Transport infrastructure and technical efficiency in a panel of countries: Accounting for endogeneity in a stochastic frontier model

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Borradores de ECONOMÍA

No. 1187
2021

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Transport infrastructure and technical efficiency in a panel of countries: Accounting for endogeneity in a stochastic frontier model[♦]

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Abstract

In this paper, a global production frontier is estimated using stochastic frontier models to assess the contribution of transport infrastructure to countries' performance. We find that the role of infrastructure is underestimated under the exogeneity assumption indicating that handling endogeneity is crucial in the estimation. Results suggest that a better endowment of infrastructure contributes to economic growth, highlighting its importance in explaining differences in the economic performance of countries. Efficiency measures indicate that high-income countries are more efficient than low- and middle-income countries, suggesting that there is room for improving economic performance in countries with a lower income level. Better institutions also are essential to foster countries' economic output.

JEL classification: H54, O18, O40, C19

Keywords: Transport infrastructure, stochastic frontier, efficiency, endogeneity

[♦] We would like to thank Arturo Galindo, Armando Montenegro for their suggestions and comments to a previous version of this paper and to Daniel Lasso and Sebastian Giraldo for their comments.
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Infraestructura de transporte y eficiencia técnica en un panel de países: Considerando la endogeneidad en un modelo de frontera estocástica[♦]

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Resumen

En este artículo se estima una frontera de producción global utilizando modelos de frontera estocástica para evaluar la contribución de la infraestructura de transporte en el desempeño de los países. Encontramos que el papel de la infraestructura se subestima bajo el supuesto de exogeneidad, lo que indica que tener en cuenta la endogeneidad es crucial en la estimación. Los resultados sugieren que una mejor dotación de infraestructura contribuye al crecimiento económico, destacando su importancia para explicar las diferencias en el desempeño económico de los países. Las medidas de eficiencia indican que los países de ingresos altos son más eficientes que los países de ingresos bajos y medios, lo que sugiere que hay espacio para mejorar el desempeño económico en países con un nivel de ingresos más bajo. Mejores instituciones también son esenciales para fomentar el crecimiento económico de los países.

JEL classification: H54, O18, O40, C19

Keywords: Infraestructura; Transporte; Frontera estocástica, eficiencia, endogeneidad

♦ Agradecemos a Arturo Galindo y a Armando Montenegro por sus sugerencias y comentarios a una versión previa del documento. También agrademos a Daniel Lasso y a Sebastian Giraldo por sus comentarios.

1. Introduction

The relationship between transport infrastructure and economic growth has been well documented in the economic literature. Transport infrastructure has been recognized as one of the main determinants of a country's productivity and economic growth (e.g. Aschauer, 1989a, 1989b; Munnell, 1992; Gramlich, 1994; Bougheas et al. 2000; Calderón and Servén, 2004; Barro and Sala-i-Martin, 1995; Agénor and Moreno-Dodson, 2006; Agénor, 2010; Ramey, 2020; and Ramírez et al. 2021). However, endogeneity can be an essential issue when estimating this relationship since economic and productivity growth may also affect the country's demand and supply of infrastructure (Esfahani and Ramirez, 2003).

In this paper, we use a stochastic frontier methodology to estimate a global production frontier to evaluate the contribution of transport infrastructure to technical efficiency addressing the potential endogeneity problem. The estimation is carried out for a sample of 89 countries for the period 1985-2017. Analyzing infrastructure is important given the considerable heterogeneity in its provision among countries. In this line of research, Albino-War et al. (2014) use efficiency frontier analysis, Data Envelopment Analysis (DEA), and Partial Free Disposal Hull method to assess the relative efficiency of most Middle East and North African countries and four countries in the Caucasus and Central Asia region (Azerbaijan, Kazakhstan, Uzbekistan, Turkmenistan), which are oil exporter countries (MCDOEs), in converting public investment expenditures into infrastructure. The authors proxied infrastructure with the component of the global competitiveness indicator, which includes roads, railroads, and ports, developed by the World Economic Forum, averaged over 2006 and 2012. Their results suggest that the relative efficiency of MCDOEs tends to be lower than in non-MCD (the Middle East and Central Asia) commodity-exporting countries. Then, MCDOEs have substantial room to improve public investment efficiency.

Similarly, the IMF (2015) estimates public investment efficiency on infrastructure quality and coverage across 134 countries using non-parametric efficiency frontiers. The results show that there is substantial space for improving public investment efficiency in most countries. In particular, the average efficiency gap, measured as the distance between the average country and the frontier for a given level of public capital stock and income per capita, is 27%, and the size of the gap becomes smaller as income rises.

However, these papers did not handle the potential endogeneity in the relationship between infrastructure and economic output in the non-parametric frontier's models. Few papers have empirically addressed endogeneity issues in stochastic frontier models, but none of them include infrastructure variables affecting technical efficiency. Amsler, Prokhorov, and Schmidt (2016) estimate a stochastic frontier model using data on dairy farms in Northern Spain. The authors allow for the possible endogeneity of the five inputs (labor, cows, land, hectares of land allocated to pasture and crops, and expenses) included in the model. They find that land is the only exogenous variable, and the other four inputs are endogenous. Then, the authors estimate the production function using different approaches, including instrumental variables and conclude that endogeneity makes a substantial difference in the results.

