Infrastructures and the real exchange rate

Florian MORVILLIER*

This paper investigates the nonlinear relationship between infrastructures and the Real Effective Exchange Rate (REER). Applying a Panel Smooth Transition Regression (PSTR) model to a sample of 31 countries over the period 1973-2014, we find strong evidence of a nonlinear impact of electricity generating capacity (EGC) and telecommunications on the REER dynamics. When the network is not completed or the stock of infrastructures is low, an increase in EGC and telecommunications depreciates the REER, while the additional depreciation is lower or inexistent once the network is established. Finally, turning to power grid quality, we show that higher electric power losses are associated with a REER depreciation that is particularly marked when the former are high.

JEL codes: F31, F41

Keywords: Infrastructures, Panel Smooth Transition Regression, Real Exchange Rate.

*EconomiX-CNRS, University of Paris Nanterre. 200 Avenue de la République, 92001 Nanterre Cedex, France. Email: morvillier.florian@parisnanterre.fr
I am very grateful to Valérie Mignon for valuable comments and suggestions. I would also like to thank two anonymous referees for very helpful remarks.

1 Introduction

One of the explanations for the stagnation of productivity in developing economies is the absence of adequate infrastructures (IImi and Smith, 2007). Braese et al. (2019b) estimate that deficient infrastructures result in losses of capacity utilization rates of firms, amounting to $151 billion per year for low- and middle-income countries. The lack of reliable infrastructures is a key issue because they are essential to overall competitiveness (Braese et al., 2019b) due to the associated productivity gains. The latter are of primary importance since they can reduce domestic production costs, influencing the dynamic of the Real Exchange Rate (RER). Surprisingly, the literature dealing with the effects of infrastructures on the RER is very scarce. This chapter aims at filling up this gap.

Within the literature dealing with the RER determinants, the work from Du et al. (2013) is the closest to ours. They find evidence of a robust negative effect of transport network on countries' RER.[2] Their results are encompassed in a theoretical framework within which an infrastructure improvement introduces more competition among domestic firms, lowering thus the mark-up of firms selling. If the subsequent decrease in the domestic price level is higher in this country than in other economies, it creates a depreciation of the domestic currency. Galstyan and Lane (2009) examine the effects of infrastructures using government investment. However, this variable is not suitable for this purpose for at least two reasons. First, the monetary measures of public investment are inadequate to track the effect of physical capital stock (Calderón et al., 2015). Indeed, as noted by Pritchett (1999) and Arestoff and Hurlin (2010), higher government investment does not automatically translate into a higher capital stock due to public inefficiency. Second, over time, the public sector investment is not devoted only to the financing of productive activities.

Falling into this strand of the literature, we contribute to the existing studies in three ways. Our first contribution is to take into account the multidimensionality of the infrastructure network, while Du et al. (2013) consider only one dimension. Accordingly, we propose three new Real Effective Exchange Rate (REER) determinants. Second, while the literature dealing with the REER determinants typically assumes linear relationships, we show the relevance of the nonlinearity hypothesis when accounting for infrastructures. Finally, our third contribution is to provide several transmission channels associated with these new determinants.

To this aim, this chapter investigates the effects of infrastructures on the REER using a heterogeneous panel of 31 countries over the period 1973-2014. Our empirical analysis takes into account the multidimensionality of the infrastructure network by examining the impacts of Electricity Generating Capacity (EGC) and telecommunications. While the two previous variables constitute quantitative measures of infrastructures, we also examine the quality of the electrical network using electric power transmission and distribution losses. Since infrastructure investment is characterized by the existence of network effects (Agénor and Moreno-Dodson, 2006; Candelon et al., 2013; Calderón and Serven, 2015), nonlinearities in their marginal productivities appear. To account for the

[2]The transport network includes the following elements: quantitative measures of infrastructures (kilometres of roads and rail lines), and countries' transportation capacity (goods transported by roads, railways, air and inland waterway).

presence of these network effects, we rely on the Panel Smooth Transition Regression model (Gonzalez et al., 2017). This methodology allows us to examine the nonlinear relationship between infrastructures and the REER, by investigating whether the effects of our infrastructure variables depend on their levels.

Our results show strong evidence of a nonlinear relationship between telecommunications, electric power, and the REER. When the telecommunications network is not totally completed, an increase in telecommunications per 1000 workers is associated with a REER depreciation. Once the network is completed, the additional depreciation associated with a rise in this variable is rather small. Considering the EGC per 1000 workers, we only observe a REER depreciation for "low" levels of electric power. We explain these results through the *productivity* transmission channel. As a rise in the infrastructure stock is associated with productivity gains, it leads to a reduction in production costs lowering the domestic price level and, in turn, causing a depreciation of the REER. The additional depreciation associated with higher telecommunications and EGC per worker is small or non-existent as the productivity gains are mainly concentrated when the network is not completed. Finally, higher electric power losses are associated with a REER depreciation. The latter is higher in the regime of "high" electric power losses: to face power losses, more firms have to implement costly coping measures, which may increase the price of traded goods. Considering the internal definition of the REER, it results in a depreciation of the domestic currency.

Our chapter is organized as follows. Section 2 reviews the related literature. Section 3 presents the data and methodology. Section 4 reports and discusses our empirical results. Finally, Section 5 concludes the chapter.

2 Related literature

This section reviews the relevant literature to determine the transmission channels through which infrastructures can influence the RER.[3] Section 2.1 presents the macroeconomic and microeconomic effects of infrastructures. Since transmission channels are likely to differ depending on the type of infrastructure considered, electricity and telecommunications infrastructures are discussed separately. Section 2.2 is devoted to the presentation of the impacts of the telecommunication network. Finally, Section 2.3 reviews the literature on the effects of electricity generating capacity. This section also discusses how the quality of the power grid affects the economy.

2.1 Macroeconomic and microeconomic effects of infrastructures

To shed light on the potential effects of the infrastructure stock, Barro's (1990) model constitutes a useful benchmark. He builds an endogenous growth model where public services serve as inputs to private production. In his theoretical framework, a raise in public services provided to each household-producer increases the marginal productivity of private input factors (capital and labor), thereby promoting growth. This transmission channel is one of the three "conventional channels" identified by Agénor and Moreno-Dodson (2006) in their review of

[3] Our review draws heavily upon the literature investigating the relationship between infrastructures and growth (see the surveys of Calderón and Servén (2014) and Bom and Ligthart (2014), for overviews of the infrastructures-growth nexus).

the infrastructure-growth nexus. Hulten et al. (2006) refer to this mechanism as the "non-market mediated" infrastructure effects. Infrastructure-augmented production function estimations corroborate the existence of this transmission channel. Indeed, examining a heterogeneous panel of 88 countries over the period 1960-2000, Calderón et al. (2015) obtain a long-run elasticity between infrastructure stock[4] and GDP per 1000 workers ranging from 0.07 to 0.10. Investigations at the firm level also support the previous result. Indeed, Mitra et al. (2016) find that an overall higher infrastructure stock increases the productivity of Indian manufacturing firms. Furthermore, Anos-Casero and Udomsaph (2009) show that an improvement in infrastructure quality ameliorates significantly Total Factor Productivity (TFP) of the Eastern European firms examined.

One potential drawback of the previous empirical investigations is the assumption of a linear relationship between infrastructure stock and marginal productivity. This hypothesis may be potentially misleading for two reasons. On the one hand, infrastructure is "lumpy" since the existence of a specific amount of infrastructure assets is required to observe a positive effect of infrastructure investment on private sector productivity (Agénor, 2010). On the other hand, infrastructure presents network effects as the marginal productivity of higher investment in infrastructures is a function of existing stocks (Candelon et al., 2013). Given these two characteristics, a nonlinear specification is thus more appropriate to investigate infrastructure effects. To this end, Candelon et al. (2013) rely on a Panel Threshold Regression (PTR) model. They confirm the existence of network effects for several infrastructure variables (electricity, telecommunications, and transportation) in developing economies. Once a sufficient level of infrastructure stock is reached, infrastructure investments have higher marginal productivity than other investments,[5] while their marginal effects are smaller once the network is completed. In other words, the marginal productivity of infrastructures should be higher if the network is not entirely established, while it is expected to be lower if the network is totally completed.

The second channel stems from the existence of a complementary effect between infrastructure stock and private investment. The increase in private productivity leads to a rise in the expected return of private capital, which pushes up the private investment rate. Agénor and Moreo-Dodson (2006) identify a third channel dealing with the crowding-out effects of higher public infrastructure. Crowding-out effects work through different transmission channels. Assuming that an increase in distortionary taxes finances the rise in the public infrastructure stock, it may reduce the propensity to invest. Thus, it leads to a decrease in private investment. Domestic borrowing is the second option available for the government to finance increasing capital infrastructures. In this situation, it may reduce private investment because of the rise in the domestic interest rate. The emergence of these crowding-out effects may be understood in the light of the "innovation driven endogenous growth model" of Zagler and Durnecker (2003). In this framework, private investment is crowded-out if the marginal productivity of public infrastructure is lower than its marginal costs. The model of Zagler and Durnecker (2003) raises the question of the optimal level of

[4] Calderón et al. (2015) rely on a synthetic infrastructure indicator built as the first principal component of the following variables: energy power, roads and telecommunications.

[5] The other types of investments examined by Candelon et al. (2013) are human and physical capital stocks.

infrastructure stock in the economy. Based on a “reduced-form” estimable equation, Canning and Pedroni (2008) find that infrastructure provisions are on average at their optimal level. Furthermore, Egert et al. (2009) provide evidence of overinvestment in infrastructures in some advanced economies.

Infrastructures may also affect growth through "new channels". Agénor and Moreno-Dodson (2006) propose the "adjustment costs channel". They define adjustment costs as "frictions that prevent firms from adjusting their capital stock fully and instantaneously in response to, say, a demand shock, a change in the relative price of capital, or an increase in productivity." These adjustment costs may be lower if the infrastructure stock and its quality improved. For example, in the presence of an electrical power network subject to frequent power outages, firms may have to invest in their own additional generators to meet higher demand. As a result, an improvement in the quality of the public power grid reduces their adjustment costs. Infrastructure provision also affects firm production costs through the "market-mediated" channel of Hulten et al. (2006). For their productive activity, firms purchase intermediate goods and services that are produced by industry using infrastructures such as roads, electricity and telecommunications. An improvement in the stock of infrastructures therefore helps to lower the costs of these inputs for firms.

