: (1) A low p-value counts against the null hypothesis: cross-sectional independence. (2) A low p-value counts against the null hypothesis: the groups have a common intercept, i.e. OLS outperforms the estimator based on within transformation. (3) A low p-value counts against the null hypothesis: no time effects, i.e. time-dummies, are irrelevant. (4) A low p-value counts against the GLS estimates with random-effects in favour of the estimator based on within transformation. (5) A low p-value counts against the null hypothesis: no first-order serial correlation in error terms. Heteroscedasticity robust standard errors are presented in parentheses. All estimations include time and country fixed-effects and are based on within transformation with a Huber-White Sandwich correction. *, **, *** indicates significant at the 10, 5 and 1 per cent level, respectively.