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Complementarity between human capital and public infrastructure in industrial comparative advantage

Rimvie Enoc KABORE

July 15, 2021

Abstract

The article examines the role of public capital as an infrastructure service in the acquisition of industrial comparative advantages. To achieve this in this framework, we develop a theoretical model highlighting the complementarity between public and human capital as a mechanism of industrial development, and test this idea using sectoral panel data from 1999 to 2014 across 35 advanced and less advanced countries. Our results show that the sustainable acquisition of a comparative advantage in the production of industrial goods can only be guaranteed by accumulating public capital and human capital. It shows that public infrastructure can only generate industrialization when it is made available to the economy through human capital.

Keywords: Public infrastructure, Human capital and Industrial advantage comparative

Jel Classification: F11; H41; O47

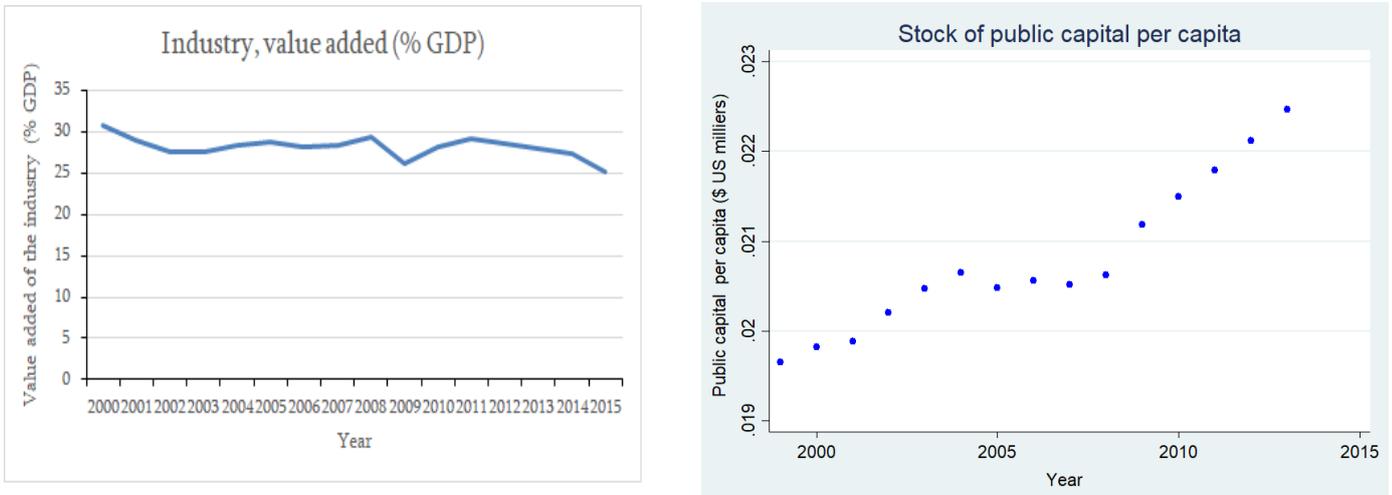
1 Introduction

The effect of public capital is not in doubt in the literature of trade (Estache and Fay, 2007; Combes et al., 2008; Semedo G., 2013) and economic growth (Barro, 1990; Canning, 1999; Aschauer, 1989, 2000; Boopen, 2006). However, this influence is not necessarily consistent, if only because it differs depending on a country's proximity to the technological frontier. In fact, public capital favors manufacturing only in countries far from the technology frontier¹, since infrastructure is not sufficient and is seldom used in these countries.

However, it is possible for a country to have public infrastructure without its industry developing, or at least to see its industry emerge, albeit with some uncertainties (je ne suis toujours pas sure ce que vous entendez par "ambiguités"). Assuredly, public capital has its importance but may not be visible at the level of production specialization. This is illustrated on the left-hand side of figure 1 below. The share of the value added of the manufacturing industry in the GDP remains constant, or even decreases in recent years, even though we observe a certain growth of the public capital stock per capita in the 2000s (see figure 1, right side). This is also accompanied by an increase in exports (see figure 2 below). These evolutions are partly due to the still embryonic dynamics of public capital accumulation and industrialization, which is not yet observable in terms of structural change. However, it is not absent in view of the evolution of exports. This paper explores the presence of certain constraints that limit the influence of public capital accumulation on the development of industrial comparative advantages. In particular, it points out that low human capital accumulation can be one such constraint.

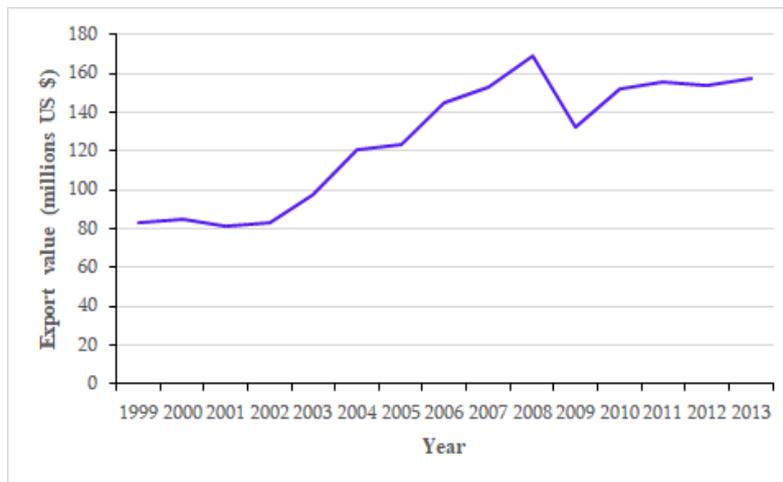
¹Countries far from the technology frontier are less productive vis-à-vis the US.

Figure 1: Evolution of industrial value added and public capital per capita in Sub-Saharan Africa



Source: Author' calculations based on the World Bank and FMI database

Figure 2: Evolution of manufacturing exports of some Sub-Saharan African countries (Value millions US \$)



Source: Author' calculations based on the UNCTAD database

In order to understand our argument, it is necessary to insist on the very nature of public capital, understood here as public infrastructure made available to the economy. In his definition of public infrastructure, [Hirschman \(1958\)](#) suggests that it should not be considered only as (physical) capital. It must also be regarded as an infrastructure service. Hirschman shows that infrastructure is not limited to facilities for transportation, telecommunications, energy, etc., but also includes all associated public services. For [Barro \(1990\)](#), infrastructure capital,

which includes roads, highways, railroads, ports and airports, telecommunication networks, electricity and water, is closely associated with the services that these infrastructures can provide. Following these definitions, we propose in this paper to treat public infrastructure as an infrastructure service and not as publicly financed physical capital, as is usually the case. This type of approach implies that there is a provision of public infrastructure that requires other factors, notably human capital. This paper develops a simple theoretical model to support this idea. Then, it empirically analyzes the ability of public infrastructure to develop a comparative advantage in industrial branches. This would depend on whether this infrastructure capital is also accompanied by human capital, improving its use in the economy.