2.2 Telecommunications: transmission channels

Telecommunication infrastructures have the potential to improve overall productivity (Datta and Agarwal, 2004). The development of the telecommunication network reduces the acquisition cost of information and facilitates the flows of information, thus promoting the innovation process (Leff, 1984; Roller and Wavermann, 2001). To investigate the relevance of this transmission channel, Mitra et al. (2016) examine the effects of Information and Communications Technology (ICT)[6] on Indian manufacturing firms over the period 1994-2010. They show that an improvement in ICT leads to an increase in TFP in several sectors in India. This effect is particularly strong in the textile, transport equipment and metal and products industries. Using the number of telephone lines per worker, Yeaple and Gollub (2007) find that this variable affects positively TFP in the sector of transport and instrument (Yeaple and Gollub, 2007).

Mobile telephones have been increasingly popular since the 1990s (Lee and Ward, 2016) and play on the ability to conduct business (Straub, 2011). This is particularly important for the agricultural sector, where new opportunities are emerging with the availability of mobile-based applications (Aker, 2011). Based on these applications, farmers have access to information such as market prices, weather, transport and agricultural techniques. Increasing mobile coverage reduces the costs of obtaining information price for consumers, traders, and producers in agricultural markets (Aker and Mbiti, 2010). As a result, better telecommunications reduce the variable cost of market participation, increasing competition between firms (Egert et al., 2009; Deichmann, 2016). This transmission channel is supported by the study of Muto and Yamano (2009) who examine how mobile phone expansion affects market

[6]The ICT indicator is obtained by applying the PCA methodology on the following variables: number of internet users, number of mobile of cellular subscription, and telephone main lines.

participation of farmers in Uganda between 2003 and 2005. They show that mobile phone network expansions have a higher effect on remote markets producing perishable goods.[7]

Macroeconomic studies have also paid attention to the relationship between the availability of telecommunications and agricultural productivity. Bravo-Ortega and Lederman (2004) fail to find evidence of a significant effect of telephone density, while Lio and Liu (2006) confirm that ICT and agricultural productivity are positively correlated in a sample of 88 countries. Lio and Liu (2006) also find evidence that ICT has a higher marginal effect on productivity for richer countries.

2.3 Electric power and power grid quality: transmission channels

Access to electricity and sufficient energy power are essential for both households and firms. An improvement in the energy-generating capacity per worker has the potential to increase industries' productivity as it is a key input in the production process, especially for energy-intensive firms. Yeaple and Gollub (2007) validate this transmission channel. In their investigation of the effects of infrastructure provision on industry-level productivity, they show that higher electrical power-generating capacity positively affects TFP of the chemicals and food products industries. The literature has also paid particular attention to the agricultural sector, since productivity improvements in this industry can be hampered by inadequate infrastructure provision (IImi and Smith, 2007). The relevance of this argument has been investigated by Bravo-Ortega and Lederman (2004). They find that an increase in the total plant generating capacity per capita improves agricultural productivity for 77 countries. Access to electricity is also crucial because it contributes to improving the hygiene and health of the population, thus increasing the productivity of the economy (Agénor, 2010).[8]

Electric power alone is not enough to increase productivity if it is not combined with a reliable power grid. Hallegatte et al. (2019) identify three main channels through which firms are likely to be affected by poor quality electrical infrastructures. First, frequent power outages have a direct impact on firms' activities by reducing their timely business activity (Iimi, 2011; Alby et al., 2013; Hallegate et al., 2019). This event affects firms differently, depending on their operating industry. Some sectors such as construction, manufacturing, hotel and restaurant industries are particularly vulnerable to power outages (Iimi, 2011). This reduction in business activity is critical because it leads to a reduction in revenues. Using district-level data for Indonesian manufacturers over the period 1985-2010, Poctzer (2017) confirms the relevance of this transmission channel. Relying on an Instrumental Variable (IV) approach, she finds that a deterioration in the electrical network is associated with a reduction in firms' value-added. Allcott et al. (2016) obtain similar results for Indian manufacturers. Using an alternative IV approach,

[7]Higher mobile coverage also results in lower price dispersion in the grain market (see Aker (2010) and Aker and Fafchamps (2015) on this issue for Niger).

[8]As noted by Agénor (2010), access to electricity allows the population to avoid the use of unwholesome cooking accessories hurtful for their health. It is worth mentioning that access to a reliable electrical network is also essential for the proper functioning of hospitals and schools.

they show that average electricity level shortages reported reduce firms' revenues from 5% to 10%.

Secondly, an unreliable electrical network can also push firms to adopt costly coping measures, such as investing in their own generators (Dethier et al., 2011; Alby et al., 2013; Braese et al., 2019b). This decision is particularly costly as it increases firms' operational costs because it requires the installation, maintenance, and operation of additional machinery (Braese et al., 2019a). Part of these additional operational costs comes from the cost of own-generated electricity. Steinbucks and Voster (2010) provide evidence that own generated electricity can be particularly costly for firms. They estimate that the price of purchasing (subsidized) electricity from the public grid is three times lower than the costs of own-generation for 8483 operating firms in Africa. The costs of these coping measures may be illustrated using Fisher et al. (2015)'s study. Coping measures are estimated to increase the unit production costs of the most energy-consuming Chinese firms by 8%. Allcott et al. (2016) provide a more nuanced analysis. They show that, due to electricity shortages, Indian firms experience an increase in their fuel expenditures, which is mostly offset by a reduction of their electricity bills. The increased operational costs induced by a low quality electricity grid also creates a distortion in the size of companies in the economy. There is a lower share of small firms in electricity-intensive sectors located in high-outages countries (Alby et al., 2013).

An electrical network of poor quality also biases technological progress towards labor-intensive technology (Alby et al., 2013) deterring the most productive investment. Indeed, frequent power outages reduce firms' productivity in Africa and Asia (Hallegatte et al., 2019). More precisely, Allcott et al. (2016), Poctzer (2017) and Guarra and Tessema (2018) respectively show that electricity disruptions hamper productivity for Indian, Indonesian and Ethiopian firms. Power grid quality affects not only firms' productivity but also their international competitiveness. In his investigation of the effects of power outages on firms' employment in Africa, Mensah (2018) also tests for the presence of this trade competitiveness channel.[9] Since an unreliable electrical network increases firms' production costs and leads to productivity losses, it is expected to have a negative effect on firms' trade competitiveness. Mensah (2018) finds that electricity shortages reduce exports from 6% to 12% for exporting African firms.

3 Data and methodology

3.1 Data

Infrastructure development being a long-term process, it is crucial to rely on long time-series to identify and assess its effects accurately. Given the broader availability of infrastructure variables over a long time horizon, the selection of our sample is then primarily guided by the existence of an adequate proxy for the Balassa-Samuelson (Balassa, 1964; Samuelson, 1964; BS hereafter) effect over a long-time period for a reasonable number of countries. The

[9] In the empirical investigation of Mensah (2018), the trade competitiveness is measured through two variables. The first one is share of the firms' sale of output in foreign markets. Mensah (2018) also use an indirect exports measure composed of the share of sales from output sold to domestic third party firms who export the products.

literature investigating the BS hypothesis has proposed various measures to take into account this key RER determinant (see Couharde et al. (2019) for a detailed description of the different proxies employed by the literature).[10] The Gross Domestic Product Per Capita (GDP PC) and the GDP per worker (GDP PW) are potential candidates as they are available over a long horizon for a large panel of countries. However, GDP PC has the drawback to assume a stable participation rate in the economy (Couharde et al., 2019). To cope with the previous limitation, GDP PW can be used but is also inadequate to measure the BS effect correctly. Indeed, assuming an increase in productivity in the tradable and non-tradable sectors, GDP PW increases while it is expected to have a neutral effect on the REER following the BS hypothesis (Ricci et al., 2013). These two drawbacks justify our decision to do not use these two measures. Another possible proxy is the ratio of the consumer price index to the producer price index (CPI-PPI). In practice, the use of this measure is, however, hardly compatible with our prerequisite of long time-series as PPI covers only the most recent years.

Considering the external version of the BS hypothesis,[11] the relative price of non-tradables to tradables appears to be a potential appropriate proxy. The BS effect was therefore taken into account using three and/or six-sectoral deflators (see Lee and Tang, 2007; Bénassy-Quéré et al., 2009; Ricci et al., 2013).[12] We choose to use a six-sectors deflator because it allows us to have a narrower sectoral classification, resulting in a more accurate distinction between tradable and non-tradable sectors.[13] The construction of the relative price of non-tradables to tradables is carried out using the Groningen Growth and Development Centre (GGDC) database as the primary source (Inklaar and Timmer, 2008). It provides value-added series in current and constant prices over ten sectors for 42 countries of Africa, Asia, and Latin America. To extend the GGDC series up to 2014, we rely on the United Nations (UN) database, which also makes available current and constant value-added series. As the sectoral classification of the previous database consists of 6 sectors, we aggregate the 10 sectors from the GGDC database into the six sectors available in the UN database.[14] It results in the six following sectors: (i) Agriculture, hunting, forestry, fishing; (ii) Mining, manufacturing, utilities (sum of C,D and E sectors); (iii) Construction; (iv) Wholesale, retail trade, restaurants and hotels; (v) Transport, storage and communications, and (vi) Other activities (sum of sectors I to P).[15] The use of the relative price of non-traded to traded goods requires a classification of the sectors between

[10] It is worth mentioning that the RPROD database, which is part of the EQCHANGE database, provides five different proxies for the BS effect (see Couharde et al., 2019).

[11] According to the external version of the BS effect, higher relative price of non-tradables to tradables appreciates the RER.

[12] The productivity differential between tradable and non-tradable sectors can also be used. However, this choice is complicated in practice due to data availability issues. The use of the productivity differential might be inadequate to identify the effects of infrastructures accurately. Indeed, as our literature review suggests, the infrastructure stock is likely to have a positive effect on productivity growth. Therefore, the simultaneous inclusion of this proxy and our infrastructure variables will come at the cost of difficulty in the disentangling of the "pure" infrastructure effect as part of this effect is probably captured by the productivity differential variable. Moreover, a proper examination of sectoral employment series between the ILOSTAT and GGDC databases over the period 1991-2011 shows considerable discrepancies between these two series. The obtention of reliable sectoral employment series over the period 1973-2014 is thus difficult. Hence, it is somewhat "heroic" to use the productivity differential as a measure of the BS effect if productivity is computed as the ratio between the sectoral value-added and employment.

[13] We decide to rely upon a six-sectors deflator because Morvillier (2020) provides evidence of a robust effect of the non-traded to traded relative price on the REER in a sample of developing and emerging economies. Indeed, the use of three or six sectors deflators both confirms the external version of the BS hypothesis.

[14] It should be noted that the GGDC and UN databases are both in ISIC Rev 3.1 classification. Another possibility would be to use the UNDATA database and start in 1980. However, as argued previously, our preference goes to longer time-series. The description of the divisions associated with each of these sectors is available in Table 6.1 in the Appendix.