Karakaplan and Kutlu (2017) also develop a panel stochastic frontier model that deals with the endogeneity problem of both frontier and inefficiency variables. The authors apply their method to analyze the Japanese cotton spinning industry's technical efficiency and market competitiveness. Their results show that market concentration is endogenous, and when its endogeneity is adequately handled, it has a more significant negative impact on the technical efficiency of cotton spinning plants. They also find that the exogenous model significantly overestimates efficiency in concentrated markets in the Japanese cotton spinning sector.

Recently, Karakaplan and Kutlu (2019) use a stochastic education cost frontier model to estimate the determinants of school district expenditures in California. They estimate the degrees of public school district cost inefficiency while addressing the endogeneity in the model. Their results indicate that the effects of student achievement and education market concentration on expenditure per pupil in California are substantially more significant when endogeneity is addressed.

Our paper contributes to the literature on three main fronts. First, we assess the role of transport infrastructure in the countries' output, using a global production frontier. Second, by estimating a stochastic frontier model, we compare the results of the exogenous model with the endogenous one, highlighting the importance of handling potential endogeneity problems that made arise. Third, for estimating the production frontier, we consider two methods that vary according to the treatment given to the infrastructure variables. In the first one, infrastructure variables directly affect the shape of the frontier and, therefore, they are included as regressors in the production function. In the second, infrastructure affects the country's efficiency, that is, the distance between the production of each country and the frontier. The difference in the efficiency measures obtained from the two models sheds light on the contribution of infrastructure to the performance of the countries.

We find that the effects of infrastructure on efficiency are substantially larger when endogeneity is handled. Results indicate that if countries operated under similar infrastructure conditions, the differences in their economic performance would be reduced since a better endowment of infrastructure would allow countries to obtain a higher product, given their provision of inputs. This result highlights the importance of infrastructure in the country's economic growth.

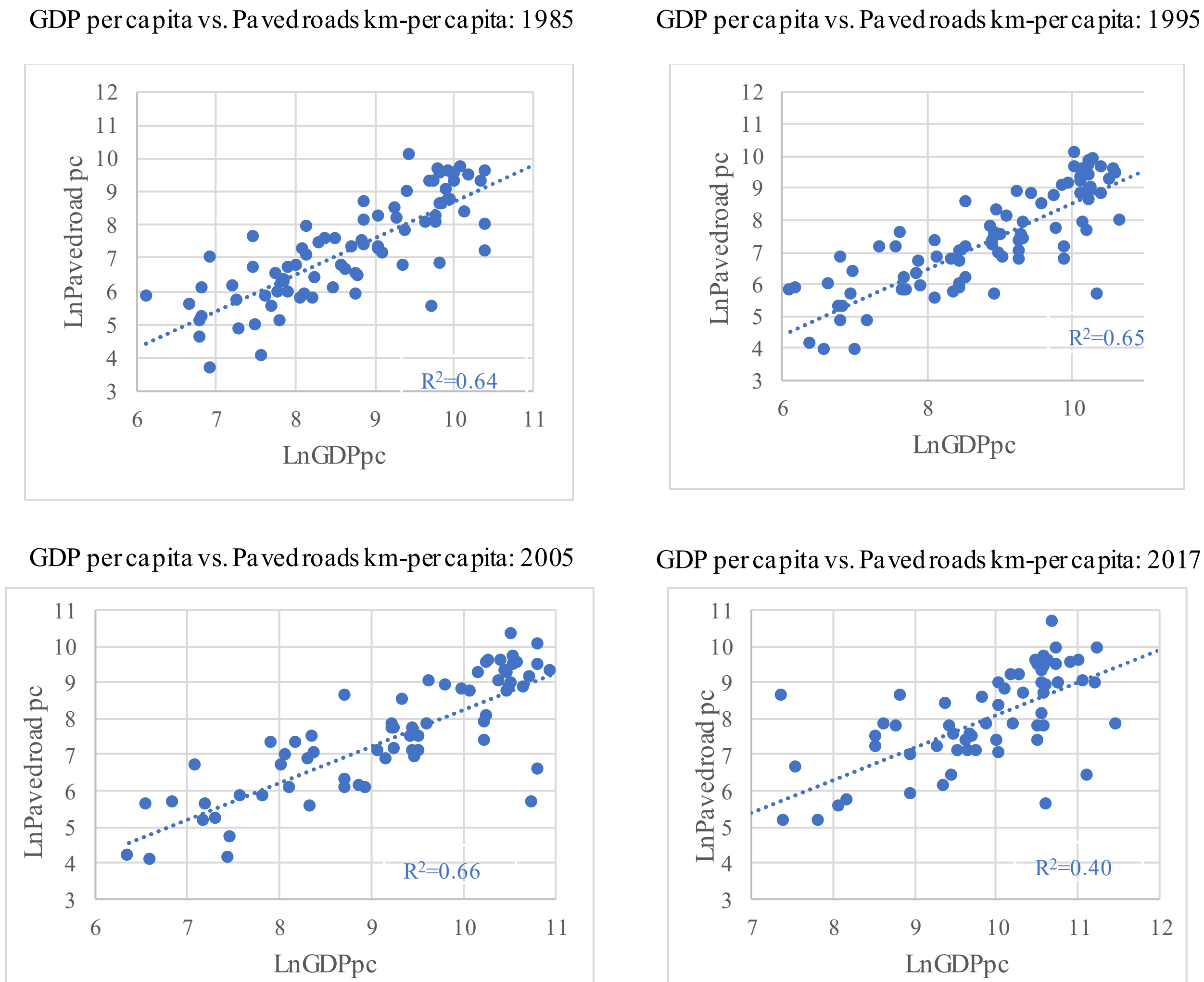
The paper proceeds as follows. Section 2 presents an overview of transport infrastructure and economic growth in a sample of countries. Section 3 outlines the econometric and empirical model. Section 4 discusses the data used to estimate the contribution of infrastructure to technical efficiency. Section 5 presents the results, and section 6 concludes.