This idea has already been integrated by policies and institutions dedicated to economic development. To improve the efficiency of investment in public infrastructure and also to enhance the quality of public services, the African Development Bank (AfDB) advocates the development of human capital. According to the Bank, a skilled labor force not only allows for the installation and maintenance of public infrastructure investments, but also ensures the sustainability and return on these investments. Considering this aspect of public infrastructure, [Devarajan and Fengler \(2013\)](#) show theoretically in their study that the African manufacturing sector could develop if, in addition to the accumulation of physical public infrastructure, countries accumulated human capital. Moreover, the growth experience of Japan and the four newly industrialized Asian countries (Singapore, Hong Kong, Taiwan, and South Korea)² reveals that economic growth involves both public and human capital accumulation. As [Dessus and Herrera \(1999\)](#) argued, the positive impact of public infrastructure on growth is due to the fact that they also included human capital in their conditional regression model. The latter tells us that without controlling for human capital, the effect of infrastructure would be insignificant.

Theoretically, we mobilize a neoclassical framework of international trade, extended to human capital, to predict the structure of manufacturing specialization ([Heckscher, 1919](#)). Our final prediction is that the country's ability to have a comparative advantage in the industrial good will depend on the complementarity between human and public capital in the production of infrastructure services. In other words, the richer the countries in public and human capital, the lower the relative price of industrial goods.

Empirically, the paper tests this prediction using manufacturing data from 35 developed and developing countries over a period from 1999 to 2013, and examines the capacity of pub-

²See Young (1992, 1993), [Lucas Jr \(1993\)](#), and [Krugman \(1994\)](#) for an analysis of the growth experience of the Asian miracles.

lic infrastructure to develop industrial comparative advantage. To our knowledge, this is the first paper that tests the impact of public infrastructure on manufacturing specialization, conditional on a given level of human capital endowment. We show that public infrastructure only positively affects manufacturing comparative advantage when it is made available to the economy through human capital. The results reveal that the ability of public infrastructure to develop a comparative advantage in the industrial sector is more important in countries with a very high level of human capital. On the other hand, its effect is less important in countries with low levels of human capital.

The paper is structured as follows: Section 2 provides a theoretical illustration highlighting the complementary relationship between public and human capital. Sections 3 and 4 present the data and the estimation technique, respectively. Section 5 shows the empirical results and discussion. Section 6 proposes an extension of the model. Section 7 concludes.

2 A theoretical model

In this section, we present a simple model to illustrate the importance of the complementarity between public infrastructure and human capital in determining comparative advantage in the industrial sector. The model is an extension of the canonical neoclassical model to include an intermediate sector providing public infrastructure³.

2.1 Final Goods Market

Demand

Consider an economy in perfect competition with two consumer goods: an agricultural good (good 1) and an industrial good (good 2). The representative consumer gets a utility from the consumption of these goods described by the function below:

$$U(X_1, X_2) = X_1^a X_2^b \tag{1}$$

with $a > 0$, $b > 0$ and X_i the quantity consumed of each good $i = 1, 2$. They choose their basket of goods (X_1, X_2) in order to maximize their utility under the budget constraint $R = X_1 + pX_2$;

³The model is an extension of the one presented in Ledezma and Lenoble (2021).

where p is the relative price of good 2 (good 1 being chosen as a numeraire) and R their income. The result of this maximization program leads to consider the following industrial and agricultural good demands:

$$X_1 = \theta R \quad (2)$$

$$X_2 = \frac{1}{p} (1 - \theta) R \quad (3)$$

where $\theta := \frac{a}{a+b}$ is the relative weight of the consumption of the agricultural good in the utility function which, given its formulation, also corresponds to the share of income devoted to the consumption of this good. The rest of the income is thus allocated to the consumption of the industrial good.

Production

Both goods are produced from an intermediate service (infrastructure) and labor with constant returns to scale. The quantity produced, Y_i , of each good $i = 1, 2$ is obtained from a specific technology for each industry:

$$Y_i = F_i(Z_i, L_i) = Z_i^{\beta_i} L_i^{1-\beta_i}, \quad 0 < \beta_i < 1, \quad i = 1, 2 \quad (4)$$

Z_i and L_i are respectively the quantities of intermediate service and labor used in sector i . These inputs are paid at prices w_Z and w_L , respectively.

The standard first-order conditions of the producer's program suggest that each factor be used to the point where its marginal productivity (in value) equals its wage. This implies the equalization of the factor remuneration ratio $\frac{w_L}{w_Z}$ at the marginal rate of technical substitution (from infrastructure service to labor), $TMST_{Z_i, L_i} := \frac{\partial F_i}{\partial L_i} / \frac{\partial F_i}{\partial Z_i}$. Considering our production functions with constant returns, the marginal productivities can be described as a function of the intensity of the intermediate service $z_i := \frac{Z_i}{L_i}$ as $\frac{\partial F_i}{\partial Z_i} = \beta_i z_i^{\beta_i - 1}$ and $\frac{\partial F_i}{\partial L_i} = (1 - \beta_i) z_i^{\beta_i}$. The optimality condition of the producer's program becomes:

$$TMST_{Z_i, L_i} = \frac{w_L}{w_Z} \Leftrightarrow z_i = \left(\frac{\beta_i}{1 - \beta_i} \right) \frac{w_L}{w_Z} \quad (5)$$

Without loss of generality, we will assume that $\beta_2 > \beta_1$, which implies that the industrial good will be intensive in intermediate services and the agricultural good in labor. For a given level of factor remuneration, the factor intensities of consumer goods verify $z_2 > z_1$.

2.2 Intermediate services

Production and equilibrium in the input market of intermediate services

Intermediate services Z are produced by a private sector that uses both public infrastructure capital (K_p) and human capital (H). The production function of intermediate services is assumed to follow a constant elasticity function of the following type:

$$Z(H, K_p) = [a_H H^\alpha + a_p K_p^\alpha]^{1/\alpha} \quad -\infty < \alpha < 1 \quad (6)$$

where a_H and a_p represent specific efficiency parameters for each factor. This formulation will later allow us to grasp the complementary role of human and public capital in determining the specialization of production in free trade.

