Technological Absorptive Capacity and Development Stage: Disentangling Barriers to Riches*

J. Rodrigo Fuentes†   Verónica Mies‡

September 3, 2019

*This work was supported by the National Fund for Science and Technology of Chile Fondecyt, [grant number 1150433]. We would like to thank participants at the North American Summer Meeting of the Econometric Society, EEA and LACEA meetings, Anderson School of Management at UCLA,Pontificia Universidad Católica de Chile and the Universidad de Chile seminars. We also thank the thoughtful comments of the editor and two anonymous referees. The usual disclaimer applies.

†P. Universidad Católica de Chile. Address: Av. Vicuna Mackenna 4860, Macul, Santiago, Chile. Phone: ++56 2 23 544 308, mailto:rodrigo.fuentes.cl

‡P. Universidad Católica de Chile. Address: Av. Vicuna Mackenna 4860, Macul, Santiago, Chile. Phone: ++56 2 23 544 308, mailto:vmies@uc.cl

Abstract

Adoption of better technologies is a crucial way for developing countries to close productivity gaps with leading economies. However, the possibility of growing through technological adoption depends decisively on the country's absorptive capacity. We build a theoretical model of technology adoption that focuses on four factors that shape the countries' technological absorptive capacity, namely: i) years of education; ii) quality of the educational system; iii) barriers that impede the entry and exit of firms; and iv) the institutions that enhance or impede the diffusion of new technologies. We calibrate the model for a sample of 86 economies. The United States is our benchmark leading economy. We disentangle the relative weight of each development factor in explaining per capita income differences and study patterns in relationships between the type of development barrier and the level of development. Our results show that in relative terms, years of education and education system quality along with high barriers to opening new firms are the main impediments that middle to high-income economies face in closing the gap with the United States. Education as whole (quality plus years of education) explains 50% of the gap between high-income countries and the United States while the entry costs account for nearly 25% of this gap. A remarkable result is the small effect that individual reforms have on steady-state productivity in low-income countries. Outside of institutional framework, the remaining three factors are individually responsible for less than 15% of the gap. This result is explained by poor global absorptive capacity that reduces the effect of each factor when implemented individually. In fact, there are significant nonlinearities between development level and the effects of individual reforms, which are due to the strong complementarities between the different development factors.

Keywords: TFP, technological adoption, development, income gaps, barriers, human capital. JEL Class: O33, O11, O50

1 Introduction

The current consensus in the literature is that disparities in total factor productivity (TFP) largely explain observed differences in the level of long-run GDP per capita across countries (see, for example, Klenow and Rodriguez-Clare, 1997; Parente and Prescott, 2002; Hall and Jones, 1999; and Caselli, 2005). Based on this, theoretical and empirical studies have focused on explaining TFP gaps among economies, usually stressing a single specific mechanism. However, the impact of any factor or policy on closing the TFP gap, between a particular economy and the leader, will depend on the level of development and all the additional implemented policies in that economy. Within one theoretical framework, this paper analyzes and quantifies the outcomes of different development factors on closing TFP gaps, paying special attention to how complementarities among the different factors and the level of development determine the factors marginal effects.

One way of thinking about these issues is to consider that all economies in the world face the same stock of usable knowledge (Parente and Prescott, 2000) or the same technological frontier (Howitt, 2000). However, the ability to capture that knowledge or to adopt the technological frontier differs among economies because they have different technological absorptive capacities that, in turn, translate into persistent differences in per capita income. This type of model considers long-term income differences as the result of frictions associated with access to this frontier such as limited human capital, taxes limiting innovation and adoption activities, costly patent applications and protections, limited rule of law, or other factors. The main issue we are concerned with in this paper is to address the relative importance of each type of friction in explaining cross-country income differences, relating them to the stage of development.

The approach follows in this paper builds on Howitt (2000), who extends a quality-ladder model of growth to include international diffusion of knowledge. In particular, the model of Howitt (2000) specifies that innovations arrive randomly at a rate that depends on a constant parameter linked to the productivity of the research technology and on a production factor, typically R&D investment. Following this specification, we link the productivity parameter to institutions that enhance or diminish the productivity of R&D activities [1]. Second, we redefine the production factor as a combination of effective units of R&D investment and domestic skills used in the innovation process [2]. Finally, we allow for frictions in the R&D markets that enables us to take taxes or distortions that affect the entry and exit of R&D firms into account [3]. Thus, based on the specification of Howitts (2000) model, we include three aggregate factors that correspond to years of education, educational quality, and institutions that favor R&D, and we also include one micro factor corresponding to entry barriers for new firms.