2. Transport infrastructure and economic growth: An overview

The positive relationship between transport infrastructure and output is presented in graphs 1 and 2. For our sample of countries, paved roads and railroads per inhabitant are highly correlated with GDP per capita. For the period 1985 and 2017, the length of paved roads per inhabitant is strongly correlated with GDP per capita, with the correlation coefficient (R^2) between 0.66 and 0.40 (Graph 1). The length of the railways per inhabitant is also correlated with GDP per capita, with a R^2 coefficient between 0.53 and 0.42 during the same period (Graph 2).

Graph 1

GDP per capita and kilometers of paved roads per capita: sample of countries

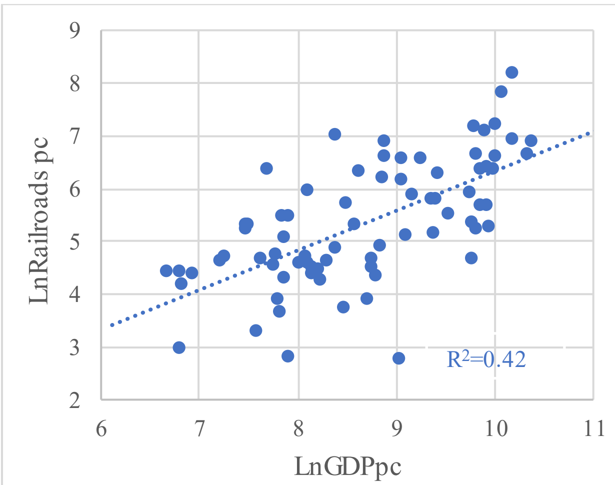


Sources: Feenstra, Inklaar and Timmer (2015), Canning (1998), World Development Indicators, ECLAC(2002)

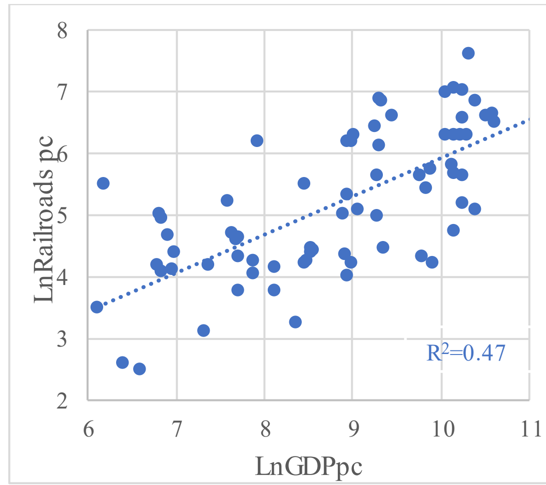
Graph 2

GDP per capita and kilometers of railroads per capita: sample of countries

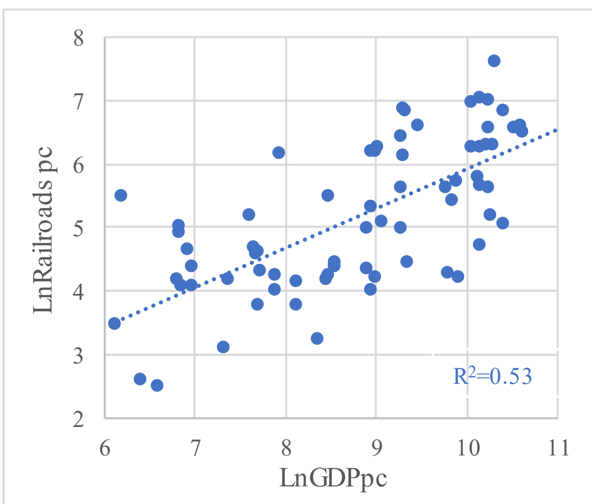
GDP per capita vs. Railroads per capita: 1985



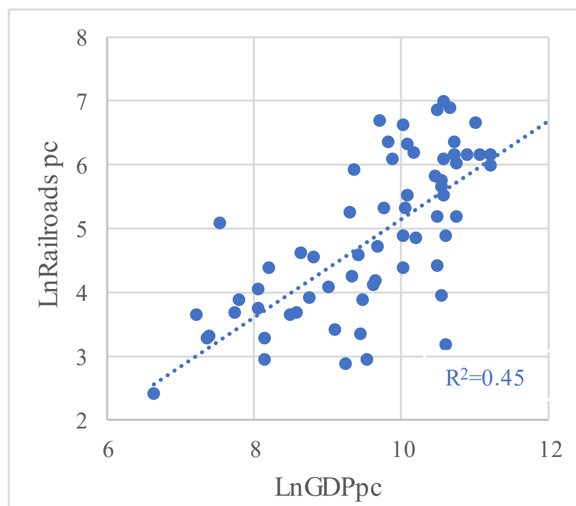
GDP per capita vs. Railroads per capita: 1995