The price (or remuneration) of public capital w_K and that of human capital w_H are taken as given from the perspective of the representative producer of intermediate services. Their demand for inputs is thus obtained through a reasoning analogous to that of the case of producers of final goods. When the public capital intensity is denoted by $k := \frac{K_p}{H}$ and the relative remuneration of human capital (with respect to public capital), $\frac{w_H}{w_K}$, the optimality condition of the producer of intermediate services (i.e. the analogous condition of equation (5)) is written:

$$k = \left(\frac{a_p w_H}{a_H w_K} \right)^{\frac{1}{1-\alpha}}. \quad (7)$$

In order to keep the analytical framework as simple as possible, we assume that the available stocks of public and human capital are exogenously fixed at \bar{K}_p and \bar{H} , respectively. Since the intermediate services sector is the only sector that uses both forms of capital, the equalization of the relative supply of public capital $\bar{k} := \bar{K}_p/\bar{H}$ to its relative demand— equation (7), in turn, sets the relative remuneration of human capital:

$$\bar{k} = \left(\frac{a_p w_H}{a_H w_K} \right)^{\frac{1}{1-\alpha}}. \quad (8)$$

2.3 Autarkic equilibrium

Equilibrium conditions

The total labor of this economy is available in quantity L and allocated entirely to the production of agricultural and industrial goods. Full employment of labor thus implies:

$$L = L_1 + L_2 \quad (9)$$

Intermediate services are, on the other hand, sold to producers of final goods so that:

$$Z = Z_1 + Z_2 \quad (10)$$

Finally, in autarky, the consumption of each good must be entirely satisfied by national production:

$$X_i = Y_i \quad \forall i = 1; 2 \quad (11)$$

Relative factor prices and goods prices in autarky

In the neoclassical view, relative autarky prices depend on endowments through the determination of factor remuneration. Since factors are used up to the point where their marginal productivity in value equals their price, we can equalize the marginal productivities in value between sectors and obtain the relative price of goods. Following this logic for the intermediate services, we have $p \frac{\partial F_2}{\partial Z_2} = w_z = \frac{\partial F_1}{\partial Z_1}$. This allows us, using the production functions given in (4) and the optimality equation of the producer's program (5), to write the relative price of the industrial good (good 2) as follows:

$$p = \Phi(\beta_1, \beta_2) \left[\frac{w_L}{w_Z} \right]^{\beta_1 - \beta_2} \quad (12)$$

where $\Phi(\beta_1, \beta_2) = \frac{\left(\frac{1-\beta_1}{\beta_1}\right)^{1-\beta_1} \beta_1}{\left(\frac{1-\beta_2}{\beta_2}\right)^{1-\beta_2} \beta_2} > 0$ is a set of technological parameters.

Lemma 1. *When the industrial good is intensive in infrastructure services, i.e. $\beta_2 > \beta_1$, then the relative price of the industrial good is positively correlated to the relative remuneration of intermediate services, the factor used intensively in its production.*

This usual result from the neoclassical world, combined with conditions from the market for infrastructure services, will allow us to find the origin of comparative advantages in our model.

The relative remuneration of the factors in autarky remains to be obtained. It is determined in general equilibrium, when the factor and goods markets clear (equations 9 to 11) while verifying optimal behavior on the part of the consumer and representative producers (equations

2, 3 and 5). The algebraic manipulation of these relationships, for a given level of infrastructure service production, allows us to write:

$$\frac{w_L^a}{w_Z^a} = \Psi(\theta, \beta_1, \beta_2) \frac{Z}{L}, \quad (13)$$

where $\Psi(\theta, \beta_1, \beta_2) = \frac{(1-\beta_2)+\theta(\beta_2-\beta_1)}{\theta(\beta_1-\beta_2)+\beta_2} > 0$ is a collection of technological and demand parameters. Equation (13) thus relates the relative remuneration of labor to the relative scarcity of inputs used in the final goods sectors. It is only valid when the economy is in autarky since we have considered the equilibrium between national production and consumption. For this reason, we add index a . By substituting (13) in the price equation (12), for a total production of intermediate infrastructure services at full employment of public and human capital, we obtain the relative autarky price of the industrial good p^a .

$$p^a = \Phi(\beta_1, \beta_2) \left[\frac{1}{\Psi(\theta, \beta_1, \beta_2)} \frac{L}{[a_H \bar{H}^\alpha + a_p \bar{K}_p^\alpha]^{1/\alpha}} \right]^{\beta_2 - \beta_1} \quad (14)$$

When there is complementarity between the inputs of the infrastructure services production function (that is, when $\alpha \rightarrow -\infty$ and large in absolute value), the industrial comparative advantage depends simultaneously on the abundance of human and public capital.

Proposition 1. *At the time of opening to free trade, under the hypothesis that the domestic economy is small on the world market, its capacity to present a comparative advantage in the production of this good will depend on the complementarity between human and public capital in the production of infrastructure services.*

We test this prediction empirically in the following sections.

3 Data and stylized facts

3.1 Data

To empirically test our model, we use a panel of sixteen manufacturing industries disaggregated according to the international classification HS89/1992 for 35 countries over the period 1999 to 2013 (see table 1 below). We mobilize sectoral data for indicators of comparative advantage and national and sectoral data on production factors that may have an impact on international trade. The original data source is mainly the World Integrated Trade Solution (WITS) database, Penn World Table version 9 (PWT.9), and the IMF Fiscal Affairs Department. We

focus on the manufacturing industry because it better represents the theoretical framework outlined and has the advantage of illustrating, in part, the low share of developing countries in world trade.

Table 1: List of countries and industries

Industries	Countries	Countries	Countries
Animals	Australia	India	Thailand
Chemicals	Belgium	Italy	Tunisia
Food products	Benin	Japan	United States
Fuels	Central African Republic	South Korea	
Footwear	China	Morocco	
Hides and Skins	Ivory Coast	Mali	
Machinery and Electrical	Congo	Mauritania	
Metals	Germany	Malaysia	
Minerals	Denmark	Niger	
Miscellaneous	Spain	Netherlands	
Plastic or Rubber	France	Philippines	
Stones and Glass	Gabon	Senegal	
Textiles and Clothing	United Kingdom	Singapore	
Transportation	Ghana	Sierra Leone	
Vegetable	Greece	Sweden	
Wood	Indonesia	Togo	

Source: Author' calculations

Table 2 presents descriptive statistics for our data. One of the characteristics of our data, as previously announced, is the use at the industrial level of the indicator of specialization, i.e revealed comparative advantage (RCA). Data on this indicator is provided by the World Integrated Trade Solution (WITS) database. A second special feature of our data is that we use a relatively large sample that covers both developed and developing countries. In addition, we use data on factor intensities and factor endowments. While the indicator of factor intensities depends on the specificity of each industry, the measure of factor endowments depends on the specificity of countries. We thus propose a harmonized data set on indicators of comparative advantage, intensity and factor endowments at the manufacturing industry level for a large sample.

Table 2: Descriptive statistics

Variables	Obs.	Mean	Std.Dev	Min	Max
ACR	45 954	1.33	2.21	0	36.18
rhci	42 853	8.025	0.896	6.04	9.94
rci	42 853	86152.85	27952.96	27266.57	152631.3
hce	42 723	7.70	3.22	0.99	13
kpu	48 105	0.021	0.018	0.0013	0.072
kpr	48 105	0.055	0.049	0.0011	0.147
kptot	48 105	0.076	0.064	0.0030	0.208

Note: All our variables are per capita except for our dependent variable ACR and the variables rci and rhci. Variables hce, kpu, kpr and kptot represent human capital endowments, public capital endowments, private capital endowments and total physical capital endowments, respectively. They are expressed in thousands of constant 2005 international dollars. Variables rhci and rci measure human capital intensity and physical capital intensity, respectively.