A key component of this model is the idea of catching-up, the concept that lagging behind the global technology frontier facilitates technological growth through

[1] This parameter is included in the spirit of Parente and Prescott (2002) regarding barriers in seizing the available world stock of knowledge. In an empirical analysis, Comin and Hobijn (2004) found that openness to trade is one of the most relevant variables to explain the speed of technology adoption by less developed countries.

[2] From the theoretical empirical point of view there are arguments that human capital is one of the key elements in technology adoption. For these arguments see Nelson and Phelps (1966), Bartel and Lichtenberg (1987), Acemoglu and Zilibotti (2001), Benhabib and Spiegel (2002), and Comin and Hobijn (2004).

[3] Microeconomic distortions that affect entry and exit of firms and their consequences on TFP has been documented by Bergoeing et al. (2015).

adoption. However, at the same time, as lagging behind usually reflects a poor technological absorptive capacity, we are able to explain why laggard countries fail to grow faster despite making reforms. In our model, technology is the only factor affecting productivity. Thus, we use both terms technological change and productivity improvement indistinctively.

Later, we calibrate the implied steady-state TFP for a sample of 86 countries. Our benchmark leading economy is the United States, and we measure every outcome relative to it. The calibrated model closely resembles the relative TFP distribution of our sample and has a good fit of other endogenous variables of the model such as R&D investment and firms' entry/exit rates. We conduct some policy experiments by improving each development factor one at a time to the level of the United States and compute the corresponding impact on TFP gaps. The impact of each change depends on the distance to the frontier and the economy's technological absorptive capacity.

The model produces complementarities among the four factors that enable us to understand the type and degree of complementarities that affect the final impact of different reforms. In particular, a reform's impact depends on the level of development through two opposing effects. On one hand, the lower the economic development level, the greater the distance to the technological frontier and, therefore, the greater the benefits of improving any of the development factors (higher incentives to invest in adoption activities). The reason for this is that potential growth through adoption increases with the technology gap. On the other hand, a low economic development level implies that development factors are generally at low levels, producing a poor technological absorptive capacity. This poor absorptive capacity diminishes the impact of any particular reform because said reform is applied in a poor economic environment.

In order to study whether impacts vary with development level, we divide the sample of countries into four income groups: high, upper-middle, lower-middle, and low-income countries. We find that the representative low-income country with poor absorptive capacity (poor institutional framework, high costs of opening new firms, low quality of the educational system, and fewer years of education) require big bang type of reforms. Despite the great distance to the technological frontier, the effects of individual reforms are minimal because of the low levels of all other factors. That is, complementarities among factors explain a large share of TFP gaps. High-income countries also show a low impact from individual factors despite having good technological absorptive capacity. The reason is that they are already close to the technological frontier and thus the potential gains are lower. As expected, complementarities explain little of the gap with the leader. In contrast, upper-middle- and lower-middle-income economies exhibit significant effects from individual reforms. They have a large potential for growth through catching up and their technological absorptive capacity is sufficiently good.

When comparing the relative importance of each factor by income group we find the following: the level of institutional framework explains the largest share of TFP gaps for the poorest economies. The impact of changing their institutional framework is three times the impact of changing entry costs and almost five times the impact of changing the available education (quantity and quality). As countries develop, this factor loses relative importance. In fact, it accounts for a lower share of the TFP gap than any other factor for high-income countries. In contrast, entry barriers and educational quality show the opposite result. In relative terms, these factors account for a smaller proportion of the gap for low-income countries but increase their relative importance as economies develop. For low-income countries, those two factors explain less than 15% of the corresponding TFP gap compared to 50% in the case of high-income countries. Finally, the importance of complementarities decreases monotonically with development level. In the case of poor countries, the impact of any reform is low because the technological absorptive capacity is low, thus complementarities become important.