GDP per capita vs. Railroads per capita: 2005



GDP per capita vs. Railroads per capita: 2017

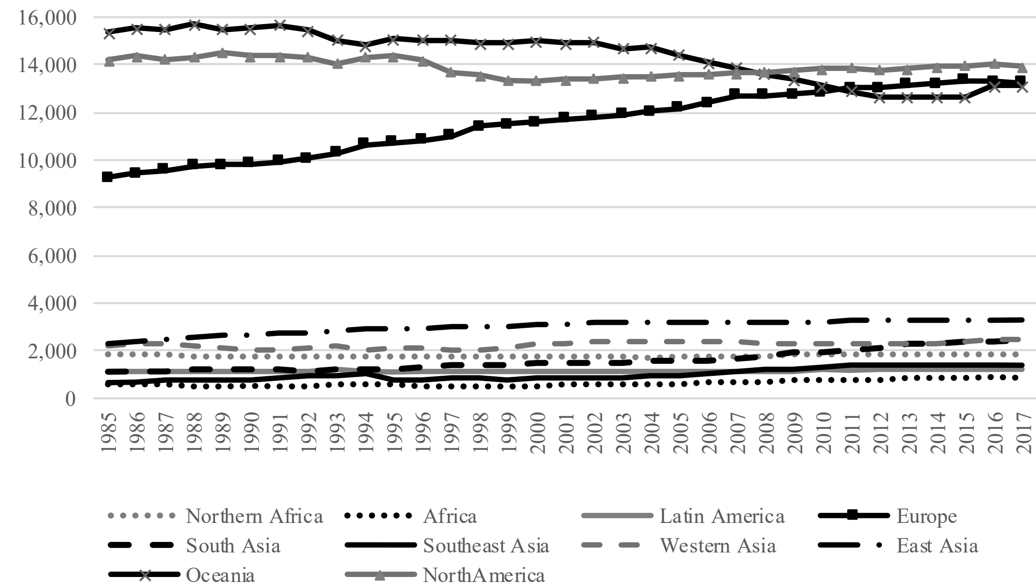


Sources: Feenstra, Inklaar and Timmer (2015), Canning (1998), World Development Indicators, ECLAC(2002)

Graphs 3 and 4 show the evolution of the length of paved roads and railroads per inhabitant, respectively, by regions of our sample. There is a considerable gap between Europe, North America, Oceania, and the rest of the areas regarding paved roads per inhabitant. The same pattern occurs when railroads per capita are compared among regions, although the gap is smaller.

Graph 3

Paved Roads (km per inhabitants): average sample by regions



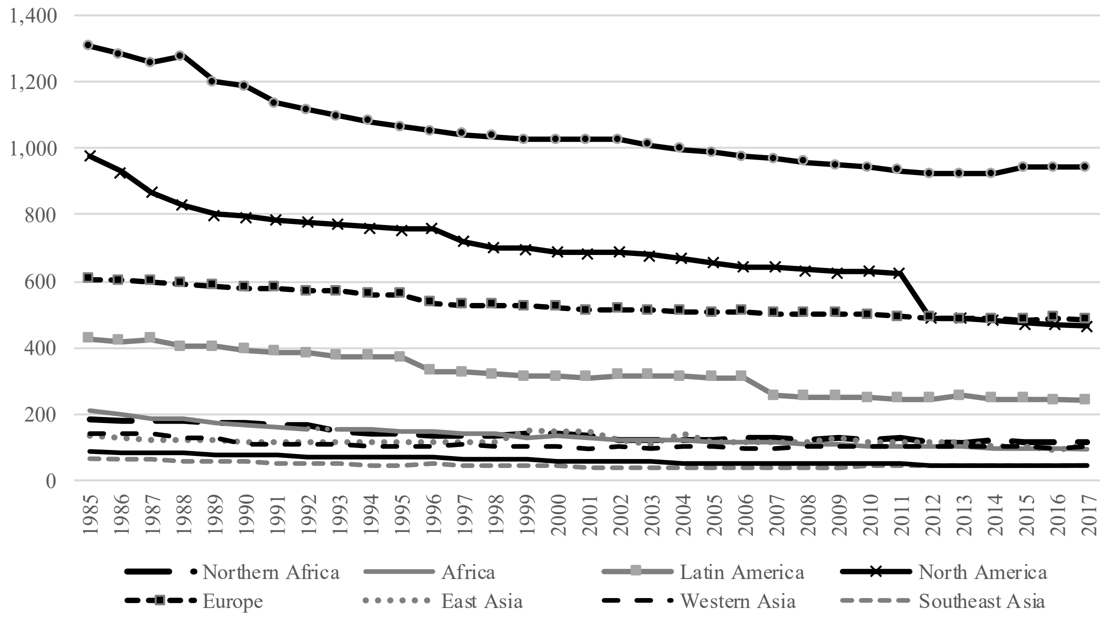
Sources: Canning (1998), World Development Indicators, ECLAC(2002)

Except for Europe and South Asia, there are no significant increases in the length of the paved road network per inhabitant between 1985-2017. On the other hand, there is a decrease in the railways per inhabitant in most regions during the same period.