Source: Author' calculations

Revealed Comparative Advantage as a proxy for specialization

To observe comparative advantages directly is difficult, if not impossible, given that autarky prices are not observable in a situation of proven international trade. This is so since they are highlighted in a purely theoretical framework. To circumvent this obstacle, we use an indirect measure by means of trade flows, namely a synthetic indicator of comparative advantages revealed as specialization or competitiveness. Historically, this indicator was first used by [Balassa \(1977, 1986\)](#), then reused by several authors in international economics, especially in empirical work on specialization issues. [Balassa \(1979\)](#), [Stern and Maskus \(1981\)](#), [Bowen \(1983\)](#), [Maskus \(1983\)](#), [Proudman et al. \(1997\)](#), and [Proudman and Redding \(2000\)](#) used it to analyze the trade and production structure of countries. This indicator suggests that international trade in goods reflects the differences in costs between countries and, consequently, reveals the comparative advantages of these countries. Observations on trade performance, in this case exports, are therefore a measure of the comparative advantages revealed. The greater a country's relative performance in trade in a given good, the greater its comparative advantage in the production of that good. Mathematically, this indicator is defined as follows:

$$ACR_{ijk} = \frac{x_{ijk}/X_{ij}}{x_{wjk}/X_{wj}} \quad (15)$$

Where x is the value of exports of good k from country i to country j , and X is total exports from country i to countries j ; w denotes the world as the origin. We consider the world as the trading partner of the sample countries and use the natural logarithm of the RCA in our study.

RCA measures the relative advantage or disadvantage of a country in a specific industry. An RCA value greater than 1 indicates that a country's share of exports in the industry exceeds its share of world exports in the same industry. If this is the case, we infer that the country has a comparative advantage in that sector. The coefficients can be used to compare sectors within the same country, but also to compare countries within the same sector. By contrast, if the indicator is less than 1, the country is not specialized in the sector (i.e. comparative disadvantage). The greater the disadvantage, the closer the indicator is to zero.

Table 3 presents the statistics of revealed comparative advantage in manufacturing by industry (average of the total sample). This table reveals a heterogeneous distribution of comparative advantage across industries and shows the industries in which countries have a comparative advantage. Thus, table 3 shows that, on average, the countries in our sample have a comparative advantage in 9 industries (more than half), with a very high level of comparative advantage in minerals and the food processing industry. Only in 6 industries do countries have a revealed comparative disadvantage, namely transportation, fuel, textiles and clothing, metals, plastics or rubber and other industries. The coefficients of variation show that there is some heterogeneity in the distribution.

Table 3: Measurement of ACR by industry (mean values and coefficient of variation)

Industries	Observation	Mean	Std.Dev	Coeff. of variation
Animals	2 398	1.87	3.55	1.90
Chemicals	5 252	1.05	1.11	1.06
Food products	4 359	2.19	3.93	1.79
Fuels	482	0.93	1.28	1.38
Footwear	1 884	0.94	1.46	1.55
Hides and Skins	1 395	1.01	1.21	1.20
Machinery and Electrical	1 395	0.77	0.69	0.90
Metals	5 226	0.80	0.52	0.65
Minerals	966	3.46	7.79	2.25
Miscellaneous	4 341	0.55	0.43	0.78
Plastic or Rubber	960	0.84	0.64	0.76
Stones and Glass	1 927	1.51	2.93	1.94
Textiles and Clothing	6 560	1.90	2.85	1.5
Transportation	1 922	0.66	0.74	1.12
Vegetable	4 781	1.70	1.46	0.86
Wood	2 757	1.29	2.07	1.60

Note: An RCA value greater than 1 indicates a comparative advantage in the sector. In contrast, an RCA value between 0 and 1 shows a comparative disadvantage in the sector.

Explanatory variables

The type of estimation used requires both the mobilization of endowment data and factor intensities.

- **Factor intensities.** In our study, we use two types of factor intensity: human capital intensity and physical capital intensity. We consider, as a proxy for human and physical capital intensity, respectively, the revealed human capital intensity ($rhci$) and the revealed physical capital intensity (rci). These indicators are provided by the WITS database and are calculated as weighted averages of the respective factor endowments of the countries that produce each good, with the weights derived from the revealed comparative advantage.
- **Relative factor endowments.** We consider three types of factor endowments: human capital endowment (hce), private capital (kpr) and public capital (kpu). Human capital is measured by estimates of the average length of schooling of the working age population. These estimates are based on the levels of education attained, which are transformed into the number of years of schooling. This proxy for human capital is motivated by [Barro and Lee \(2013\)](#). Public and private capital factor endowments are obtained from the

International Monetary Fund (IMF) Fiscal Affairs Department’s new 2017 database. All of these variables are expressed on a per capita basis. To obtain them, we divide them by the number of employed persons (labor force) from the Penn World table 9.

The construction of physical and human capital intensity indicators, using time-varying weights based on the dependent variable, i.e. exports, could pose an endogeneity problem. To remove this doubt, we realize a non-causality test according to Granger, proposed by Dumitrescu and Hurlin (2012), for panel data. Table 4 and 5 show that there is no causality between exports and factor intensities in any direction.

Table 4: Results of the non-causality test (ACR \rightarrow Human capital intensity)

Test statistics	Value	P-value
W-bar (\bar{W})	1.6854	
Z-bar (\bar{Z})	0.4846	0.6279
Z-bar tilde (\tilde{Z})	0.2242	0.8226

Source: Author’ calculations

Table 5: Results of the non-causality test (Human capital intensity \rightarrow ACR)

Test statistics	Value	P-value
W-bar (\bar{W})	0.2655	
Z-bar (\bar{Z})	-0.5193	0.6279
Z-bar tilde (\tilde{Z})	-0.4631	0.6433

Source: Author’ calculations

To defend our argument, we separate the total sample into two subsamples according to the level of factor endowment of countries. We use the average factor endowment of all countries as a criterion. Thus, countries with above average public capital endowments are referred to as high public capital endowment countries, while those with below average endowments are considered low public capital endowment countries. The same is true for human capital endowment. Tables 6 offer the classification of countries according to their public capital endowment and human capital endowment, respectively. Countries that are highly endowed with public capital are also highly endowed with human capital.

Table 6: Classification of countries according to their level of public capital endowment per capita

Countries with a high per capita public capital endowment	Countries with a low per capita public capital endowment
Australia	Benin
Belgium	Central African Republic
Germany	China
Denmark	Ivory Coast
Spain	Congo
France	Ghana
Gabon	India
United Kingdom	Indonesia
Greece	Morocco
Italy	Mali
Japan	Mauritania
South Korea	Niger
Malaysia	Philippines
Netherlands	Senegal
Singapore	Sierra Leone
Sweden	Togo
United States	Thailand
	Tunisia

Note: Countries with high public capital endowments per capita are those with above average levels of public capital endowments, while those with low public capital endowments per capita are those with below average levels. A classification according to human capital endowment produces the same results.

