REM WORKING PAPER SERIES

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José Pedro Pontes and Joana Pais

REM Working Paper 032-2018

March 2018

REM – Research in Economics and Mathematics
Rua Miguel Lúpi 20,
1249-078 Lisboa,
Portugal

ISSN 2184-108X

The role of infrastructure efficiency in economic development – the case of underused highways in Europe

by

José Pedro Pontes[1] and Joana Pais[2]

Abstract: In this paper, we establish a two way causality between the phenomenon of the infrastructure which is underused (the so called "white elephant case") and the aggregate productivity level (TFP) of the economy. On the one hand, the fact that a transport infrastructure is not used so much as it could be is itself a cause of low TFP, because it represents a low productivity for an important item of social capital. On the other hand, low aggregate productivity makes firms strategies founded on large scale of production and exports more risky, given the possibility that the political decision to build the required transport infrastructure may never be taken.

Keywords: Total Factor Productivity, Efficiency in Infrastructure Use; Economic Development, Transport Economics.

JEL Classification: O12, O47, R40.

Acknowledgements: This paper had the support of UECE (Research Unit on Complexity and Economics) is financially supported by FCT (Fundação para a Ciência e a Tecnologia), Portugal, which is gratefully acknowledged. This article is part of the Strategic Project (UID/ECO/00436/2013).

[1] Lisbon School of Economics and Management (ISEG), University of Lisbon (UL), Research Unit on Complexity and Economics (UECE) and Research in Economics and Mathematics (REM), corresponding author. Email ppontes@iseg.ulisboa.pt.

[2] Lisbon School of Economics and Management (ISEG), University of Lisbon (UL), Research Unit on Complexity and Economics (UECE) and Research in Economics and Mathematics (REM).

Introduction

Since SOLOW's (1957) seminal paper, economists are well aware that a large share of labor productivity growth is not accounted by the increase in capital per worker, Hence its causes remain largely unknown so that they should be gauged by means of a statistical residual, the *total productivity factor* (henceforth TFP). It is widely agreed that this residual expresses the closeness of the economy to the technological frontier. This closeness is limited by the degree of efficiency in the use of capital stock at the economy level.

The measure of TFP is far from exact since it relies on an estimate of total capital stock which is fundamentally not fully observable and it is often blended with aggregate productivity as technical progress appears to be embodied in new plant and equipment. Nevertheless, it appears that SOLOW (1957)'s residual is an important share of total economic growth. For instance, BURDA and SEVERGNINI (2009) estimate a proportion in TFP variation in the US case of about one third of total economic growth for the time period between 1994 and 2004. For less developed countries, this share appears to be even higher. NDULU (2006) deems that slightly less than one half of the economic growth differential between Africa in the south of Sahara and other developing countries can be accounted for by slow aggregate productivity growth.

In some sense, the TFP concept is just a "measure of ignorance" of economic science about the causes and hindrances of economic growth. There were several attempts to overcome this ignorance, the more direct one was the generalization of the concept of "capital" along two broad directions: from "physical capital" to "human capital" (as in MANKIW, ROMER and NEIL, 1992); and from "private capital" to "public capital" also labeled as "infrastructure" (as in ASCHAUER, 1989, and BARRO, 1990). While in empirical terms this generalization appeared to diminish the size of the Solow residual, it increased the degree of returns to scale in aggregate production at the theoretical level thereby confirming main assumptions of endogenous growth theory.

The inclusion of public capital as a main growth factor covered two different types of inputs, namely the "physical infrastructure" (such as roads, railways, water distribution, power generation and distribution, telecommunications and so on) and the so called "legal infrastructure". The latter type is related with the capacity that agents in an economy have to celebrate and enforce the contracts which govern transactions.

A different approach was started by HULTEN (1996) consisting in approximating aggregate productivity through indicators of effectiveness of use of pieces of physical infrastructure. An ineffective infrastructure compels private firms to invest privately in complementary inputs, such as private power generators, thereby reducing their capacity to invest productively (REINIKKA and SVENSSON, 2002).