In addition, graphs 5 and 6 present the evolution of the length of paved roads and railroads per inhabitant, respectively, for some countries of our sample. As observed, there are significant differences among countries regarding transport infrastructure. Wealthy countries, such as France, New Zealand, and the United States, exhibit considerably more paved roads per capita than middle-income countries, such as Mexico, Thailand, Turkey, Colombia, and Argelia, and much more than low-income countries, such as India, Senegal, Ghana, Zimbabwe, among others. In turn, on average, oil exporter countries, Kuwait, Iraq, Iran, Qatar, and Saudi Arabia, have a higher provision of paved roads than most middle and low-income countries. As Albino et al. (2014) indicate, the high oil prices during the last decade helped maintain important levels of public investment in infrastructure in most oil exporters countries. A similar pattern occurs when railroads per capita are compared among countries.

Graph 4

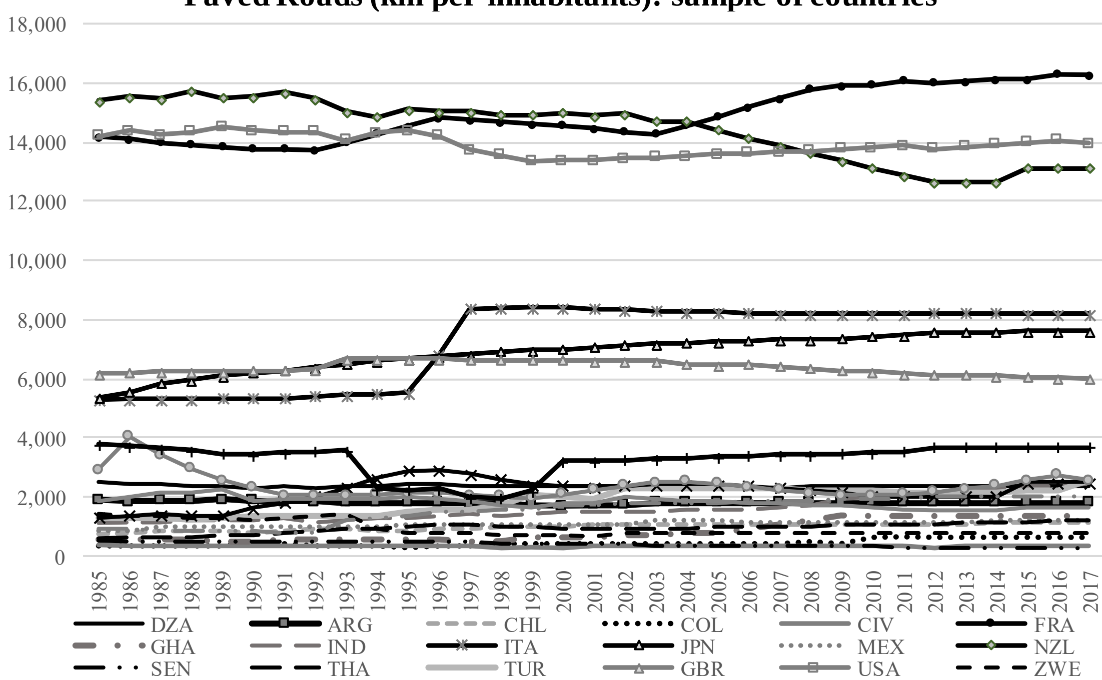
Railroad length (km per inhabitants): average sample by regions



Sources: Canning (1998), World Development Indicators, ECLAC(2002)

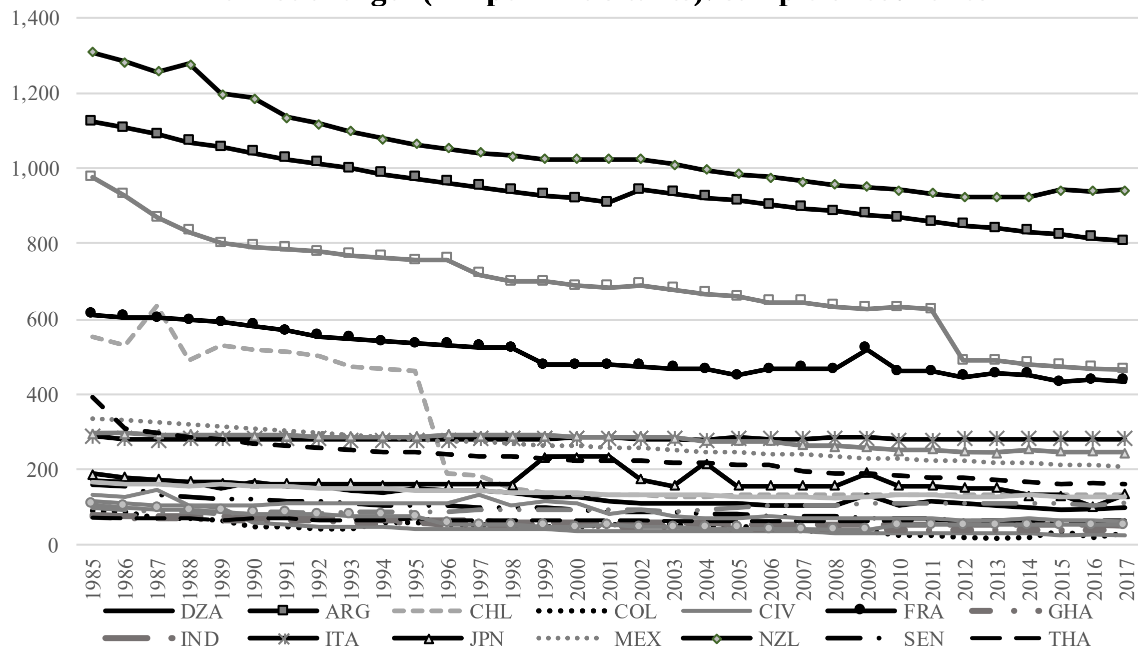
Graph 5

Paved Roads (km per inhabitants): sample of countries



Sources: Canning (1998), World Development Indicators, ECLAC(2002)