[15] The description of the divisions associated with each of these sectors is available in Table 6.2 in the Appendix.

tradable and non-tradable. To do so, we rely on the classification proposed by De Gregorio et al.'s (1994)[16] according to which construction, wholesale, retail trade, restaurants and hotels, and other services are classified in the non-tradable sector, while agriculture, manufacturing, mining, utilities and transport are treated as tradable goods.

To derive the six-sectors' deflator, we follow Lee and Tang (2007) and compute country-specific weights for each sector ($\omega_{i,k}$), measured by their value-added ($VA_{i,t}$) share in total output:

$$\omega_{i,k} = \frac{\sum_{t=1}^{T} VA_{i,k,t}}{\sum_{k \in h} (\sum_{t=1}^{T} VA_{i,k,t})} \tag{1}$$

where i is the country, h denotes the nature of the sector k under consideration, i.e., tradable (T) or non-tradable (NT) sector.

For each country i, the aggregated value-added deflator of the non-tradable ($pva_{i,t}^{NT}$) and tradable ($pva_{i,t}^{T}$) sectors is then calculated as a weighted average of value added deflators for respectively all non-tradable sectors and all tradable sectors:

$$pva_{i,t,f}^{NT} = \sum_{k \in NT} (\omega_{i,k} \times pva_{i,t}^{k}) \tag{2}$$

$$pva_{i,t,f}^{T} = \sum_{k \in T} (\omega_{i,k} \times pva_{i,t}^{k}) \tag{3}$$

where $pva_{i,t,f}^{NT}$ and $pva_{i,t,f}^{T}$ are expressed in logarithmic terms. Denoting $def6$ the BS measure based on six-sectors' value-added deflators, we get for a country i at time t:

$$def6\_f_{i,t} = (pva_{i,t,f}^{NT} - pva_{i,t,f}^{T}) \tag{4}$$

This variable is expressed as a deviation from the main trading partners:

$$def6\_fr_{i,t} = def6\_f_{i,t} - \sum_{j=1}^{N} w_{i,j,t} (pva_{j,t,f}^{NT} - pva_{j,t,f}^{T}) \tag{5}$$

Since we seek to measure the pure BS effect rather than investigate its robustness, we assume fixed weights in the aggregation process of sectors into non-tradables and tradables.[17] Among the 42 countries initially available in the GGDC database, 11 of them are not included due to data availability issues as the PSTR methodology requires a balanced panel.[18] Given this constraint, our final sample consists of 31 countries: 11 advanced (Denmark, France, Germany, Italy, Japan, the Netherlands, Singapore, Spain, Sweden, the United Kingdom and the United

[16] This classification has been widely used in the literature (see Lee and Tang, 2007; Ricci et al., 2013; Gubler and Sax, 2019; among others).

[17] The assumption of fixed weights in the aggregation process of the sectors into non-tradables and tradables can be relaxed (see Morvillier (2020) on this issue). However, this issue is probably not important for our purpose as the aggregation process strategy does not affect the validation of the BS hypothesis for developing and emerging economies, explaining our choice.

[18] The following countries are not included: Bolivia, Botswana, China, Costa Rica, Ethiopia, Hong Kong, Malawi, Mauritius, Nigeria, South Africa, and Taiwan.

States of America), 15 emerging (Argentina, Brazil, Chile, Colombia, Egypt, India, Indonesia, Korea, Malaysia, Mexico, Morocco, Peru, Philippines, Thailand and Venezuela) and 5 developing (Kenya, Ghana, Senegal, Tanzania and Zambia) economies. Our dataset spans from 1973 to 2014. The end date of our sample is guided by data availability regarding the electricity power and distribution losses variables.

The Electricity Generating Capacity (1000 kilowatts, EGC hereafter) series are extracted from the Canning database (1998) ending in 2002. In order to obtain a consistent time series for each country, we filled up the missing values for the period 2003-2014 using the same source as Canning. To do so, we rely on the United Nations Energy Statistics Yearbooks. The quality of the electrical network is measured using electric power and distribution losses (% GDP).[19] It is the loss transmission between sources of supply and point of distribution. An increase in this indicator means a deterioration of the electrical network quality. This variable comes from the World Development Indicators (WDI) database of the World Bank. Our telecommunication indicator is the sum of the number of main-line and mobile subscriptions.[20,21] The first variable is extracted from the International Telecommunication Union database, while the second one comes from WDI. We also consider mobile subscriptions as abstracting the significant development of mobile phones will not allow us to take into consideration the entire expansion of the telecommunication network.

Transport facilities are another essential dimension of a country's infrastructure network, which includes the road network. However, several difficulties hamper the inclusion of this variable in our analysis. The main issue is to obtain consistent road series over a long time period for our sample of countries. On this point, Canning (1998) notes that: "For total roads, the definition and coverage of the data vary too much over time and across countries to produce a consistent series." This variation in the definition also makes difficult the extension of the time series up to 2014. Due to this inconsistency, we are unfortunately unable to include the roads network in our empirical analysis. To avoid scale effects in the network, we express EGC and telecommunications per 1000 workers (see Candelon et al. (2013) and Calderón et al. (2015) for similar uses).

The Real Effective Exchange Rate (REER) series against 186 trading partners –based on a time-varying weighting scheme (non-overlapping five-year average weights)– are extracted from the EQCHANGE database (Couharde et al., 2018). An increase in the REER indicates an appreciation of the domestic currency. Based on the literature dealing with the RER determinants, we include the following control variables in our model: trade openness (GDP share), the logarithm of the fertility rate, government consumption expenditures (GDP share), Net Foreign Asset (NFA) position (GDP share). Trade openness has been included as a proxy for trade liberalization (IMF, 2013). This determinant should be negatively signed as further trade liberalization is expected

[19] This variable has been used, for example, by Calderón and Chong (2004) in their investigation of the relationship between infrastructures and income distribution.

[20] See Egert et al. (2009) for a similar use.

[21] It is worth mentioning that telecommunications are part of a more general concept, known as the Information and Communications Technology (ICT). However, the development of ICT is a relatively recent fact. It is therefore difficult to include this evolution coherently in our framework, explaining our focus on the telecommunication dimension alone.

to lower the domestic price level. According to the Froot-Rogoff effect (Froot and Rogoff, 1991), higher government consumption should positively influence the RER as government consumption expenditures is biased towards non-traded goods. The fertility rate is considered as control variable as Rose et al. (2009) find a positive effect for this determinant as the young's consumption is biased towards non-traded goods. Considering the intertemporal budget constraint (Lane and Milesi-Ferretti, 2002), the Net Foreign Asset position constitutes a RER determinant. A country running a current account deficit should experience a more depreciated exchange rate in order to restore exeternal equilibrium. All the control variables are extracted from WDI, except the NFA series which come from Lane and Milesi-Ferretti database (2004). In the presence of numerous potential candidate variables, a variable selection approach can be appropriate to select the most relevant determinants. Since the start date of our sample is earlier than usual, the number of potential determinants is rather small limiting the relevance of such an approach. Moreover, as the PSTR methodology can be subject to omitted variable bias, we chose to include the most commonly used REER determinants to avoid this issue. It should be noted that Terms of Trade (TOT) are not included due to data availability issues as this variable is only available since 1980 for developing economies. Turning to the number of workers, they are extracted from the Penn World Table 9.0 (Timmer et al., 2015). A summary of all the variables, as well as their sources, is available in Table 6.3 in the Appendix. The descriptive statistics associated with our variables (stationary) are reported in Table 7.1 in the Appendix. We also check for the presence of colinearity between our regressors through the estimation of linear specifications. We obtain a Variance Inflation Factor around two showing the abscence of colinearity between our regressors.

3.2 Methodology

To investigate the existence of a nonlinear relationship between infrastructures and the REER, we rely on the PSTR model proposed by Gonzalez et al. (2017). The PSTR can be viewed as a linear heterogeneous panel data model that allows the coefficients to vary across time and cross-section depending on the values of the transition variable (Gonzalez et al., 2017). The adjustment of the estimated coefficients is smooth. The basic PSTR model with two extreme regimes is defined as follows:

$$y_{it} = \mu_i + \beta_1' X_{it} + \beta_2' X_{it} \times F(q_{it}; \gamma, c) + \phi' Z_{it} + \epsilon_{it} \tag{6}$$

for i=1,...,N, N being the number of countries, and t=1,...,T. y_{it} denotes the dependent variable, μ_i are country fixed effects, X_{it} is the set of variables to which the nonlinearity is applied, Z_{it} is a vector of control variables, and ϵ_{it} is an independent and identically distributed error term. F(.) is a transition function which is bounded between 0 and 1, expressed as follows considering a logistic specification:

$$F(q_{it}; \gamma, c) = \Big(1 + exp\big(- \gamma \prod_{j=1}^{m} (q_{it} - c_j)\big)\Big) \tag{7}$$

with γ>0 denotes the speed of transition, $c_1 < c_2 < ... < c_m$ are the threshold parameters and q_{it} is the transition variable.

Considering equation (3.6), the marginal effect of X_{it} is given by:

$$\frac{\partial y_{it}}{\partial X_{it}} = \beta_1' + \beta_2' \times F(q_{it}; \gamma, c)$$

The marginal effect of X_{it} is thus a weighted average of the coefficients β_1' and β_2' that depends on the values of the transition variable.