Source: Author' calculations

3.2 Stylized facts

Table 7 shows heterogeneity in the manufacturing sector in terms of factor intensity. In this sector, there are industries with high public capital intensity, i.e. with a use of public capital per capita above the average, while others have low public capital intensity per capita, i.e. industries with a lower than average use of public capital per capita. We note the existence of a correlation between public capital intensive and human capital intensive industries. Thus, industries that are highly public capital intensive also have a high human capital intensity⁴. This correlation reinforces our argument on the complementarity between these two factors.

Table 7: Distribution of sectors according to public capital intensity

Low public capital intensity sectors	Public capital intensive sectors
Footwear	Machinery and Electrical
Hides and Skins	Metals
Textiles and Clothing	Miscellaneous
Animal	Plastic or Rubber
Food products	Stone and Glass
Minerals	Transportation
Vegetable	Wood
	Chemicals
	Fuels

Note: A sector is low public capital intensive when the use of public capital by that sector is lower than the average use of public capital by all sectors. When a sector's use of public capital is higher than the average use, that sector is identified as high intensity. We do not present here the distribution of sectors according to their human capital intensity because the sectors that are intensive in public capital are the same as those intensive in human capital.

Source: Author' calculations

Figure 3, on the left-hand side, shows the levels of revealed comparative advantage of countries with high and low public capital endowments per capita. This figure demonstrates that, paradoxically, countries with low infrastructure endowments, i.e. those with below-average endowments, have a revealed industrial comparative advantage compared to countries with high infrastructure endowments. The level of revealed comparative advantage of low capital endowment countries in infrastructure is about twice that of high endowment countries, especially before the 2008 period.

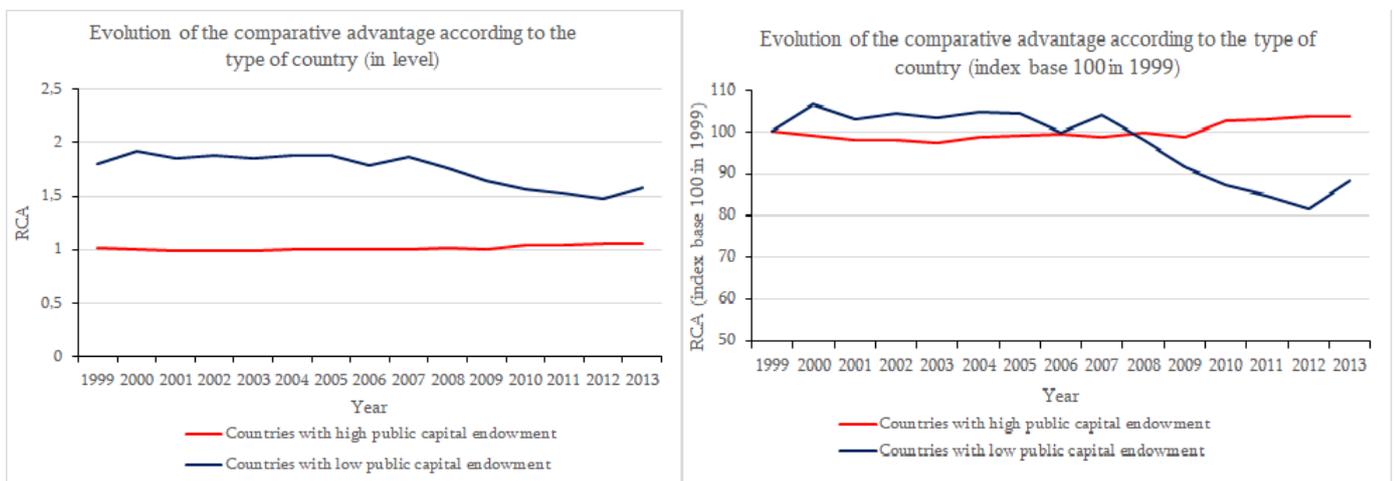
However, it is important to note that there has been a strong deterioration in comparative

⁴The results on the distribution of sectors according to their human capital intensity are not presented, as they are the same as in table 7.

advantages for countries with low levels of public capital endowment in the recent period. Despite a degree of public capital accumulation, as we can see from figure 4, the decline in their industrial comparative advantage has not been contained and countries have not been able to maintain their comparative advantage in the recent period. This implies that public capital accumulation alone would be insufficient to foster the development of a long-term industrial comparative advantage.

The right side of figure 3 shows that the revealed comparative advantage goes from an index of 100 to an index of 80 (base 100 in 1999) over the period 1999-2012, that is a decline of nearly 20 percent. At the same time, countries with high levels of public capital endowment experienced an increase in their revealed comparative advantage of about 5 percent.

Figure 3: Evolution of the RCA according to the level of public capital endowment of countries



Source: Author' calculations based on the WITS database

Figure 4: Evolution of public capital per capita by country category (index base 100 in 1999)

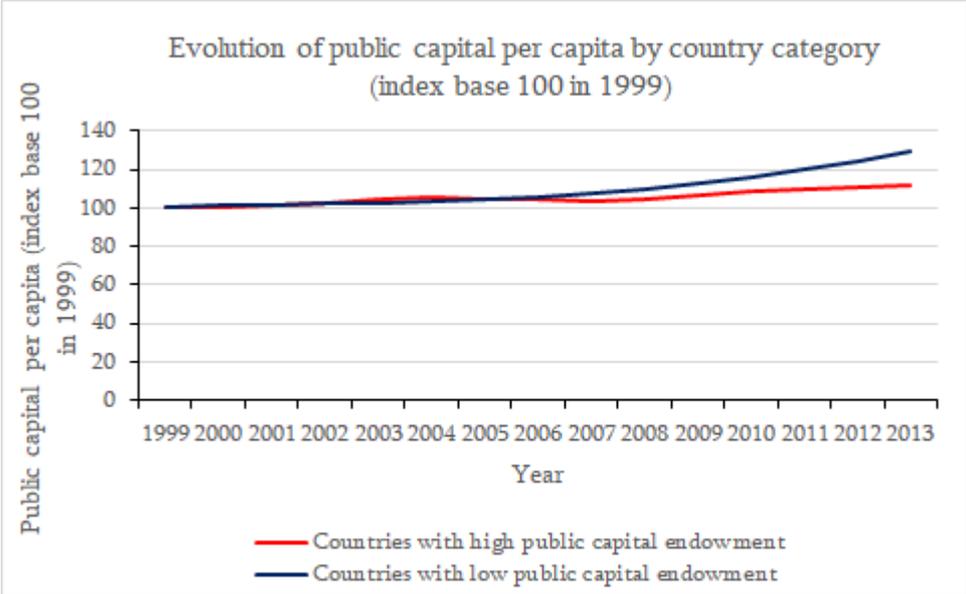
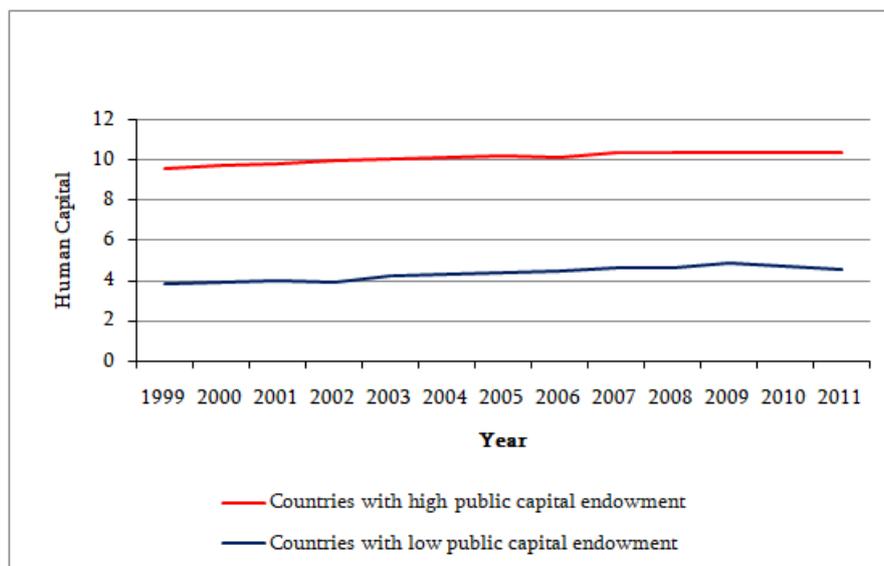