Graph 6
Railroad length (km per inhabitants): sample of countries



Sources: Canning (1998), World Development Indicators, ECLAC(2002)

3. Econometric and empirical models

This paper estimates a global stochastic frontier for a sample of countries during the period 1985-2017. The global production frontier is a function, $y = f(x)$, that describes the maximum product, Y, that a country produces using a basket of inputs, X (physical capital, labor, and infrastructure in this case). The distance between each country's production and the frontier measures technical inefficiency, which varies between 0 and 1, the closer to 1, the country is more efficient.

Based on Kumar and Russell (2002) and Kumbhakar and Wang (2005), the global production frontier is estimated using stochastic frontier techniques by using maximum likelihood methods, which allow estimating the distance of the different countries (technical inefficiency) to an estimated global production frontier. Let's consider the following stochastic frontier model:

$$ln y_{it} = \beta_0 + \sum_{k=1}^{K} \beta_k ln\, x_{k,it} + \boldsymbol{\varepsilon}_{\mathrm{i,t}} \quad (1)$$

$$\varepsilon_{it} = v_{it} - u_{it} \quad (2)$$

Where y is the output, x_k is the vector of k inputs. The error term (ε) can be decomposed into two components: a random part ($\boldsymbol{v}$) and a non-negative component that measures technical inefficiency ($\boldsymbol{u}$), which corresponds to the distance of each country from the global production frontier and takes non-negative values. We consider two alternative methods for estimating the production frontier, according to the treatment given to the infrastructure variables. In the first method, the infrastructure variables (z) affect the efficiency (distance between the production of each country and the frontier). In the second, infrastructure variables are directly included as regressors in the production function.

In the first alternative, the estimation is carried out using the Battese and Coelli (1995) approximation, in which the efficiency term, $\boldsymbol{u}$, is a function of the z_m vector of m infrastructure variables.

$$u_{it} = z_{m,it}\delta_m + W_{it} \tag{3}$$

Where W is a random variable, which is defined as the truncated normal distribution with mean 0 and variance σ^2, δ_{m} is a parameter to be estimated, and *i* denotes a country and *t* a year. From the normal mean that assumes that u is a random variable that is distributed $N(0,\sigma_u^2)$, where the mean of the conditional distribution is given by:

$$E[(u_{it}|\varepsilon_{it})] = \frac{\sigma\lambda}{1+\lambda^2}\left[\frac{\phi(\varepsilon_{it}\lambda/\sigma)}{1-\Phi(-\varepsilon_{it}\lambda/\sigma)} - \frac{\varepsilon_{it}\lambda}{\sigma}\right] \tag{4}$$

where ϕ and Φ are the density and distribution functions of the standard normal mean, and λ and σ are the standard deviations of the composite error term, we can obtain the mean of the conditional truncated normal distribution, changing expression from $\varepsilon_{it}\lambda/\sigma$ to $\mu^* = \varepsilon_{it}\lambda/\sigma + \mu/\sigma\lambda$ in equation (4). Then the truncated normal distribution has an additional parameter to be estimated μ.

Potential endogeneity problems may arise in estimating the production frontier in both alternatives due to the relationship between the dependent and the infrastructure variables (Ramírez et al. 2021). Endogeneity in a stochastic frontier model would lead to inconsistent parameter estimates. To handle the endogeneity issue, we follow the methodology for endogeneity in stochastic frontier models recently introduced in the literature by Amsler, Prokhorov, and Schmidt (2016, 2017) and Karakaplan and Kutlu (2017) and Karakaplan (2017, 2018). In this paper, we use the instrumental variable (IV) approach in the stochastic frontier.[1] As instrumental variables, we consider military spending executed by countries since expenses are not associated with fluctuations in economic activity and are driven by geopolitical factors (Avellan et al. 2020). Military expenditures are positively correlated with the infrastructure variable, although there could also be a tradeoff between these two variables. We also include the roughness of the terrain, which is divided by the population, to consider the population density in the roughest areas.

4. Data

The data set consists of annual country-level information on aggregate output (real GDP), inputs (capital stock at constant prices and labor, defined as the number of people employed increased by human capital), and infrastructure variables (length in kilometers of paved roads in per capita terms, and the kilometers of railways per capita). We also include the variable landlocked in the set of infrastructure variables, which could be a proxy, although imperfect, of seaports availability. Landlocked is a dichotomous variable that is one if a country has access to the sea and 0 otherwise. We also include institutional variables to evaluate the effect of infrastructure in countries with different degrees of institutional quality.

We use a panel data structure for a sample of 89 countries for the period 1985-2017. We get the data on output and inputs from the "Penn World Tables," the socioeconomic variables (population and human capital (average years of education)) from the World Bank. Information on transport infrastructure is taken from the World Bank, Canning (1998), and updates by this author, and the landlocked dummy variable from Mayer and Zignago (2011). The data on institutions come from the International Country Risk Guide (ICRG). Regarding instrumental variables, information on military expenses is from the Stockholm International

[1] We used the code for Stata developed by Karakaplan (2017, 2018), which allows estimating stochastic production frontier models with endogeneity in inputs and environmental variables.