Infrastructure such as roads can be ineffective either because it is in a bad condition due to poor maintenance, or because it is oversized on account of bad planning or overpricing (RIOJA, 2003). In the latter case, they are usually labeled as *white elephants*. We will focus on the economic factors explaining the latter type of apparently "irrational" infrastructure provision.

For this purpose, we will use the framework of development economics (ROSENSTEIN-RODAN, 1947; MURPHY, SHLEIFER and VISHNY, 1989; KOHEI and TABATA, 2013), where each of a set of economic agents, who are tied by demand or cost complementarities, decides either to stick to a “traditional technology” (small scale, constant returns, local sales only) or to switch to a “modern technology” (large scale, increasing returns, exports).

Since, in standard development economics, the complementary agents are symmetric, the economy usually works as coordination game with two symmetric equilibria, namely the *Big Push* (all firms invest in modern technology) and the *Poverty Trap* (each agent sticks to traditional technology). Hence, the asymmetric outcome where the highway is built but the firms do not use it, thus remaining confined to local customers, can never arise in equilibrium. In order to allow for a *white elephant* equilibrium, we feature an asymmetric game where a political agent (the *Government*) decides whether to build a highway or not and a firm (or set of firms) decides whether to use the infrastructure or not.

The fact that the Government is a player in this political-economic game, leaves us with the question of specifying its payoff function. While there exist many different forms of stating political payoffs in an exact theoretical form, it is hard to establish these kinds of behavior empirically. Furthermore, public choices in developing countries are often described in terms of “corruption” or “political sins”, whose aggregate rationality is hard to assess (see, among others, DAL BÓ and ROSSI, 2007; CHAKRABORTY and DABLA-NORRIS, 2011). Consequently, we opted to model this situation through an incomplete information game, where the *Government* has two types, namely a “builder/active” and a “non-builder/passive” type, which fully determine the provision of the highway.

Some data on efficiency in highways use and total factor productivity across countries of the European Union

For a subset of 24 countries in the European Union (the **EU28**, without *Cyprus, Latvia, Luxembourg* and *Malta*, but including the *United Kingdom*), we gathered the data shown in Table (2.1).

EU countries	x, Dens. Pop.	y, Dens. Highways	g, Δ% TFP 2000-2004
Austria	99	2.0	1.0
Belgium	344	5.8	0.6
Bulgaria	70	0.4	4.0
Croatia	76	2.2	2.3
Czech Repub	131	0.9	6.3
Denmark	126	2.6	0.6
Estonia	29	0.3	6.4
Finland	16	0.2	1.7
France	111	1.8	0.5
Germany	225	3.6	0.7
Greece	84	0.9	2.3
Hungary	108	1.6	2.9
Ireland	60	1.3	1.7
Italy	195	2.2	–0.4
Lithuania	45	0.5	7.8
Netherlands	394	6.4	–0.3
Poland	122	0.3	3.0
Portugal	114	2.9	–0.5
Romania	91	0.1	5.6
Spain	87	2.9	–0.8
Slovakia	111	0.9	3.5
Slovenia	99	3.8	1.9
Sweden	20	0.4	1.4
United Kingdom	246	1.5	1.0

(2.1)

The meaning of the variables is the following:

x is the country population density, measured in People per Km^2 in years 2006/2007, according to *Eurostat*.

y is the density of highways within the country, measured in 1 Km of highway *per* 100 Km^2 of surface in the end of year 2011. The source is the *European Union Road Federation Yearbook 2014 - 2015*.

g is the country average annual growth rate in *total factor productivity* during the period 2000 - 2004, according to BURDA, Michael and Battista SEVERGNINI (2009), "TFP growth in Old and New Europe", *Comparative Economic Studies*, 51: 447 - 466. The formula employed to measure TFP is the so-called "Solow-Törnqvist residual", which amounts to

$$\left(\frac{\Delta A}{A}\right)_t = \frac{\Delta Y_t}{Y_{t-1}} - \omega_{t-1}\frac{\Delta K_t}{K_{t-1}} - \left(1-\omega_{t-1}\right)\frac{\Delta N_t}{N_{t-1}} \qquad (2.2)$$