Figure 5 suggests that these changes in the revealed comparative advantages of the two groups of countries may be associated with their accumulation of human capital. It demonstrates that in countries with a high public capital endowment, the level of human capital is very high in contrast to countries with a low public capital endowment. The countries that have gained a comparative advantage in manufacturing since the 2000s (see figure 3, right side), are countries that have a high level of human capital endowment. These countries, in addition to being highly endowed with public capital, have a high level of human capital.

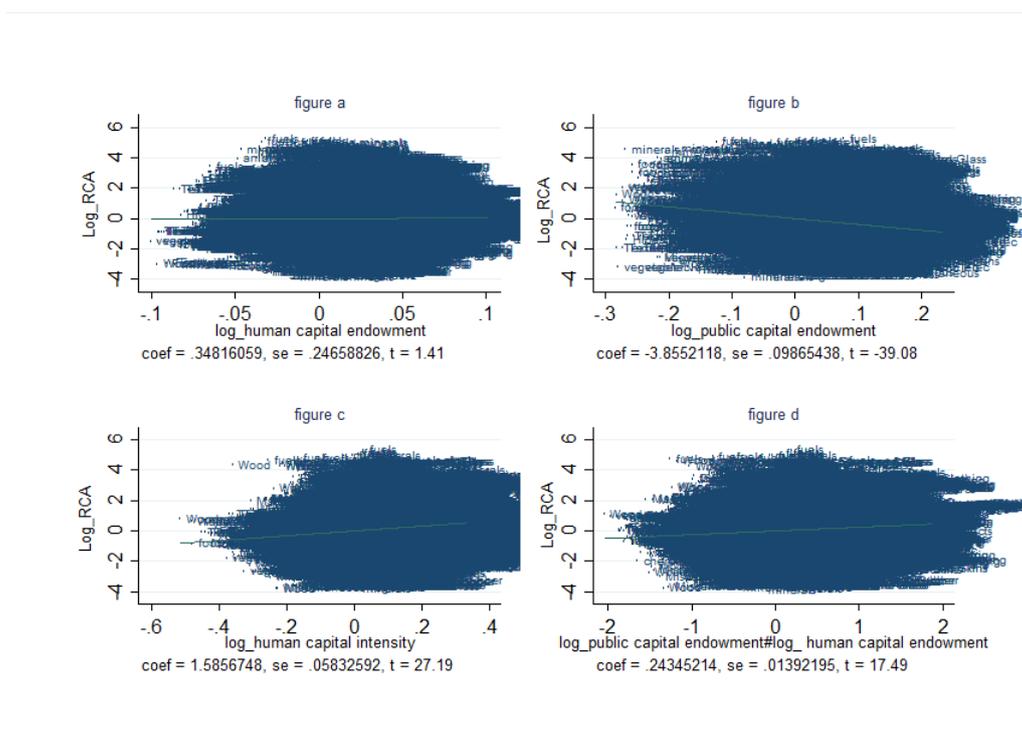
Moreover, in this same period, several authors have observed a slowdown in the dynamism of global value chains due to relocations and crises, which may be associated with the fall in comparative advantage in countries with low public capital endowments. While global value chains have enabled industrialization, it is not sustainable until countries catch up with their human capital accumulation. All these arguments reveal the existence of a modulator in the relationship between public capital and comparative advantage, which could be human capital. Figure b of graph 6 shows, through descriptive regressions, that public capital has a negative impact or a weak influence on comparative advantage when on its own: in other words, when public infrastructure is not made available to the economy by a qualified labor force. On the other hand, the interactive effect between public capital and human capital has a positive impact on industrial comparative advantage (figure d).

Figure 5: Evolution of human capital according to the public capital endowment per capita of countries



Source: Author' calculations based on the WITS and FMI database

Figure 6: Effect of public capital and/or human capital on industrial comparative advantage



Note: We control this descriptive regression by country, sector and year effects.

Source: Author' calculations

4 Estimation strategy

The aim of our study is to capture the responses of public capital endowment when it interacts with human capital endowment and the responses of a country's share of exports in a given sector to the share of world exports in the same sector. We start from a reduced, linear and simple model with four distinct variables (see table 2) that we use to construct three groups of interaction variables that will represent our main explanatory variables.

Econometric specification

The specification of our model includes interactions of the three forms of capital in their endowments and intensities.

To start with, the first interaction term consists of crossing the human capital endowment with its intensity: *human capital endowment* \times *human capital intensity* ($\ln hce_{it} \times \ln rhci_{ts}$). Such a consideration captures the effect of the availability of human capital when this capital is in fact offered and used intensively in the sector. Moreover, we assume that whatever the form of physical capital, whether private or public, the intensity remains the same and is equal to the intensity of physical capital (physical capital is the sum of private and public capital). This allows us to calculate the other interaction terms.

The second interaction term is analogous to the first (relating to human capital) and multiplies private capital by physical capital intensity, *private capital endowment* \times *physical capital intensity* ($\ln kpr_{it} \times \ln rci_{ts}$).