Peace Research Institute (SIPRI)'s military expenditure database. The variable roughness of the terrain comes from Nunn and Puga (2012).

5. Estimation results

Table 1 shows the parameters and standard deviations of the stochastic global production frontier for the exogenous and endogenous estimations of two models: Model 1 considers z variables as affecting the distance between the production of each country and the frontier. Model 2 considers z variables as regressors of the production function and, therefore, affect the frontier's shape. In both cases, the estimation for the exogenous model is carried out by using Battese and Coelli's approach (1995), in which infrastructure and the institutional variables are the environmental variables. In turn, the endogenous model is estimated by following Karakaplan's (2017, 2018) methodology. As mentioned, the endogenous model uses military spending and terrain ruggedness index as instruments. The endogenous test rejects the hypothesis that the correction for endogeneity is not necessary. So, there is endogeneity in the model, and a correction is needed.[2]

The first-order coefficients for the capital and labor, which correspond to average partial elasticities, suggest that an increase in inputs is reflected, on average, in higher production levels. Indeed, an increase of 1% in the total capital stock raises the product between 0.60% and 0.67%, and a 1% increase in labor increments the product between 0.37% and 0.45%, depending on the model.

[2] Results from the first step of the estimation are available upon request.

Table 1: Estimates of the global production frontier. Instruments: Military spending and terrain ruggedness index

	Model 1		Model 2	
	Endogenous model	Exogenous model	Endogenous model	Exogenous model
Constant (β_0)	0.8229***	0.8981***	0.8097***	0.8822***
	(0.025)	(0.037)	(0.025)	(0.036)
ln(Capital Stock)	0.6330***	0.6667***	0.5953***	0.6511***
	(0.018)	(0.014)	(0.025)	(0.014)
ln(labor)	0.4196***	0.3815***	0.4450***	0.3712***
	(0.021)	(0.015)	(0.030)	(0.015)
ln(Capital Stock^2)	-0.0758***	-0.0781***	-0.0931***	-0.0809***
	(0.010)	(0.011)	(0.010)	(0.011)
ln(labor^2)	-0.0145	-0.0476***	-0.0407***	-0.0505***
	(0.017)	(0.017)	(0.015)	(0.016)
*ln(Capital Stock*labor)*	0.0408***	0.0593***	0.0661***	0.0681***
	(0.012)	(0.013)	(0.011)	(0.012)
Constant (δ_0)	-0.4013**	-0.0787***		
	(0.190)	(0.028)		
ln(Infrastructure)	-0.2405***	0.3785	0.1253***	0.0273*
	(0.042)	(0.446)	(0.027)	(0.014)
Landlocked	0.4159	-0.1746***	-0.0975	-0.2931***
	(0.447)	(0.015)	(0.064)	(0.079)
ln(Investment profile)	-0.0841***	-0.0787***	0.0413***	0.1099***
	(0.024)	(0.028)	(0.015)	(0.008)
ln (σ_u^2)			-0.348*	-0.223
			(0.173)	(0.174)
ln(σ_v^2)		-4.6885***		-4.708***
		(0.032)		(0.032)
ln(σ_w^2)	-4.9667***		-4.966***	
	(0.033)		(0.033)	
Endogeneity Test	$Chi^2(1)=20.96$		$Chi^2(1)=15.24$	
	(0.000)		(0.000)	
Observations	1,906	1,906	1,906	1,906
Log Likelihood	-523.43	1639.46	-523.95	1634.5

Source: Authors' calculations Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Regarding infrastructure variables, results significantly differ between the endogenous and exogenous models. The coefficients of infrastructure are larger and more significant when endogeneity is considering in both models, highlighting the importance of handling potential endogeneity issues in the estimation.

Considering that the endogeneity test supports the endogenous models, the interpretation of results is based on these models since the parameter efficiency estimates would be inconsistent in the exogenous ones. In Battese and Coelli's functional form, a negative (positive) coefficient has a positive (negative) effect on technical efficiency. Thus, having more km of per capita paved roads and railroads brings countries closer to the production frontier, indicating that countries with better infrastructure are more efficient and benefit from a more favorable environment than countries with lower infrastructure endowments.[3] In turn, the landlocked variable has no significant effect on the efficiency of countries. In the model that infrastructure affects the shape of the frontier rather than the distance to the frontier, roads and rail infrastructure also have a positive and significant effect. In contrast, the landlocked variable does not have a significant one.

To assess the effect of institutions on countries' efficiency, we include the indicator of countries' investment profiles as a proxy for institution quality. This variable evaluates the factors that affect the country's investment risk and results from the sum of three subcomponents: viability/expropriation of the contract, repatriation of profits, and late payments. This variable is positive and significant in both models, indicating that countries with higher investment profiles are more efficient. To this extent, they are closer to the production frontier. Thus, better institutions contribute to better economic performance in terms of efficiency.[4]

Table 2 presents the technical efficiency calculations obtained from the endogenous model estimations of the production frontier under Models 1 and 2. The difference between

[3] It is worth mentioning that in the exogenous model, infrastructure is not significant.
[4] We include the interaction between institutional and infrastructure variables in the estimations to assess the effect of infrastructure on countries with different degrees of institutional quality. However, this interaction is not significant.

efficiency measures from the models indicates the contribution of the infrastructure variables to the country's performance. Results show that for 1985-2017, the average technical efficiency obtained from Model 1 is 0.4947 and from Model 2 is 0.6109. Although in both cases, high-income countries are more efficient than low and middle-income countries, when the infrastructure variables directly affect the production function (Model 2), countries registered, on average, less dispersed efficiency measures than those estimated under Model 1 (Figure 1).[5] Thus, transport infrastructure helps explain the heterogeneities between countries mainly by its contribution to technical efficiency rather than its effect on the accumulation of factors.