In expression (2.2), the l. h. s. shows the relative variation in TFP between periods $t-1$ and t. In the r. h. s., $Y_t, K_t,$ and N_t stand for aggregate output, capital stock and employment in period t. $\omega_{t-1} \equiv \left(S_{K_t} + S_{K_{t-1}}\right)/2$, where S_{K_t} represents the share of capital in national income in period t.

We estimate by OLS the equation

$$y = \alpha_0 + \alpha_1 x + \varepsilon \qquad (2.3)$$

with the usual iid assumptions on the error term. The theoretical expectation is that $\alpha_1 > 0$. Since highways provision should be driven by travel demand, it is expected to be directly proportional to population density. Indeed, the estimated structure is

$$\hat{y} = 0.0949 + 0.0144x \qquad (2.4)$$

This indeed a tight fit with $R^2 \approx 0.64$. The assumption that $\alpha_1 = 0$ can be rejected with an error smaller than 0.01.

We can measure the efficiency levels in the use of highways by travellers by calculating the negatives of the residuals of this fit. We label this variable as z. Observations of z in EU countries are shown in Table (2.5).

EU countries	Highways use efficiency, z
Austria	–0.48
Belgium	–0.754
Bulgaria	0.702
Croatia	−1.011
Czech Repub.	1.08
Denmark	–0.692
Estonia	0.212
Finland	0.125
France	–0.107
Germany	–0.267
Greece	0.404
Hungary	0.049
Ireland	–0.342
Italy	0.702
Lithuania	0.242
Netherlands	–0.634
Poland	1.551
Portugal	−1.164
Romania	1.305
Spain	−1.553
Slovakia	0.792
Slovenia	–2.28
Sweden	–0.017
United Kingdom	2.136

(2.5)

Then we calculate the Pearson correlation coefficient between variables g (TFP average annual growth rate in the period 2000 - 2004) and z (efficiency level in the use of highways). This coefficient is shown to be about 0.436 . It is different from zero in the significance level 0.05 .

A discussion about the meaning of the correlation between variables g and z will be made in the following section.

A model of association between highway use efficiency and total factor productivity

The observed strong correlation between TFP and efficiency in highways use across most EU countries can be rationalized as deriving from a two way causality. On the one hand, highways are an important part of the aggregate capital stock and its specific productivity is included in the overall TFP accounting.

On the other hand, to build many infrastructures in an economy characterized by low aggregate productivity will lead likely to the emergence of the so-called *white elephants*, i. e., public capital which will be barely used. In order to model this latter direction of causality, we present the following model, inspired by MURPHY et Al. 1989.

We presuppose a spatial economy composed by two symmetric regions. In each one of these, a composite consumer good is produced by a fringe of small, competitive firms, under a constant returns technology, where one unit of labor is transformed into one unit of output. We define

$$\begin{aligned} w &\equiv \text{ wage rate} \\ p &\equiv \text{ delivered price of composite consumer good} \\ \pi &\equiv \text{ firm profit} \end{aligned} \tag{3.1}$$

We assume that each region contains n identical consumers/workers with a demand function which is strictly decreasing in price and exhibits a unit constant price elasticity. Consequently, the aggregate demand for the composite good in each region is given by

$$d = \frac{y}{p} \tag{3.2}$$

where y stands for the aggregate income of consumers in each region.

As the firms producing the composite good are competitive, their profits will be zero in equilibrium. Furthermore, we assign specific values to parameters such that

$$w = p = 1 \tag{3.3}$$

Since there is a positive transport cost for the composite good between the regions, each competitive firm can only sell to local customers thus refraining from any kind of export. Hence, this technological/geographical pattern will be labelled as “proximity to consumers”.