The implementation of the PSTR methodology involves three steps: (i) specification, (ii) estimation, and (iii) evaluation. The specification step tests the null hypothesis of linearity against the alternative of PSTR. To this aim and for robustness purposes, we rely on the six homogeneity tests proposed by Gonzalez et al. (2017). Two of them consist of different versions of a Lagrange Multiplier (LM) test. To handle heteroskedasticity and cluster-dependency issues, we also use the bootstrapped version of the LM test with the residual-based wild bootstrap (WB) and the wild cluster bootstrap (WCB) tests (see Gonzalez et al. (2017) for details). In the PSTR model, the parameters are estimated using nonlinear least squares on demeaned data. Following the procedure of Gonzalez et al. (2017), we also implement two misspecification tests. As explained by the authors, these tests are used to check if the estimated model "provides an adequate description of the data". The first specification test consists of testing the null hypothesis of PSTR against the alternative hypothesis of Time-Varying PSTR (TV-PSTR). Finally, a WCB specification test is implemented to check if the null hypothesis of our PSTR specification is rejected in favor of the alternative hypothesis of PSTR with two transition functions.[22]

Our literature review suggests that part of our infrastructure variables' effects may occur through an increase in productivity. This transmission channel is likely to cause difficulty in the identification of the "pure" infrastructure effect if a proxy for the BS effect is simultaneously included in the specification. This issue is probably mitigated by the use of the relative price of non-traded to traded goods as a measure of the BS effect. However, to check the robustness of our results to this issue, we consider two different specifications for our infrastructure variables. To disentangle the "pure" infrastructure effect, our first specification excludes the BS effect. As the previous specification suffers from an obvious omitted variable bias, our second specification augments the first one with the relative price of non-traded to traded goods. Our first specification aims to investigate the existence of a nonlinear relationship between the telecommunications network and the REER:

$$reer_{it} = \mu_i + \beta_1' telecom_{it} + \beta_2' telecom_{it} \times F(telecom_{it}; \gamma, c) + \phi' Z_{it} + \epsilon_{it} \tag{8}$$

where $reer_{it}$ denotes the logarithm of the REER, and $telecom_{it}$ is the logarithm of the telecommunication per 1000 workers for country i at time t. This variable acts as the transition variable. Z_{it} is the vector of control variables

[22]To save space, we do not report the results of the linear specification, but they are available upon request from the author.

which include: government consumption expenditures (gov cons), trade openness (open), the fertility rate (fertility) and the NFA position (nfa). According to equation (3.8), the effect of the telecommunication stock on the REER depends upon its own level. Depending on the values reached by the telecommunication stock, the link between telecommunication infrastructures and the REER is given by β_1' in the first regime (when F(.)=0) and $\beta_1'+\beta_2'$ in the second regime (when F(.)=1). Turning to the second specification, we have:

$$reer_{it} = \mu_i + \beta_1' telecom_{it} + \beta_2' telecom_{it} \times F(telecom_{it};\gamma,c) + \phi' W_{it} + \epsilon_{it} \tag{9}$$

where W_{it} includes all the aforementioned control variables, to which we add the proxy for the BS effect def_6r. This specification aims to check the robustness of our results to the interaction between our infrastructure variable and the BS effect. The telecommunications stock constitutes only one dimension of an infrastructure network. Hence, we also examine the nonlinear relationship between electricity generating capacity and the REER:

$$reer_{it} = \mu_i + \beta_1' egc_{it} + \beta_2' egc_{it} \times F(egc_{it};\gamma,c) + \phi' Z_{it} + \epsilon_{it} \tag{10}$$

where egc_{it} denotes the logarithm of the Electricity Generating Capacity per 1000 workers of country i at time t. This specification allows us to focus only on the nonlinear effect of the power plant capacity per workers and disentangle the "pure" effect of the EGC per 1000 workers on the REER. As before, we check the robustness of the findings emerging from equation (3.10) using the following second specification:

$$reer_{it} = \mu_i + \beta_1' egc_{it} + \beta_2' egc_{it} \times F(egc_{it};\gamma,c) + \phi' W_{it} + \epsilon_{it} \tag{11}$$

We further investigate the nonlinear relationship between the power grid quality and the REER dynamic through the estimation of the following equations:

$$reer_{it} = \mu_i + \beta_1' eleclosses_{it} + \beta_2' eleclosses_{it} \times F(eleclosses_{it};\gamma,c) + \phi' Z_{it} + \epsilon_{it} \tag{12}$$

$$reer_{it} = \mu_i + \beta_1' eleclosses_{it} + \beta_2' eleclosses_{it} \times F(eleclosses_{it};\gamma,c) + \phi' W_{it} + \epsilon_{it} \tag{13}$$

where $eleclosses_{it}$ is the electric power and distribution losses (% GDP). Note that all explanatory variables are stationary, some of them being expressed in first difference to reach stationarity. Table 7.2 in the Appendix provides a summary of the panel unit root tests results.[23]

[23]The detailed results of the panel unit root tests are available upon request from the author. We also check for the presence of colinearity between our regressors through the estimation of linear specifications. We obtain a Variance Inflation Factor around two showing the abscence of colinearity between our regressors.

4 Estimation results

4.1 Telecommunication infrastructures

We start our empirical analysis by testing the null hypothesis of linearity in equations (3.8) and (3.9) using the logarithm of telecommunications per 1000 workers as the transition variable. Here, our purpose is to test whether the effect of telecommunications on the REER depends on the level of the telecommunication network reached. The results of the homogeneity tests are reported in Table 7.3 in Appendix, and show that the null hypothesis of homogeneity is strongly rejected in favor of the nonlinearity alternative for both equations (3.8) and (3.9). Therefore, the inclusion of the BS effect in our specification does not affect the existence of a nonlinear relationship between the telecommunication stock and the REER. Overall, our results provide evidence that the telecommunication per 1000 workers impacts the REER differently, depending on the level of the telecommunications stock reached. Table 1 below reports the estimates of equations (3.8) and (3.9); the associated transition functions being displayed in Figures 8.1 and 8.2 in the Appendix.

Table 1: Telecommunications: results

	Regime 1	**Regime 2**	**Regime 1**	**Regime 2**
	(1.1)	(2.1)	(3.1)	(4.1)
Δopen	-0.311**		-0.295*	
Δnfa	0.069		0.028	
gov cons	-0.607		-1.434*	
Δfertility	0.486		0.0833	
telecom	-0.696*	-0.220***	-0.614**	-0.187***
def6_fr			0.560***	
gamma	0.714***		0.711**	
c	4.475***		4.475***	
TVP parameters WCB test	0.992		0.927	
RNL WCB test	0.968		0.993	

Note: This table reports the estimation of PSTR models (Eq. (3.8) in columns (1.1) and (2.1) and Eq. (3.9) in columns (3.1) and (4.1)). *** (resp. **, *) denotes significance at the 1% (resp. 5% and 10%) level based on robust standard errors. The TVP parameters WCB test checks the null hypothesis of our PSTR specification against the alternative hypothesis of time-varying PSTR. The RNL WCB tests the null hypothesis of our PSTR specification against the alternative hypothesis of PSTR with two transition functions. 10.000 bootstrap replications used.

Let us first start with a brief discussion of our control variables. Our estimations provide support for the negative effect of trade openness on REER found by previous studies (see Dufrénot and Yehoue, 2005). Trade openness being included as a proxy for trade liberalization, an increase in this variable is thus expected to lower domestic prices leading to a depreciation of the REER.

We find no evidence of a significant effect for the NFA position and fertility rate growth rate. Turning to government consumption expenditures, their effect is significantly negative only in the second specification (column 3.1). This result is contrary to the Froot-Rogoff effect (Froot and Rogoff, 1991, 1995). Indeed, an increase in government consumption expenditures is expected to appreciate the REER since the former are biased towards non-tradable goods.

Finally, following the BS effect, a rise in the productivity in the tradable sector leads to an increase in wages in the same sector. Assuming wage equalization across sectors, it leads to a rise in the relative price of non-traded to traded goods, pushing up the general price level and leading, therefore, to a RER appreciation. Our results show that the relative price of non-tradables to tradables is significant at the 1% level (see column 3.1). A 1% increase in the relative price of non-tradables to tradables leads to a REER appreciation of about 0.560%. We thus find evidence in favor of the external version of the BS effect.

Let us now examine the nonlinear relationship between telecommunications per 1000 workers and the REER. The PSTR methodology allows us to make the distinction between two regimes, depending on the level of infrastructures. In the case of the telecommunications infrastructure, the first regime may be viewed as the situation in which the network is not totally completed corresponding to a telecommunication per 1000 workers (in logarithm) below 4.47. This regime encompasses approximatively 25% of our observations and includes developing and emerging economies presenting a telecommunication network under construction. The second regime corresponds to a state in which the network is totally completed. Our results show that, in the first regime, an increase in the telecommunications per 1000 workers has a negative effect on the REER. In this regime, the telecommunication infrastructure is more or less significant depending upon the specification considered. The elasticities associated to our telecommunication indicator vary a little across our different specifications. The inclusion of the BS effect thus does not substantially affect the estimated elasticities. Indeed, the estimated coefficients go from -0.614 to -0.696 in the first regime, while they range from -0.801 to -0.916 in the second regime. Our results provide evidence of a strong marginal effect of the telecommunications per 1000 workers on the REER: in the first regime, a 1% increase in the telecommunication stocks per 1000 workers leads to a REER depreciation of 0.614% to 0.696%.

We explain this negative relationship between the telecommunication stock and the REER in light of three transmission channels. The first one is based upon the productivity-enhancing effect of telecommunications. We refer to this transmission channel as the *productivity* channel. An increase in the telecommunication stock per worker leads to an increase in the marginal productivity of private inputs. Indeed, an improvement in the telecommunication network lowers the acquisition cost of information and fosters the innovation process (Leff, 1984; Roller and Wavermann, 2001). This productivity surge leads to a reduction in the domestic unit cost of production, resulting in lower domestic prices. As a consequence, the REER depreciates.

The *market mediated* channel of Hulten et al. (2006) is the second transmission channel explaining our results. According to Hulten et al. (2006), a larger infrastructure stock reduces the purchasing costs of intermediate goods and services. This channel is relevant in the case of the telecommunication network as its development allows firms to reach a greater number of potential suppliers for the purchase of their inputs. Firms are thus likely to obtain a lower price for intermediate goods and services. Depending on their mark-up strategy, domestic firms may decide to lower their selling price. Thus, it leads to a reduction in the domestic price level, causing a REER depreciation.

According to the third, competition channel, an improvement in the telecommunication network facilitates the flow of information. Moreover, the extension of mobile phone favourably affects the ability to do business (Straub, 2011). These different effects are likely to increase the number of market participants. This higher competition between firms may lead to a price reduction, depreciating the domestic currency. This transmission channel may be more limited to specific sectors of the economy. Among the three channels proposed to explain our results, the *productivity* channel is probably the most relevant one, as supported by Candelon et al. (2013) and Calderón et al. (2015). The *market mediated* and *competition* channels come in support to the *productivity* channel.

Another interesting result is that most part of the depreciation of the domestic currency is concentrated in the network establishment phase, which we considered to be the first regime. Indeed, in the extreme case (when F(.)=1), the marginal effect of telecommunication is given by -0.916 (resp. -0.801) for equation (3.8) (resp. equation (3.9)). The additional depreciation caused by an increase in the telecommunication per 1000 workers is therefore relatively small. This result is consistent with the fact that the majority of the productivity gains occurs at the beginning of the network. Thus, the major part of the reduction in the production costs is settled in the first regime, where the potential domestic price reduction is higher, explaining the higher REER depreciation. The evidence that the majority of the productivity gains are concentrated in the construction phase of the telecommunications network is supported by the findings from Candelon et al. (2013).