When equivalent environments are assumed (Model 2), the average technical efficiency of the low-income countries is higher in 0.1980 than the efficiency obtained from Model 1. In high-income countries, the difference reduces to 0.0671, which can be attributed to the advantages these countries might get from their infrastructure conditions. Indeed, while the high-income countries have an average of 10,176 kilometers of paved roads and railways per capita, the middle-income countries have 1,843 and the low-income countries 715. These figures stand out the importance of infrastructure in explaining differences in efficiency across countries and indicate that high-income countries could be obtaining lower returns to infrastructure investment, middle-income countries might still get returns on infrastructure, but with diminishing marginal returns. In contrast, low-income countries might have high returns.

Regarding the oil-exporting countries, it can be highlighted the high levels of efficiency obtained under both models. This group of countries also has the greatest difference in the efficiency measures obtained from the two models, suggesting the importance of transport infrastructure in the economic performance of these countries. The elevated oil prices observed in part of the analyzed period could explain these results. As Albino et al. (2014) mention, this resulted in high levels of public investment in most oil exporters.

[5] The groups' distribution is based on 2020 information from the World Bank available on: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

Table 2: Technical Efficiency

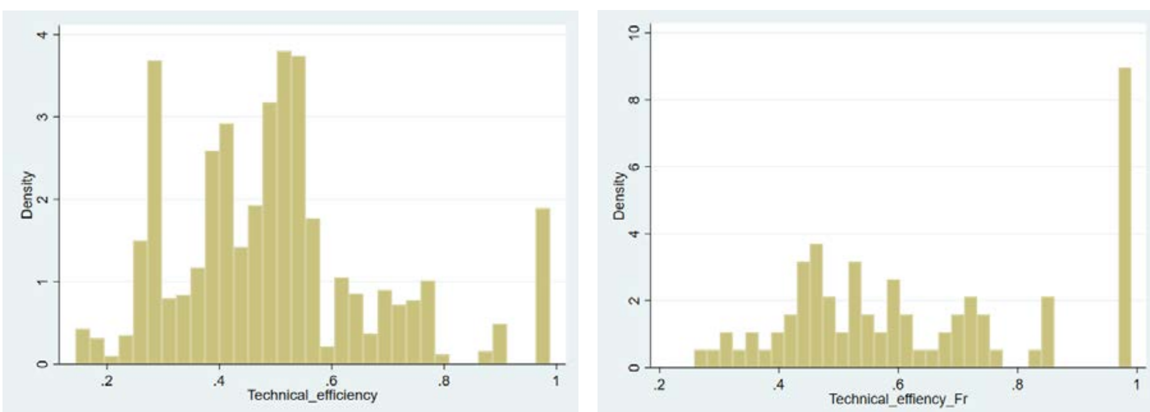
Instruments: Military spending and terrain ruggedness index

Groups of countries	Model 1		Model 2		Dif (3)-(1)
	Average (1)	Stand. Dev. (2)	Average (3)	Stand. Dev (4)	
Global frontier	0.4947	0.1818	0.6109	0.2043	0.1162
Low-income countries	0.3741	0.1258	0.5721	0.1606	0.1980
Middle-income countries	0.4890	0.1980	0.5814	0.1896	0.0924
High-income countries	0.5866	0.1557	0.6537	0.2300	0.0671
Main oil exporting countries	0.7504	0.2673	0.8843	0.1705	0.1339
Non-oil countries	0.4793	0.1635	0.5854	0.1879	0.1061

Source: Authors' calculations

Figure 1. Frequency distributions of technical efficiency

Model 1 | Model 2



Source: Authors' calculations

6. Conclusions

This paper estimates a global production frontier to evaluate the effect of infrastructure on countries' economic performance by considering two estimation methods and addressing potential endogeneity problems. In the first method, infrastructure variables directly affect the shape of the frontier and, in the second, they affect the country's efficiency. The difference in the efficiency measures obtained from the two models provides information on infrastructure contribution to countries' economic growth. For a large sample of countries, we find that the effects of infrastructure on efficiency are considerably larger and more significant when endogeneity is handled. Then, the role of transport infrastructure on efficiency is underestimated under the exogeneity assumption.

Results support the endogenous models and indicate that a better endowment of infrastructure would allow obtaining a greater economic product, highlighting its importance in the differences in the economic performance of countries. Efficiency measures indicate that high-income countries are more efficient than low- and middle-income countries, suggesting that there is room for improving economic output. Transport infrastructure helps explain the heterogeneities between countries mainly by its contribution to technical efficiency rather than its effect on the accumulation of factors.

In terms of public policy, the results of this paper highlight the need to dedicate more resources to build and maintain transportation infrastructure, considering the impact it has on economic growth through improving the efficiency of the countries' resources. Strong institutions also are essential for countries to promote better economic performance in terms of efficiency.

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