In each region, we presuppose that one of the firms has the option to switch to an increasing returns technology, where it produces $\alpha > 1$ units of composite good by employing 1 unit of labor as a unit variable cost and spending F units of labor as a fixed cost. Therefore F stands for a capital cost, and it comprises both physical capital (an equipment embodying a new technology) and “legal capital” (the cost of overcoming the public regulations and formalities which make any kind of industrial reorganization intrinsically difficult). The unique firm which switches to a modern technology becomes the most efficient one and it drives the competitors out of business thereby becoming a monopolist. Consequently, we label this strategy as “concentration”.

As MURPHY et Al. (1989) remarked, the firm which becomes a monopolist keeps unchanged the delivered price p which it charges the consumers. Indeed, if it rises the price, it would be undercut and driven out of business by the competitors. It does not pay to decrease the price either, because it already sells to all consumers at price p and the price elasticity of the demand for the composite good is one.

For simplicity, we will also assume that the wage rate is not affected by the transition to a modern technology. The associated rise in consumers' income is fully accounted for by the dividends which accrue to firm shares which are fully held by consumers.

The degree of spatial concentration of manufacturing depends crucially on the availability of transport infrastructure linking the two regions which compose the country. The Government is a player in this game and it takes the political decision of either building a highway connecting the two regions or refraining from building it. In the former case, a firm with a modern technology can supply the other region through exports by incurring a positive but arbitrarily small freight expenditure per unit of output dispatched, ε. By contrast, if the highway is not built, transport costs across regions are prohibitive and the firm is able to sell only to consumers living in the region where it is located.

If the Government builds the highway, and production is concentrated, the monopolist's profit can be written as

$$\pi = \left[\left(p - \frac{w}{\alpha}\right) + \left(p - \varepsilon - \frac{w}{\alpha}\right)\right]\left(\frac{y}{p}\right) - Fw$$

By taking into account (3.3) and the fact that the transport cost between regions, ε, is arbitrarily small, the concentrated firm's profit can be approximated by

$$\pi \approx 2\left(1 - \frac{1}{\alpha}\right) y - F \qquad (3.4)$$

Since a single modern firm supplies both regions, its profit should be equally shared by all consumers. Consequently, the aggregate income in each region can be written as

$$y = \frac{\pi}{2} + nw = \frac{\pi}{2} + n \qquad (3.5)$$

By substituting y from (3.5) in (3.4) and solving for π, we obtain the profit of a concentrated firm that exports to the other region in a situation where the Government takes the political decision to build a highway linking the two regions.

$$\pi \approx 2n(\alpha - 1) - \alpha F \qquad (3.6)$$

We deal now with the situation where there is productive concentration but each firm can sell only in its local market. This follows from the fact that the Government refrains from investing in a highway linking the regions.

The firm's profit is now expressed by

$$\pi = \left(p - \frac{w}{\alpha} \right) \left(\frac{y}{p} \right) - Fw = \left(1 - \frac{1}{\alpha} \right) y - F \tag{3.7}$$

Since consumers within each region hold the shares of the concentrated firm which operates there, the regional consumer income is

$$y = \pi + nw = \pi + n \tag{3.8}$$

Solving together (3.7) and (3.8), we obtain the profit of a concentrated firm if the political decision of building a modern transport infrastructure is not taken.

$$\pi = n(\alpha - 1) - \alpha F \tag{3.9}$$

The working of this economy is featured here by means of a static game, where an economic decision is taken by a firm, which represents a set of productive units, and a political decision (either to invest or not invest in a transport infrastructure) is taken by the Government.

As it was remarked in the Introduction, it is hard to assess empirically the rationality of the Government's behaviour, which seems often to depend upon motives apparently not related with the political decision per se. This explains why many public decisions are described through terms such as "corruption" or "political sins", particularly in developing countries. This reason led us to model this situation as an *incomplete information game*, where the Government has two types and exhibits a dominant strategy for its type. By contrast, the representative firm is profit maximizing and shows a single type.