4.2 Electricity Generating Capacity

Table 2 shows that the linearity hypothesis is strongly rejected for equation (3.10), suggesting that the electricity generating capacity has a nonlinear impact on the REER. Our empirical strategy also aims to check the robustness of this nonlinearity to the potential interaction with the BS effect. The results of homogeneity tests applied to equation (3.11) provide weaker evidence in favor of the nonlinearity hypothesis. Indeed, half of the tests implemented do not reject the null hypothesis of linearity. The interaction between the BS effect and the EGC per worker thus affects the existence of a nonlinear relationship. Table 2 below reports the estimation results of equations (3.10) and (3.11), using the logarithm of the electricity generating capacity per 1000 workers as the transition variable.[24]

[24] The associated transition functions are reported in Figures 8.3 and 8.4 in the Appendix.

Results concerning our control variables are almost similar to those obtained previously. The most noticeable difference is the significance of the growth rate of fertility in the first specification (see column 1.2). The fertility rate is expected to influence the REER through two main channels. The first one is the savings channel, according to which a rise in the fertility rate leads to lower savings as the young dependency ratio increases. Moreover, a rise in the fertility rate also increases young consumption, which is biased towards non-traded goods. The positive expected sign for this determinant is confirmed by our results (see column 1.2).

Table 2: Electricity generating capacity: results

	Regime 1	**Regime 2**	**Regime 1**	**Regime 2**
	(1.2)	(2.2)	(3.2)	(4.2)
Δopen	-0.385***		-0.368**	
Δnfa	0.097		0.056	
gov cons	1.578		0.323	
Δfertility	0.768***		0.423	
egc	-0.428***	-0.0734	-0.324***	-0.111
def_6r			0.639***	
gamma	609.8**		609.8*	
c	0.127***		0.126***	
TVP parameters WCB test	0.244		0.395	
RNL WCB test	0.850		0.374	

Note: This table reports the estimation of PSTR models (Eq. (3.10) in columns (1.2) and (2.2) and Eq. (3.11) in columns (3.2) and (4.2)). *** (resp. **, *) denotes significance at the 1% (resp. 5% and 10%) level based on robust standard errors. The TVP parameters WCB test checks the null hypothesis of our PSTR specification against the alternative hypothesis of time-varying PSTR. The RNL WCB tests the null hypothesis of our PSTR specification against the alternative hypothesis of PSTR with two transition functions. 10.000 bootstrap replications used.

Regarding our variable of interest, the estimation results show that the electricity generating capacity per 1000 workers is significant at the 1% level in the first regime (columns 1.2 and 3.2). Although the significance of the electric power is not affected by the inclusion of the BS effect, the marginal effect varies somewhat considerably across both specifications. Indeed, the elasticities range from a low of -0.324 to a high of -0.428. In the first regime (column 1.2) i.e. for electricity generating capacity per 1000 workers below 0.127, a 1% increase in this variable is associated with a REER depreciation of about 0.428%. This first regime encompasses approximatively half of our sample including our five developing eonomies and several emerging economies such as Brazil, Egypt and Indonesia. In other words, for low levels of EGC per 1000 workers, an increase in this variable depreciates the domestic currency. Two of the transmission channels previously detailed are helpful to understand how an improvement in energy affects the REER. Indeed, we also explain the negative effect of the EGC per 1000 workers in light of the *productivity* channel. Increasing electrical energy helps to realize productivity gains, especially in energy-intensive industries. Then, these productivity gains may lead to a domestic price reduction, generating, in turn a REER depreciation. The "market mediated channel" is also useful to understand our findings. Indeed, the costs of intermediate inputs are potentially lower as higher energy power per worker is available in the economy. This reduction in the costs of intermediate inputs is probably stronger in industries relying heavily on inputs produced by energy-intensive firms. As a result of this reduction, firms may choose to lower their selling price, resulting in a depreciation of the REER.

In the case of the telecommunication network, we find that the additional depreciation is rather weak once the network is totally completed. Considering the EGC effect in the second regime, no additional depreciation is present as shown by the non significance of this variable (see columns 2.2 and 4.2). Another interesting difference is that the EGC marginal effect seems to be lower than the one obtained for telecommunication (-0.428 for EGC versus -0.696, in a comparable specification). This difference may be due to the divergence in productivity gains associated to these two infrastructure variables. Assuming that the majority of the effect works through the *productivity* channel, it means that the productivity gains associated to telecommunications are higher than the ones offered by electric power. Based on this assumption, the domestic price reduction would be higher than the one due to an increase in EGC per worker. This assumption appears to be relevant for two reasons. On the one hand, one could expect that the productivity gains associated to a rise in electric power are concentrated in energy-intensive sectors leading to more limited productivity gains. On the other hand, an improvement in the telecommunication network should increase overall productivity as it is not concentrated only in specific sectors, as suggested by Datta and Agarwal (2004).

4.3 Electric power losses

The investigation of the effects of electric power losses on the REER is probably richer than the one offered by the analysis of the EGC. Indeed, as suggested by our literature review, the transmission channels through which electricity power losses could affect the REER are more numerous. We begin our empirical investigation with the results of the homogeneity tests. For our first specification (equation 3.12), we are unable to reject the null hypothesis of homogeneity at the 5% significance level. Since this specification yields no evidence for nonlinearity, equation (3.12) is not estimated. Turning to our second specification, Table 7.3 shows that three of the six tests implemented do not reject the null hypothesis of linearity. Because of the weak evidence of rejection of the null hypothesis, we have to be cautious about the existence of a non-linear relationship between electric power losses and the REER. Table 3 below reports the estimation results of equation (3.13); the related transition function being displayed in Figure 8.5 in the Appendix.

Our estimation allows us to distinguish between two regimes, the first regime being characterized by a level of electric power transmission and distribution losses below 9.369% of GDP. As in the case of the electricity generating

Table 3: Electric power loss: results

	Regime 1	**Regime 2**
Δopen	-0.290**	
Δnfa	0.032	
gov cons	-0.146	
Δfertility	-0.333	
eleclosses	-0.016**	-0.017***
def6	0.709***	
gamma	0.853	
Coefficient	9.369	
TVP parameter WCB test	0.941	
RNL WCB test	0.558	

Note: This table reports the estimation of PSTR models (Eq. (3.13)). *** (resp. **, *) denotes significance at the 1% (resp. 5% and 10%) level based on robust standard errors. The TVP parameters WCB test checks the null hypothesis of our PSTR specification against the alternative hypothesis of time-varying PSTR. The RNL WCB tests the null hypothesis of our PSTR specification against the alternative hypothesis of PSTR with two transition functions. 10.000 bootstrap replications used.

capacity, 50% of our observations are included in this first regime, mainly advanced economies experiencing fewer electricity power losses compared to developing economies. The second regime, i.e. observations having a level of electric power transmission and distribution losses over 9.369% of GDP, encompasses several emerging economies and developing countries presenting more frequent and sizeable power outages. Our estimation show that, in the first regime, there is a significantly negative effect of the electrical network quality. A 1% increase in electric power losses (in % GDP) is associated with a REER depreciation of 0.016 %. Two different transmission channels may explain this finding. On the one hand, electric power losses affect the economy by forcing firms to adopt costly coping measures. On the other hand, an electrical network of weak quality lowers firms' revenues and also leads to a demand reduction. We examine how these two transmission channels affect the REER using the standard definition of the REER and its internal version.[25] Given the standard REER definition, electric power losses may be associated with an appreciation or a depreciation of the domestic currency. The implementation of costly coping measures by firms increases their production costs, pushing the domestic price level upwards. Thus, a deterioration of the electrical network could lead to a REER appreciation. In the following, we refer to this channel as the *coping measures* channel. Furthermore, higher electric losses may also reduce domestic demand due to the cut in firms' activity. Decreasing domestic demand may lower the domestic price level, causing a REER depreciation. This channel is called the *demand* channel. As we find evidence of a depreciation of the domestic currency, this suggests that the *demand* channel outweighs the effects of the *coping measures* channel.

Although power outages impact firms by pushing them to adopt costly coping measures, this effect probably affects firms differently depending on their operating sector. Therefore, the use of the internal RER definition is probably more appropriate to explain our findings. The implementation of these coping measures is likely to be more expensive in the tradable sector (manufacturing industries) than in the non-tradable sector (hotels and restaurants, for example) as tradables rely more heavily on machines for their production. Thus, the cost increase would be higher in the tradable sector than in the non-tradable one. Hence, we can expect that the non-tradable price increase is lower than the one observed in the tradable sector, explaining the REER depreciation. Our second transmission channel states that higher electric power losses are associated with shrinking revenues and lower demand in the economy, affecting both sectors. It is thus difficult to know which sector is more strongly affected by this shrinking demand, and infer about the potential impact on the internal RER. Following the effects on the non-tradable and tradable sectors, two situations can be distinguished. Assuming that the non-tradable sector is more hardly influenced by this demand decrease, the REER would depreciate. On the contrary, the REER would appreciate if the tradable sector is more strongly affected than the non-tradable sector. Although significant, it is worth noting that the marginal effect of electric power losses is rather economically weak. The presence of antagonist effects may explain this weakness.

Turning to the second regime, it corresponds to a situation in which the electric power losses are higher than

[25] According to the internal version, the RER is defined as the ratio between the non-tradables and tradables prices.

9.369% of GDP. We interpret this regime as the "high" electrical power loss regime. In this regime, a 1% increase in the electric power losses depreciates the REER by 0.033% (-0.016-0.017). We thus observe an intensification of the depreciation of the domestic currency for higher electric power losses. To explain this result, let us rely on the internal definition of the RER and the *coping measures* channel. In the first regime, as power outages are less frequent, some firms may decide to do not invest in their own generators. Once the power outages become more frequent, firms may buy their own generators to face this event. Thus, they experience higher costs of own generated electricity, higher production costs, and higher tradable prices. The depreciation is higher since higher electric power losses make firms coping measures more costly.

5 Conclusion

This chapter aims to show the relevance of infrastructures in explaining the dynamic of the REER. We investigate the existence of a nonlinear relationship between several infrastructure variables (telecommunications, electric power, and power grid quality) and the REER, depending on their own levels. To this aim, we apply a PSTR model to a panel of 31 countries over the 1973-2014 period. We also provide an in-depth discussion on the potential transmission channels for each of these determinants.

Our results show strong nonlinear relationships between the telecommunications, EGC per 1000 workers and the REER. When the network is not totally completed (first regime), an increase in the EGC and telecommunications depreciates the REER, while the additional depreciation is lower or non-existent once the network is established (second regime). These different results are mainly explained in light of the *productivity* and *market mediated* channels. According to the *productivity* channel, an improvement in the EGC and telecommunication network leads to productivity gains that reduce production costs. Thus, the domestic price level is lower and the REER depreciates. Following the *market mediated* channel from Hulten et al. (2006), an increase in the infrastructure stock in the economy lowers the cost of purchasing intermediate goods and services, reducing the domestic production costs. Consequently, as previously, the REER depreciates due to the fall in the domestic price level. Furthermore, our results show that the majority of the effect of EGC and telecommunications is concentrated in the network construction phase, where productivity gains are higher (Candelon et al., 2013). Since productivity gains are concentrated in the first regime, the domestic price level reduction is also mainly present in this regime, in line with our results.