Finally, the last interaction term is special because it is in triple interaction. This specification captures the complementary effect between public capital and human capital. In the last term, we multiply public and human capital endowments by human capital intensity, not physical capital intensity, because human capital is our moderating variable. We thus obtain the term *public capital endowment* \times *human capital endowment* \times *human capital intensity* ($\ln kpu_{it} \times \ln hce_{it} \times \ln rhci_{ts}$). Our main estimation equation is written:

$$\begin{aligned} \ln ACR_{its} = & \beta_0 + \beta_1 \ln kpu_{it} \times \ln hce_{it} \times \ln rhci_{ts} + \beta_2 \ln hce_{it} \times \ln rhci_{ts} \\ & + \beta_3 \ln kpr_{it} \times \ln rci_{ts} + \delta_t + \delta_i + \delta_s + \epsilon_{ist} \end{aligned} \quad (16)$$

This is a simple linear interaction model that will be estimated from ordinary least squares (OLS) where:

- $\ln RCA$ is our dependent variable defining the revealed comparative advantage of a country i in year t in a sector s expressed in natural logarithm;

- three groups of interaction variables on the right-hand side of equality in the equation are our previously defined explanatory variables;
- δ_t , δ_i et δ_s capture unobservable time fixed effects, country fixed effects and sector fixed effects respectively;
- $\epsilon_{ist} \sim N(0, 1)$;

Individual fixed effects aim to control for any permanent differences across countries in the dependent variable; sector fixed effects capture differences across sectors in the dependent variable, while time effects capture aggregate and country and sector specific macroeconomic shocks that may affect all groups equally. With the methodology used, i.e. the one that considers factorial interaction, we can account for a possible bias of omitted variables such as GDP, population, quality of institutions, exchange rate, conflict, insecurity, aid, etc. These variables, that can vary between countries and sectors over time, are captured partially through interactive terms that vary by sector and country over time.

In view of the nature of the variables used and the objective of the study, once the estimates are made, we calculate the marginal effects of public capital in the regression. As mentioned by [Ledezma et al. \(2009\)](#) in their paper, when we introduce an interaction term of two variables A and B , the evaluation of the global effect of variable A requires a calculation of its marginal effect, conditional on the values that the variable B can take.

Since we introduced interaction terms between public capital endowment and human capital endowment, the evaluation of the expected overall effect of public capital ($lnkpu$) on comparative advantage requires the calculation of its marginal effect, conditional on specific values of human capital endowment. The marginal effects of public capital in our estimation model allow us to interpret coefficient $\hat{\beta}_1$ in each of our specifications as an elasticity. Formally, it is a partial elasticity. Through our main equation (16), we obtain the marginal effects as follows:

$$E_{m|kpu} = \frac{\partial \ln AC R}{\partial \ln kpu} = \hat{\beta}_1 \underbrace{\ln hce * \ln rhci}_{X_1}. \quad (17)$$

It is easier to observe that a positive and significant $\hat{\beta}_1$ shows that a 1% increase in public capital leads to a $\hat{\beta}_1 X_1$ % increase in comparative advantage. In our regressions, we assess the marginal effect and its statistical significance for various levels of human capital, i.e. the sample mean, as well as one and two standard deviations above and below the mean.

5 Empirical results and discussion

Table 8 below presents the results of the different tests of the effect of public capital on industrial comparative advantage, conditional on the level of human capital accumulated by the country, using the main model (equation 16). For each regression, the bottom portion of the table presents the estimated marginal effects of the public capital indicator for different levels of relative human capital endowment: mean of the sample human capital stock, one and two standard deviations (SD) above and below that mean.

The second column of table 8 offers the results of the estimation of the main model. It shows a positive and highly significant marginal effect of public infrastructure on comparative advantage. This positive effect of the availability of public infrastructure is all the more important the higher the stock of human capital. These results suggest that the industrializing effect of public infrastructure is particularly present when human capital accumulation is above average, with estimated elasticities above 1. *Ceteris paribus*, for a country that is better endowed with human capital than the average in two standard deviations, an increase of 1% in public capital leads to an increase in comparative advantage of 1.55%. While a country that is less endowed with human capital than the average in two standard deviations, a 1% increase in public capital leads to a 0.381% increase in the share of manufacturing exports.

Table 8: Estimating the marginal effect of public infrastructure on RCA

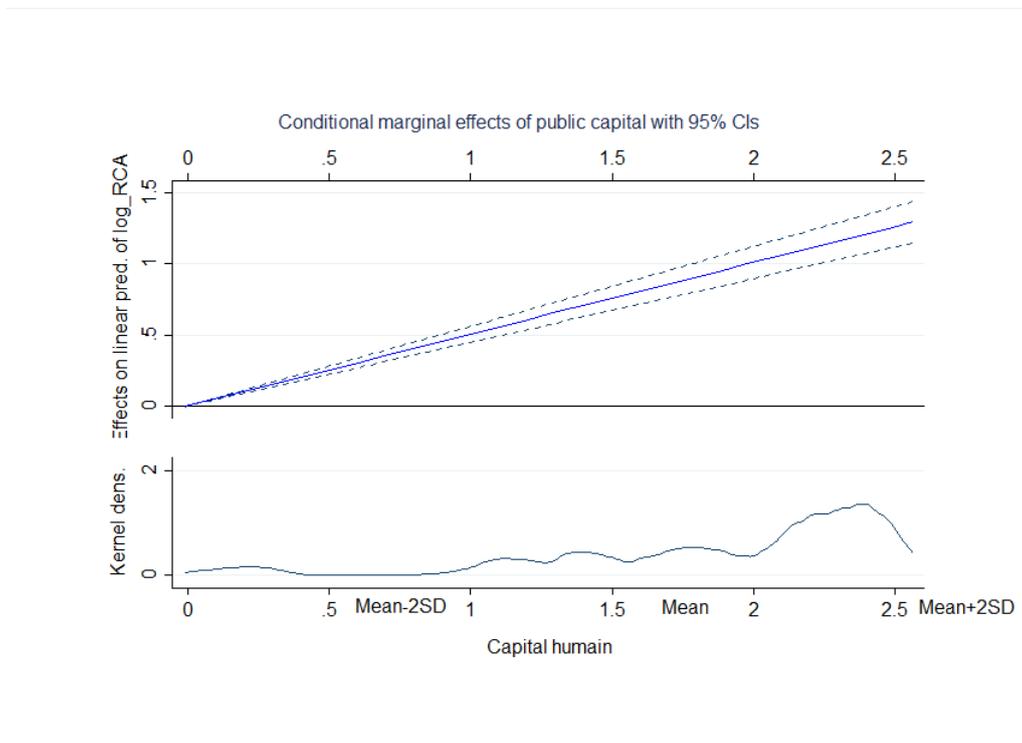
	Main model	Shock control model	Model with 1 lag
<i>Panel A: Dependent variable— Specialization (log RCA)</i>			
Public capital endowment × Human capital endowment × Human capital intensity	0.243 (0.0139)***	1.058 (0.0301)***	0.270 (0.0148)***
Human capital endowment × Human capital intensity	1.586 (0.0583)***	4.916 (0.1056)***	1.672 (0.0616)***
Private capital endowment × Physical capital intensity	0.012 (0.0032)***	0.107 (0.0067)***	0.014 (0.0035)***
Country fixed effects	yes		yes
Year fixed effects	yes		yes
Sectors fixed effects	yes	yes	yes
Country fixed effects × Year fixed effects		yes	
Constant	-3.979 (0.156)***	-2.972 (0.192)***	-4.092 (0.166)***
Observations	42,560	42,560	39,240
R-squared	0.298	0.349	0.299
<i>Panel B: Marginal effect of public capital</i>			
2 SD below the mean	0.381 (0.0218)***	1.656 (0.0472)***	0.430 (0.0236)***
1 SD below the mean	0.673 (0.0385)***	2.926 (0.0834)***	0.753 (0.0413)***
Mean	0.966 (0.0552)***	4.196 (0.1196)***	1.076 (0.0590)***
1 SD over the mean	1.258 (0.0719)***	5.466 (0.1558)***	1.398 (0.0767)***
2 SD over the mean	1.550 (0.0887)***	6.736 (0.1920)***	1.721 (0.0944)***