More specifically, the economic agents believe that the Government's payoffs are,

- δ, which takes values $\begin{cases} 1 & \text{with probability } p \\ -1 & \text{with probability } (1-p) \end{cases}$, if a highway is built.
- 0, if a highway is not built.

Hence, the payoff matrix of this two persons, static and incomplete information game can be easily written.

Government		Firm: Concentration	Firm: Proximity to consumers
	Build highway	$a_{11} = \delta, b_{11} = 2n(\alpha - 1) - \alpha F$	$a_{12} = \delta, b_{12} = 0$
	Not Build	$a_{21} = 0, b_{21} = n(\alpha - 1) - \alpha F$	$a_{22} = 0, b_{22} = 0$

(3.10)

This game may have different Bayesian-Nash equilibria, according to the way the parameters n, α and F and the belief p are specified. Here, we limit ourselves to the conditions where an underused transport infrastructure may arise, i.e. to the outcome resulting from the pair of strategies $(\text{Build Highway, Proximity to consumers})$.

It is clear that a necessary condition for a "white elephant" to emerge is that is built in the first place, so that it is more likely when the belief p is high. However, this belief should not be too high because then firms would opt for "geographical concentration" and start using the highway to export consumer goods to the other region.
An upper bound on the belief p follows from the condition that, from the firm's viewpoint, the expected payoff of "proximity to consumers" should not be lower than the expected payoff of "concentration", for a given value of p. From payoff matrix (3.10), this means that

$$pb_{11} + (1-p)b_{21} \le pb_{12} + (1-p)b_{22}$$

Or, equivalently,

$$p\left[2n(\alpha-1)-\alpha F\right]+(1-p)\left[n(\alpha-1)-\alpha F\right]\le 0 \tag{3.11}$$

If we solve (3.11) in relation to p, we obtain the condition

$$p \le \left(\frac{\alpha}{\alpha-1}\right)\left(\frac{F}{n}\right)-1 \tag{3.12}$$

In order to interpret (3.12), we rewrite it in terms of the belief that the Government **does not build** the highway, $(1-p)$. The condition becomes

$$1-p \ge 2-\left(\frac{\alpha}{\alpha-1}\right)\left(\frac{F}{n}\right) \tag{3.13}$$

It is clear that the r. h. s. of inequality (3.13) is an increasing function of α (the "labor productivity" in an economy with modern technology) and a decreasing function of $\left(\frac{F}{n}\right)$ (the "capital intensity" of this kind of economy). Hence, by definition it is also a proxy of total factor productivity as it is given by SOLOW (1957)'s residual.

The fact that highways are not so much used as they could be is *per se* a cause of low aggregate productivity, as an important piece of social capital exhibits a low productivity level. But the causal relation also runs in the other way. Indeed, as (3.13) shows, the domain of beliefs by the firm for which the conservation of a locally oriented strategy is a best reply decreases with the rise in aggregate productivity following from the adoption of modern, spatially concentrated technologies.

A low initial level of aggregate productivity increases the riskiness for the firm of selecting productive methods which entail large scale production and exports and it strengthens the dominance for economic agents of strategies founded upon local sales. If the new transport infrastructure is eventually put in place, it will be barely used thus becoming a "white elephant".

Concluding remarks

We have seen that that a two way causality can be established between the phenomenon of little infrastructure use (the so called “white elephant” situation) and aggregate productivity. On the one hand, the fact that a transport infrastructure is underused is in itself a determinant of low TFP, because it represents a low productivity level for an important item of social capital. On the other hand, low aggregate productivity makes firm strategies founded on large scale of production and exports more risky, given the possibility that the political decision to build the required infrastructures may never be taken.

Besides the above described kind of inefficiency, other sources of poor infrastructure on the supply side are common in developing economies, due namely to careless maintenance or management. Run down public hospitals and schools or underground networks in big cities are common examples in Southern European countries. It would be interesting in future research to assess the theoretical connection between these kinds of supply side inefficiency with the low demand case which was the subject of this paper.

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