Although the EGC and telecommunications share similarities in terms of transmission channels, we also propose a specific canal for the telecommunication infrastructures. Improvements in the telecommunication network are associated with an increase in competition between domestic firms, in line with the *competition* channel. Thus, the domestic price level is reduced and the REER depreciates.

Furthermore, our results show that higher electrical power losses are associated with a REER depreciation that is stronger in the "high" electric power loss regime. To face power losses, firms may adopt costly coping measures, increasing their production costs and leading thus to a rise in the tradables' price. As a result, the REER depreciates following an increase in the loss of electric power.

Overall, our findings show the existence of three additional RER determinants that lead to domestic currency depreciation. These factors can be useful in the assessment of equilibrium exchange rates, which is required in the computation of currency misalignments.

*Appendix

6 Data

Table 6.1: Sectors decomposition: GGDC database

ISIC Rev. 3.1 code	ASD sector name	ISIC Rev. 3.1 description
AtB	Agriculture	Agriculture, Hunting and Forestry, Fishing
C	Mining	Mining and Quarrying
D	Manufacturing	Manufacturing
E	Utilities	Electricity, Gas and Water supply
F	Construction	Construction
G+H	Trade services	Wholesale and Retail trade;
		Repair of motor vehicles, motorcycles and personal and household goods, Hotels and Restaurants
I	Transport services	Transport, Storage and Communications
J+K	Business services	Financial Intermediation, Renting and Business Activities (excluding owner occupied rents)
L,M,N	Government services	Public Administration and Defense, Education, Health and Social work
O,P	Personal services	Other Community, Social and Personal service activities, Activities of Private Households

Table 6.2: Six sectors' classification

Sector	Divisions
Agriculture, hunting, forestry, fishing	01-05
Mining, manufacturing, utilities	10-41
Construction	45
Wholesale, retail trade, restaurants and hotels	50-55
Transport, storage and communications	60-64
Other activities	65-99

Source: International Standard Industrial Classification of All Economic Activities (ISIC), Revision 3.1, United Nations.

Table 6.3: Data sources

Primary	Abbreviation	Data sources	Comments
Government consumption expenditures	gov cons	WDI	Expressed as share of GDP
Net Foreign asset	nfa	Lane and Milesi-Ferretti (2007)	Expressed as share of GDP
Trade openess	open	WDI	Sum of exports and imports as share of GDP
Fertility rate	fertility	WDI	Births per woman
Real Effective Exchange Rate	reer	EQCHANGE	REER based on 186 trade partners using time-varying weights
Commercial weights	w__ijt	CEPII EQCHANGE	Time-varying weighting scheme
Electricity Generating Capacity	egc	Canning (1998) and UN energy Statistical Year books	Electricity Generating Capacity per 1000 kilowatts
Electric power transmission and distribution losses	elec__losses	WDI	Percentage of GDP
Number of main-lines		International Telecommunication Union	
Mobile cellular subscriptions		WDI	subscriptions to a public mobile telephone service that provide access
			to the PSTN using cellular technology
Number of workers		PWT 9.0	Number of persons engaged
Values added of division 01-05		GGDC and UNCTAD	Value added of the sector 01-05 in constant/current 2010 us dollars
Values added of division 10-41		GGDC and UNCTAD	Value added of of the sector 10-41 measured in constant/current 2010 us dollars
Values added of division 45		GGDC and UNCTAD	Value added of the sector 45 measured in constant/current 2010 us dollars
Values added of division 50-55		GGDC and UNCTAD	Value added of the sector 50-55 measured in constant/current 2010 us dollars
Values added of division 60-64		GGDC and UNCTAD	Value added of the sector 60-64 measured in constant/current 2010 us dollars
Values added of division 65-99		GGDC and UNCTAD	Value added of the sector 65-99 measured in constant/current 2010 us dollars

Note: CEPII=Centre d'Études Prospectives et d'Informations Internationales; WDI=World Development Indicators (World Bank); PWT=Penn World Table; UNCTAD=United Nations Conference on Trade and Development; GDP= Gross Domestic Product.

7 Supplementary results

Table 7.1: Descriptive statistics

Variable	Obs.	Mean	SD.	Min.	Max.
Real Effective Exchange Rate (log)	1302	4.666	0.400	3.337	7.507
Openness (first difference)	1302	0.718	7.931	-93.29	68.24
Fertility rate (first difference)	1302	-0.0144	0.0263	-0.172	0.191
Six sectors deflator (log)	1302	0.0617	0.266	-1.149	1.052
Government consumption expenditures (% GDP)	1302	15.48	5.719	4.851	40.48
Net Foreign Asset position (first difference)	1302	0.168	11.72	-165.7	130.8
Electricity power transmission and distribution losses	1302	10.66	5.876	1.496	37.43
Electricity Generating Capacity per 1000 workers (log)	1302	-0.0269	1.309	-3.273	2.140
Telephone per 1000 workers (log)	1302	5.874	1.913	1.272	8.497

Source: Author's calculations

Table 7.2: Panel unit root tests: summary

Variable	Abbreviation	Integration order
Real Effective Exchange Rates	reer	I(0)
Openess	open	I(1)
Fertility rate	fertility	I(1)
Deflator 6 sectors relative (fixed weights)	def6_fr	I(0)
Government consumption expenditures	gov cons	I(0)
Net Foreign Asset (NFA) position	nfa	I(1)
Electricity power transmission and distribution losses	eleclosses	I(0)
Electricity Generating Capacity per 1000 workers	egc	I(0)
Telecommunication per 1000 workers	telecom	I(0)

Source: Author's calculations

Table 7.3: Summary of the homogeneity tests

Equation	Transition variable	LM_X	LM_F	HAC_X	HAC_F	WB_PV	WCB_PV
Equation (3.8)	telecom	0.000***	0.000***	0.011**	0.012**	0.000***	0.000***
Equation (3.9)	telecom	0.000***	0.000***	0.006***	0.007***	0.000***	0.000***
Equation (3.10)	egc	0.000***	0.000***	0.030**	0.030**	0.000***	0.010**
Equation (3.11)	egc	0.000***	0.000***	0.118	0.122	0.000***	0.128
Equation (3.12)	eleclosses	0.080*	0.080*	0.480	0.490	0.203	0.545
Equation (3.13)	eleclosses	0.004***	0.005***	0.36	0.37	0.049**	0.380

Note: LM_X denotes the χ^2 Lagrange Multiplier (LM) test, LM_F the LM test with a Fisher distribution, HAC_X the LM test with Heteroskedasticity Autocorrelation Consistent (HAC) error term, HAC_F the LM test with a Fisher distribution with HAC error term, WB (resp. WCB) stands for residual-based wild (resp. wild clustered) bootstrap. All these tests are based on the null hypothesis of linearity/ homogeneity against the PSTR model. ***(resp. **,*) denotes the rejection of the null hypothesis at the 1% (resp. 5%, 10%) significance level. 10.000 bootstrap replications used.

8 Figures

Figure 8.1: Transition function: telecommunication per 1000 workers (logarithm): equation (3.8)

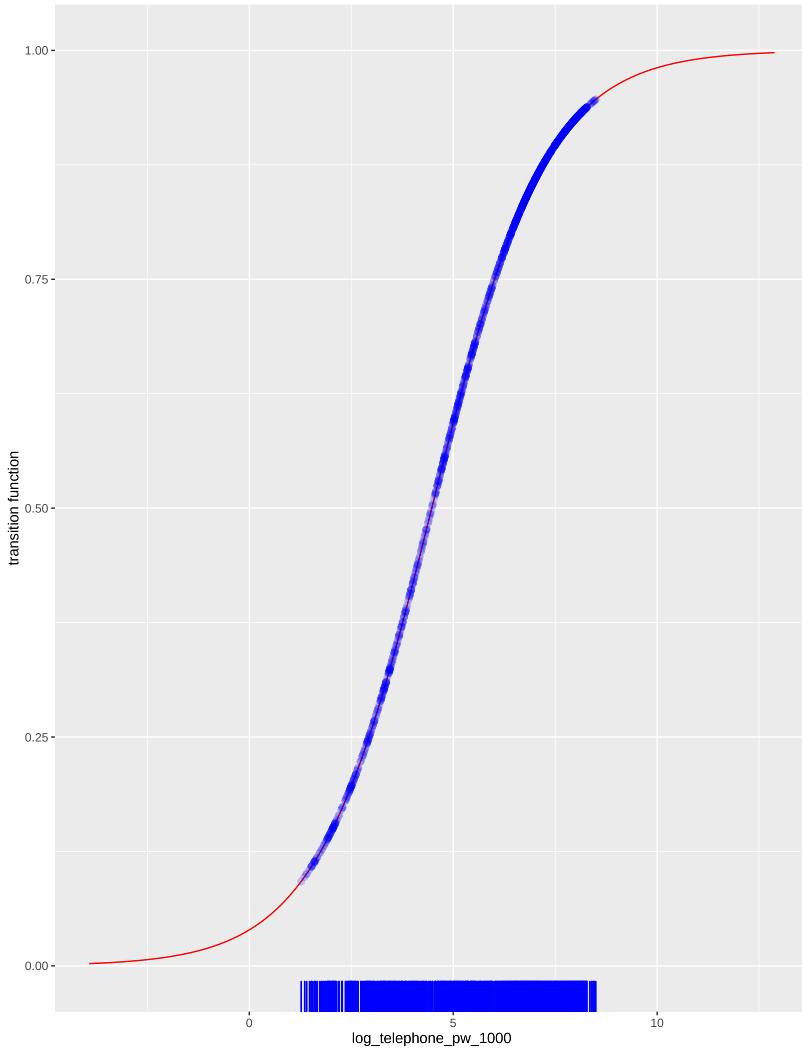


Figure 8.2: Transition function: telecommunication per 1000 workers (logarithm): equation (3.9)