Finally, the last exercise illustrates the non-linear effect of each factor on TFP gaps. We measure the change in each factor's marginal effect as we change the values of all other factors plus/minus one standard deviation. For each factor and each income group all marginal effects increase with the level of the absorptive capacity. This implies that the positive impact of improving a country's absorptive capacity more than offsets the negative impact of a smaller productivity gap. The exception is the high-income group; all marginal effects diminish with the level of the absorptive capacity. In this case, the absorptive capacity is already high and the negative effect of a smaller productivity gap dominates the final effect. In other word, policies as analyzed here, have some degree of complementarity, which become more important for less developed economies.

Our approach is based in a large body of literature that provides explanations for cross-country differences in TFP. One can think of these explanations as how different factors affect the possibility of adopting the technological frontier. This capacity is usually limited by barriers that hamper the full use of more efficient technologies (see for example Parente and Prescott, 1999; Midrigan and Xu, 2014 [4]); distortive

[4] Midrigan and Xu (2014) argue that financial frictions affect TFP through deterring the entrance of new firms and capital misallocation. They found the first channel to be the most important one, which is precisely one of the channels that we emphasize in this paper.

policies that produce misallocation of resources (Banerjee and Duflo, 2005; Lagos, 2006; Restuccia and Rogerson, 2008; Hsieh and Klenow, 2009; Bartelsman, Haltiwanger and Scarpetta, 2012; and Bento and Restuccia, 2017); inadequate human capital that obstructs the implementation of an adopted technology (Nelson and Phelps, 1966; Benhabib and Spiegel, 2002; Acemoglu and Zilibotti, 2001; Caselli and Coleman, 2006) and institutional framework that is unfriendly to the adoption activity (Acemoglu, 2009; Parente and Prescott, 1994, among others).

In a related paper, Bergoeing, Loayza and Piguillem (2015) analyze the barriers to the entry and exit of firms, finding that 50% of the technology gap between countries is explained by this type of barriers. Comin and Hobijn (2004) study the diffusion of 20 technologies in 23 countries and associate the rate of technological adoption to factors such as openness, human capital, and the economic regime of the countries under study. In a complementary paper, Okoye (2016) extends Caselli and Coleman (2006) to study whether the quality of human capital or the use of other complementarity factors (physical capital) make labor more productive, finding that complementarities with other production factors are important in explaining income differences.

Technology adoption may not be the only channel that explains TFP gaps around the world. For instance, in our exercise we obtain a residual (the part of the gap that is not explained by the considered factors) that we link to policy complementarities. Since we compute the positive outcome of one policy improvement at the time, we cannot capture the impact of collaboration across policies. An interesting feature of our simulations is that the importance of the residual in explaining the TFP gap decreases with the level of income. This may be capturing other factors outside of these policy complementarities. For example, the literature has found that structural transformation (which is closely related to the stage of development) may explain a large share of TFP differences (as explained in Restuccia et al, 2008; Duarte and Restuccia, 2010 and Herrendorf et al., 2013). Under this lens, low income countries specialized in agriculture, which is a low productivity sector, tend to show larger TFP gaps compared to industrialized countries. This is consistent with our findings.

Up to this point it is important to clarify the role of human capital. Here, the level of quantity and quality of human capital is important for the technology adoption process. The model considers how this factor interacts with pro adoption institutions and restrictions for new firms to enter in the market. We acknowledge that other mechanism has been in placed to model the role of human capital in the process of technology adoption. Acemoglu and Zilibotti (2001) and Caselli and Coleman (2006) emphasize that there are different "types" of technologies with different degrees of complementarities with skilled/unskilled labour. This mechanism help them to explain why technology developed in advanced economies is inappropriate for less developed economies. In our model human capital is exogeneous and enter as an input in the technology adoption process. Our model is unable to explain the mismatch of technologies between these two groups of countries, but we are able to contribute to explain the height of the barriers to adopt new technology in a different way. For us a low level of human capital reduces the probability of adoption, therefore, observed TFP will be lower. But, as in Howitt (2000) technology developed elsewhere is suitable to be used in the domestic economy.

Caselli and Coleman (2006) focus on this the mismatch of thechnology and human capital, taking as given the distant to frontier. We focus in how human capital contribute to the observed distant to frontier. On the other hand, Acemoglu and Zilibotti (2001) find that the largest productivity gaps are in "low-tech" sectors, for example the well-known agricultural productivity gap, suggesting that levels of education vary by sector and is relevant for successful adoption. Our model allows for sectoral differences, but it focuses in average TFP, without pointing what type of sectors are behind in low or middle-income economies.