Note: Panel A reports regressions of the intersection of public and human capital on comparative advantage. Panel B presents for each regression the marginal effects of public capital and its importance at different sample values. Standard deviations are in brackets. Significance levels : *10% ; ** 5% et *** 1%.

To illustrate these results graphically, we present a simple figure (figure 7) that shows how the marginal effect of public capital changes when human capital takes on given values.

The sloping solid line (in blue) in figure 7 shows how the marginal effect of public capital changes with the level of human capital. Any particular point on this line is $E_{m|kpu} = \frac{\partial \ln ACR}{\partial \ln kpu} = \hat{\beta}_1 \underbrace{\ln hce * \ln rhci}_{X_1}$. 95% confidence intervals around the line determine the conditions under which public capital endowments have a statistically significant effect on revealed comparative advantage. It is easily noticeable that public capital has a strong impact on comparative advantage, revealed when the level of human capital is high. Consistent with predictions, this figure shows that the effect of public capital on revealed comparative advantage in industrial sectors increases as the level of human capital increases. It also presents the distribution of the public capital stock per capita in our sample. For countries with less infrastructure (see table 6 for the list of countries according to the level of public and human capital endowment), i.e. those for which the public capital stock is less than 1 standard deviation from the average, the marginal effect is very small. The next section checks the robustness of these results by considering alternative specifications estimated by taking into account country specific shocks over time and also lags in capital investment.

Figure 7: Marginal Effect of Public Capital on Comparative Advantage



Source: Author' calculations

6 Extension and comparison

The initial model considered in the previous section is maintained and extended with the inclusion of other control variables. Relative factor prices may be important in determining the specialization, as countries are observed directly in free trade. Differences in relative factor prices are assumed to be correlated with relative factor endowments, thus determining the specialization pattern of countries. However, in free trade, the relative prices of factors may no longer depend on factor endowments and will henceforth be supported by world demand. In order to capture the effect of these relative prices, which are country specific shocks over time and for which there is no internationally comparable data, we introduce into the regressions cross-country fixed effects (country \times year) noted (δ_{it}) constructed from the interaction between the country fixed effects (δ_i) and the fixed effects (δ_t) . These fixed effects will allow to better control any evolution at the country level. Technically, this specification can be expressed as follows:

$$\begin{aligned} \ln ACR_{its} = & \beta_0 + \beta_1 \ln kpu_{it} \times \ln hce_{it} \times \ln rhci_{ts} + \beta_2 \ln hce_{it} \times \ln rhci_{ts} \\ & + \beta_3 \ln kpr_{it} \times \ln rci_{ts} + \delta_{it} + \delta_s + \epsilon_{ist} \end{aligned} \quad (18)$$

The results of this model are presented in column 3 of table 8. When we control for country-specific shocks over time by cross-fixed effects, the marginal effects of public capital are larger than in the initial model (second column). We also find that the impact of public infrastructure is positive and very significant. *Ceteris paribus*, a 1% increase in public infrastructure leads to a 6.736% increase in comparative advantage for countries whose human capital endowment is two standard deviations above the average. For countries with low endowments of human capital (i.e. countries whose level of human capital is equal to its average minus 2 standard deviations), a 1% increase in public infrastructure leads to only a 1.656% increase in comparative advantage. Yet, when these shocks are not controlled, the effect of public infrastructure is significantly positive but less important. For example, for countries with high human capital endowments, a 1% increase in public infrastructure leads to an increase in comparative advantage of only 1.5%.

A second extension consists of estimating the same model with 1 lag. This allows, on the one hand, to overcome the endogeneity problems linked to the consideration of factorial intensities that are correlated to the dependent variable. On the other hand, this specification makes it possible to consider the accumulation of infrastructure and human capital in the previous

period in determining the comparative advantage of countries. The results of the 1-lag model are presented in the last column of table 8. Compared to the results for the main model (column 2), the magnitude of the coefficients on the marginal effects of public capital are more important when we consider a lagged model. The results show that for the same level of human capital endowment, the effect of public infrastructure is more important when the variables are lagged. These very results suggest that if the effect of public infrastructure becomes even more important as the level of human capital increases, it is because past investments realized by countries have increased their public and human capital stock.

7 Conclusion

This paper has examined the complementary relationship between human capital and public infrastructure in industrial revealed comparative advantage. It mobilized a theoretical framework of comparative advantage extended to human capital and estimated in a reduced equation a model of factorial interactions. This estimation allowed us to analyze the role of human capital as a modulator of the use of public infrastructure in the development of the country's manufacturing comparative advantage.

According to our theoretical prediction, a country will have a comparative advantage in the industrial good for the same level of public infrastructure if it is better endowed with human capital. Our empirical results support this theory and reveal that the effect of public infrastructure on comparative advantage is extremely important when the level of human capital accumulation is very high. Moreover, this effect of public infrastructure is even more consequential if we control for country-specific shocks over time in our estimates or if we incorporate lags in our regressions.

Our study reveals that infrastructure itself is not enough and emphasizes that it must be accompanied by human capital to enable countries to develop an industrial comparative advantage. Countries with low infrastructure endowments may have a comparative advantage over time, thanks to the reception of FDI and global value chains. That being said, these industrial advantages cannot be preserved indefinitely. If these countries do not ensure this industrialization, which came via FDI, with human capital and infrastructure capital, they will lose their industrial comparative advantage.

Our results are particularly important for African countries. Since these countries have not received industrializing FDI, our results recommend that they go directly to public and human capital accumulation to develop their manufacturing sector. Our results also provide a

prediction for other countries such as the Maghreb and Latin American countries. For those countries that have received FDI but do not increase their level of human capital, our results predict that some of them will not be able to sustain significant industrialization, especially when there are relocation effects.

Our results can be used in economic development policies. The recommendations of the Bretton Woods institutions on policies to enhance and invest in human capital highlight that the development of human capital should make it possible to maintain and ensure the sustainability and return on public infrastructure investments. This would promote growth and economic development in countries, especially those in Sub-Saharan Africa.

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