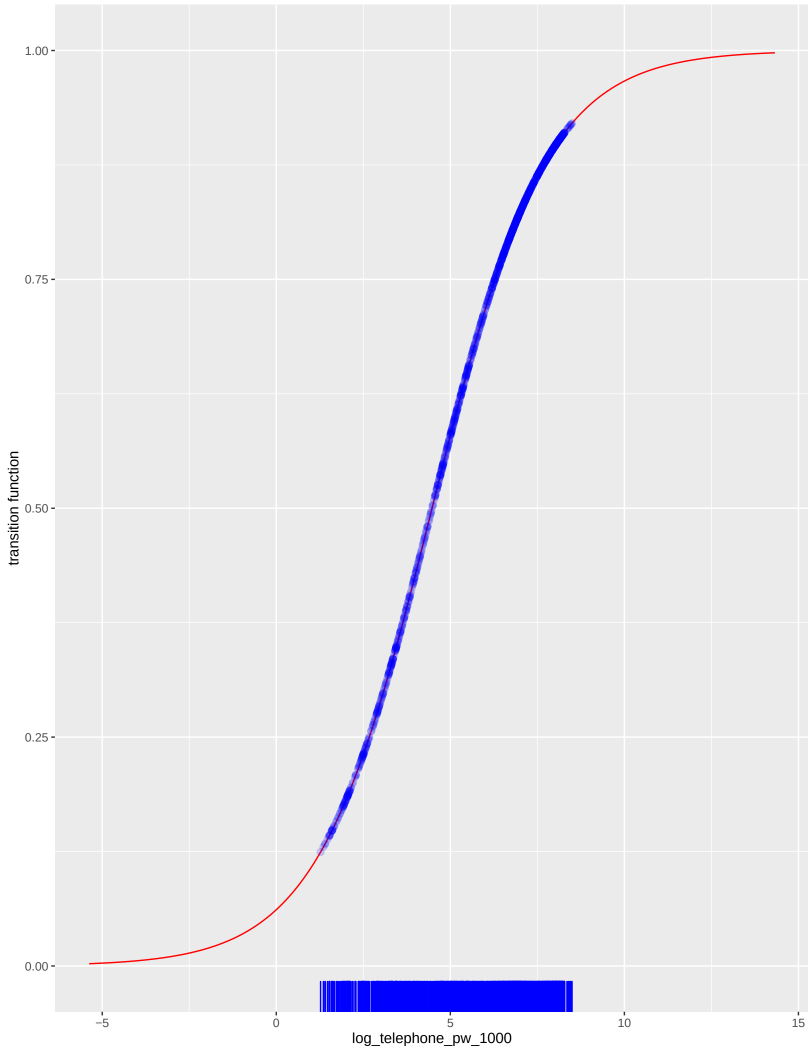


Figure 8.3: Transition function: EGC per 1000 workers (logarithm): equation (3.10)

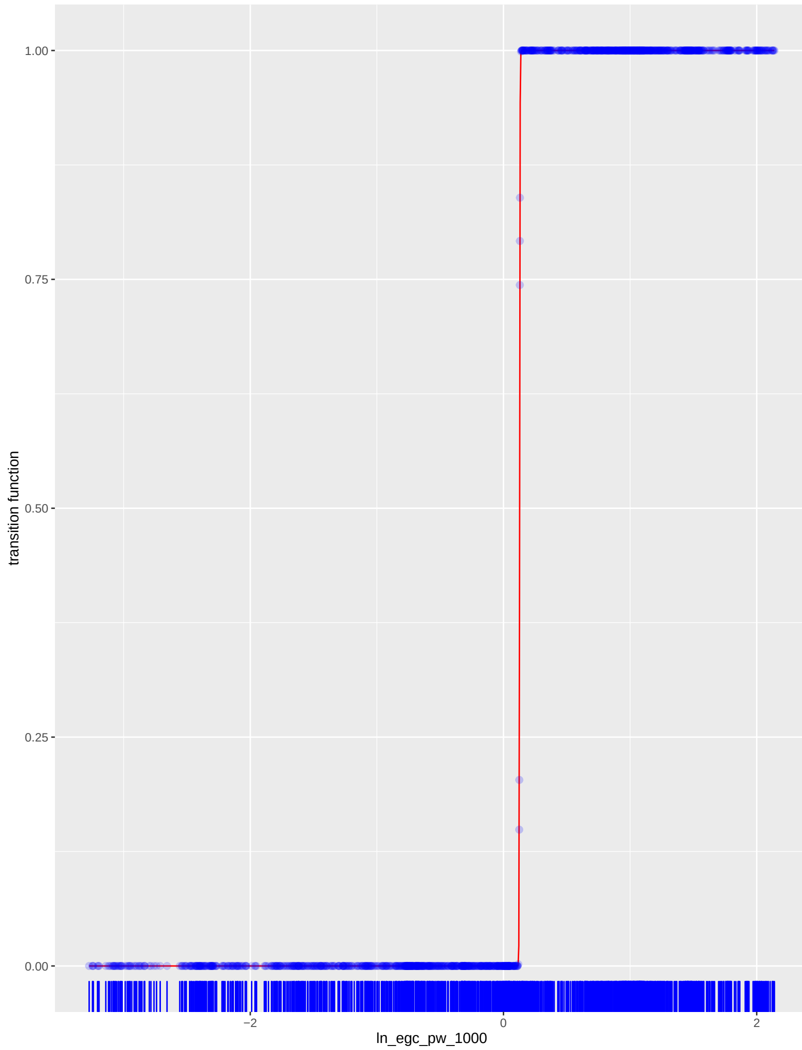


Figure 8.4: Transition function: EGC per 1000 workers (logarithm): equation (3.11)

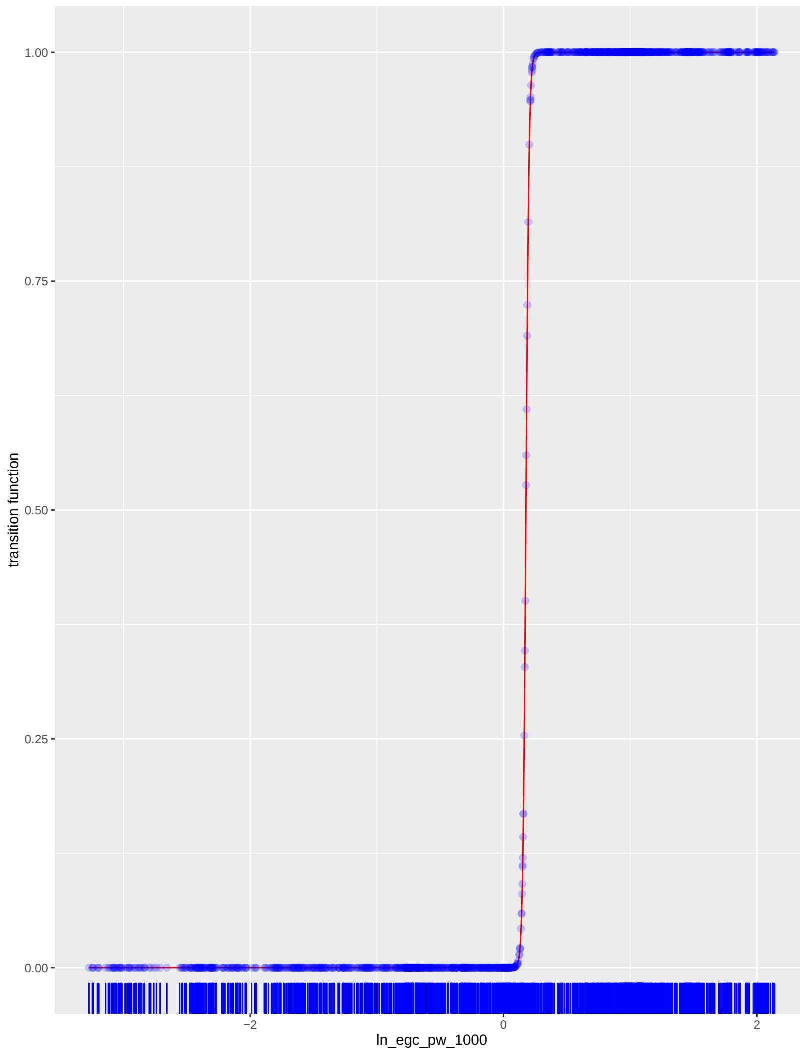
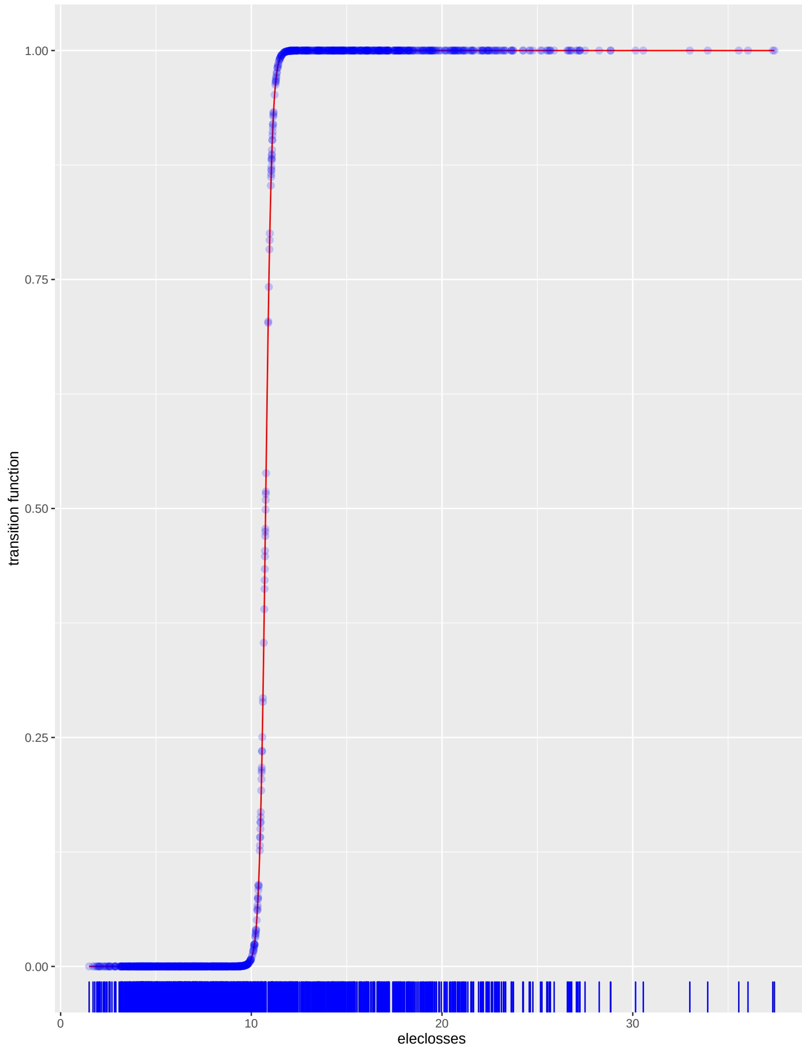


Figure 8.5: Transition function: electricity power loss: equation (3.13)



References

Agénor, P.-R. (2010), 'A theory of infrastructure-led development', *Journal of Economic Dynamics and Control* **34**(5), 932–950.

Agénor, P.-R. & Moreno-Dodson, B. (2006), *Public infrastructure and growth: New channels and policy implications*, The World Bank.

Aker, J. C. (2011), 'Dial "a" for agriculture: a review of information and communication technologies for agricultural extension in developing countries', *Agricultural Economics* **42**(6), 631–647.

Aker, J. C. & Fafchamps, M. (2015), 'Mobile phone coverage and producer markets: Evidence from west africa', *The World Bank Economic Review* **29**(2), 262–292.

Alby, P., Dethier, J.-J. & Straub, S. (2013), 'Firms operating under electricity constraints in developing countries', *The World Bank Economic Review* **27**(1), 109–132.

Allcott, H., Collard-Wexler, A. & O'Connell, S. D. (2016), 'How do electricity shortages affect industry? evidence from india', *American Economic Review* **106**(3), 587–624.

Anos-Casero, P. & Udomsaph, C. (2009), *What drives firm productivity growth?*, The World Bank.

Arestoff, F. & Hurlin, C. (2010), 'Are public investment efficient in creating capital stocks in developing countries?', *Economics Bulletin* **30**(4), 3177–3187.

Balassa, B. (1964), 'The purchasing-power parity doctrine: A reappraisal', *Journal of Political Economy* **72**(6), 584–596.

Barro, R. J. (1990), 'Government spending in a simple model of endogeneous growth', *Journal of political economy* **98**(5, Part 2), S103–S125.

Bénassy-Quéré, A., Béreau, S. & Mignon, V. (2009), 'Robust estimations of equilibrium exchange rates within the g20: A panel beer approach', *Scottish Journal of Political Economy* **56**(5), 608–633.

Bom, P. R. & Ligthart, J. E. (2014), 'What have we learned from three decades of research on the productivity of public capital?', *Journal of economic surveys* **28**(5), 889–916.

Braese, J., Hallegatte, S., Kornejew, M., Obolensky, M. & Rentschler, J. (2019b), *Underutilized potential: The business costs of unreliable infrastructure in developing countries*, The World Bank.

Braese, J., Rentschler, J. & Hallegatte, S. (2019a), *Resilient infrastructure for thriving firms: A review of the evidence*, The World Bank.

Calderón, C. & Chong, A. (2004), 'Volume and quality of infrastructure and the distribution of income: an empirical investigation', *Review of Income and Wealth* **50**(1), 87–106.

Calderón, C., Moral-Benito, E. & Servén, L. (2015), 'Is infrastructure capital productive? a dynamic heterogeneous approach', *Journal of Applied Econometrics* **30**(2), 177–198.

Calderón, C. & Servén, L. (2014), *Infrastructure, growth, and inequality: an overview*, The World Bank.

Candelon, B., Colletaz, G. & Hurlin, C. (2013), 'Network effects and infrastructure productivity in developing countries', *Oxford Bulletin of Economics and Statistics* **75**(6), 887–913.

Canning, D. (1998), 'A database of world stocks of infrastructure, 1950–95', *The World Bank Economic Review* **12**(3), 529–547.

Canning, D. & Pedroni, P. (2008), 'Infrastructure, long-run economic growth and causality tests for cointegrated panels', *The Manchester School* **76**(5), 504–527.

Couharde, C., Delatte, A.-L., Grekou, C., Mignon, V. & Morvillier, F. (2018), 'Eqchange: A world database on actual and equilibrium effective exchange rates', *International economics* **156**, 206–230.

Couharde, C., Delatte, A.-L., Grekou, C., Mignon, V. & Morvillier, F. (2019), 'Measuring the balassa-samuelson effect: A guidance note on the rprod database', *International Economics* .

Datta, A. & Agarwal, S. (2004), 'Telecommunications and economic growth: a panel data approach', *Applied Economics* **36**(15), 1649–1654.

De Gregorio, J., Giovannini, A. & Wolf, H. C. (1994), 'International evidence on tradables and nontradables inflation', *European Economic Review* **38**(6), 1225–1244.

Dethier, J.-J., Hirn, M. & Straub, S. (2011), 'Explaining enterprise performance in developing countries with business climate survey data', *The World Bank Research Observer* **26**(2), 258–309.

Donaubauer, J., Meyer, B. E. & Nunnenkamp, P. (2016), 'A new global index of infrastructure: Construction, rankings and applications', *The World Economy* **39**(2), 236–259.

Du, Q., Wei, S.-J. & Xie, P. (2013), Roads and the real exchange rate, Technical report, National Bureau of Economic Research.

Égert, B., Kozluk, T. J. & Sutherland, D. (2009), 'Infrastructure and growth: empirical evidence'.

Fisher-Vanden, K., Mansur, E. T. & Wang, Q. J. (2015), 'Electricity shortages and firm productivity: evidence from china's industrial firms', *Journal of Development Economics* **114**, 172–188.

Froot, K. A. & Rogoff, K. (1991), 'The ems, the emu, and the transition to a common currency', *NBER Macroeconomics Annual* **6**, 269–317.

Froot, K. A. & Rogoff, K. (1995), 'Perspectives on ppp and long-run real exchange rates', *Handbook of international economics* **3**, 1647–1688.

Galstyan, V. & Lane, P. R. (2009), 'The composition of government spending and the real exchange rate', *Journal of Money, Credit and Banking* **41**(6), 1233–1249.

Gonzalez, A., Teräsvirta, T., Van Dijk, D. & Yang, Y. (2017), *Panel smooth transition regression models*.

Gubler, M. & Sax, C. (2019), 'The balassa-samuelson effect reversed: new evidence from oecd countries', *Swiss Journal of Economics and Statistics* **155**(1), 3.

Gurara, D. & Tessema, D. (2018), *Losing to blackouts: Evidence from firm level data*, International Monetary Fund.

Hallegatte, S., Rentschler, J. & Rozenberg, J. (2019), *Lifelines: The Resilient Infrastructure Opportunity*, The World Bank.

Hulten, C. R., Bennathan, E. & Srinivasan, S. (2006), 'Infrastructure, externalities, and economic development: a study of the indian manufacturing industry', *The World Bank Economic Review* **20**(2), 291–308.

Iimi, A. (2011), 'Effects of improving infrastructure quality on business costs: Evidence from firm-level data in eastern europe and central asia', *The Developing Economies* **49**(2), 121–147.

Iimi, A. & Smith, J. W. (2007), *What is missing between agricultural growth and infrastructure development? Cases of coffee and dairy in Africa*, The World Bank.

Lane, P. R. & Milesi-Ferretti, G. M. (2002), 'External wealth, the trade balance, and the real exchange rate', *European Economic Review* **46**(6), 1049–1071.

Lane, P. R. & Milesi-Ferretti, G. M. (2004), 'The transfer problem revisited: Net foreign assets and real exchange rates', *Review of Economics and Statistics* **86**(4), 841–857.

Lee, J. & Tang, M.-K. (2007), 'Does productivity growth appreciate the real exchange rate?', *Review of International Economics* **15**(1), 164–187.

Leff, N. H. (1984), 'Externalities, information costs, and social benefit-cost analysis for economic development: An example from telecommunications', *Economic Development and Cultural Change* **32**(2), 255–276.

Lio, M. & Liu, M.-C. (2006), 'Ict and agricultural productivity: evidence from cross-country data', *Agricultural Economics* **34**(3), 221–228.

Mensah, J. T. (2016), Bring back our light: Power outages and industrial performance in sub-saharan africa, Technical report.

Mensah, J. T. (2018), *Jobs! Electricity shortages and unemployment in Africa*, The World Bank.

Mitra, A., Sharma, C. & Véganzonès-Varoudakis, M.-A. (2016), 'Infrastructure, information & communication technology and firms' productive performance of the indian manufacturing', *Journal of Policy Modeling* **38**(2), 353–371.

Morvillier, F. (2020), Robustness of the balassa-samuelson effect: evidence from developing and emerging economies, Working paper economix.

Muto, M. & Yamano, T. (2009), 'The impact of mobile phone coverage expansion on market participation: Panel data evidence from uganda', *World development* **37**(12), 1887–1896.

Ortega, C. B. & Lederman, D. (2004), 'Agricultural productivity and its determinants: revisiting international experiences', *Estudios de economía* **31**(2), 133–163.

Phillips, S. T., Catão, L., Ricci, L. A., Bems, R., Das, M., Di Giovanni, J., Unsal, F. D., Castillo, M., Lee, J., Rodriguez, J. et al. (2013), The external balance assessment (eba) methodology, Technical report, International Monetary Fund.

Poczter, S. (2017), 'You can't count on me: The impact of electricity unreliability on productivity', *Agricultural and Resource Economics Review* **46**(3), 579–602.

Pritchett, L. (1999), *Mind your p's and q's: the cost of public investment is not the value of public capital*, The World Bank.

Ricci, L. A., Milesi-Ferretti, G. M. & Lee, J. (2013), 'Real exchange rates and fundamentals: a cross-country perspective', *Journal of Money, Credit and Banking* **45**(5), 845–865.

Roller, L.-H. & Waverman, L. (2001), 'Telecommunications infrastructure and economic development: A simultaneous approach', *American economic review* **91**(4), 909–923.

Rose, A. K., Supaat, S. & Braude, J. (2009), 'Fertility and the real exchange rate', *Canadian Journal of Economics/Revue canadienne d'économique* **42**(2), 496–518.

Samuelson, P. A. (1964), 'Theoretical notes on trade problems', *The Review of Economics and Statistics* **46**(2), 145–154.

Steinbuks, J. & Foster, V. (2010), 'When do firms generate? evidence on in-house electricity supply in africa', *Energy Economics* **32**(3), 505–514.

Straub, S. (2011), 'Infrastructure and development: A critical appraisal of the macro-level literature', *The Journal of Development Studies* **47**(5), 683–708.

Timmer, M., de Vries, G. J. & De Vries, K. (2015), Patterns of structural change in developing countries, *in* 'Routledge handbook of industry and development', Routledge, pp. 79–97.

Ward, M. R. & Zheng, S. (2016), 'Mobile telecommunications service and economic growth: Evidence from china', *Telecommunications Policy* **40**(2-3), 89–101.

Yeaple, S. R. & Golub, S. S. (2007), 'International productivity differences, infrastructure, and comparative advantage', *Review of International Economics* **15**(2), 223–242.

Yehoue, M. E. B. & Dufrénot, G. J. (2005), *Real exchange rate misalignment: A panel co-integration and common factor analysis*, number 5-164, International Monetary Fund.