At last, but not least, a recent paper by Comin and Mestieri (2018) highlights the importance of the topic developed in this paper: "(...) the majority of the divergence in productivity can be accounted for by technology diffusion" (page 173, Comin and Mestieri, 2018). They find that the divergence in per capita income between Western countries and the rest of the world is due to the intensity of use of technology, rather than the delay in its adoption, since the latter has declined over time. Moreover, they find that the difference in the intensity of use is about eight times between Western and Non-western economies by year 2000. The rate of adoption, in contrast, is 40% faster in Non-Western economies than it used to be. Our work predicts that keeping the level of the structural parameters, the difference in TFP between high-income countries (Western economies) and low-income countries will be almost 5 times in steady state (for a technological frontier that grows at a constant rate). Our measure does not distinguish between the speed of adoption and the intensity of use of technologies, and we interpret it as involving both processes.

The rest of the paper is organized as follows. Section 2 presents the analytical framework and the technology adoption model. Section 3 briefly examines the aggregate implications of the micro-funded model in the previous section. Section 4 calibrates the model for a wide sample of 86 economies and evaluates the fit of the model. Section 5 discusses the different bottlenecks associated with each development stage. In this section, we analyze in detail the complementarities implied by the analytical framework. Section 6 introduces some robustness checks. Finally, Section 7 presents concluding remarks.

2 The model

The model closely follows the Schumpeterian growth models developed in Aghion and Howitt (1998) and Howitt (2000). Consider a benchmark economy out of J countries in the world economy. The benchmark economy is composed of two types of sectors: a homogeneous and competitive final goods sector, and a broad intermediate sector producing different qualities of inputs. All the relevant decisions are made in the broad intermediate sector, which is composed of a continuum of subsectors with a mass of one. Each intermediate subsector is composed of two firm types: one R&D firm and many non-R&D ones. The R&D firm engages in R&D activities to improve the currently used technology by adopting the technological frontier. When successful this firm produces improved quality intermediate input and obtains profits. The non-R&D firms are also capable of producing the intermediate input with the current technology, but with a productivity disadvantage relative to the R&D firm that successfully introduced the new technology.

Thus, technological progress is endogenous at the country level and is given through the adoption and implementation of better technologies. There is a technological frontier that grows at the exogenous rate g.

The economy is populated by two types of agents: i) a continuum of homogeneous entrepreneurs with a mass of one who live for two periods and open R&D firms and ii) a continuum of workers of a mass of one who live for one period and supply their time endowment to the final goods producer. Both types of agents derive linear utility from the consumption of the final good.

We further assume that markets are complete and that all risk is idiosyncratic. There is perfect access to foreign capital and the risk-free international interest rate is r_{Bt}. We assume that the world is in a steady state so that r_{Bt} is constant. In this setting, consumption and production decisions are independent. Time is discrete.

2.1 Producers: final goods and intermediate firms

The production of the final good Y_{it} depends on the flow of intermediate input x_{it} as it follows: $Y_{it} = A_{it}F(x_{it}, l_{it})$. The parameter A represents the productivity of the latest type of input i, and l represents labor. For simplicity, and to obtain closed form solutions at the aggregate level, we use the standard Cobb-Douglas specification (as in Howitt, 2000): $Y_{it} = A_{it}x_{it}^{\epsilon}l_{it}^{1-\epsilon}$. We assume that the labor force is homogeneously distributed across sectors. Therefore, aggregate output of the final good corresponds to

$$Y_t = \int_0^1 Y_{it}di = L^{1-\epsilon}\int_0^1 A_{it}x_{it}^{\epsilon}di \tag{1}$$

The mass of workers L corresponds to aggregate labor. As mentioned, labor is constant and equal to one in every period. The firm pays in equilibrium the marginal product of labor and the marginal product of inputs p_{it} given by:

$$p_{it} = \epsilon A_{it}x_{it}^{\epsilon-1} \tag{2}$$

Every intermediate input i includes a productivity level of A_i. The higher the productivity embedded in input x_{it}, the higher the quantity of Y_{it} generated by one unit of x_{it}. Inputs are produced with the following technology[5]:

$$x_{it} = \frac{1}{\eta} \frac{K_{it}}{A_{it}} \tag{3}$$

The intermediate firm in subsector i only uses physical capital to produce the input. Physical capital is divided by the technology embedded in the intermediate input to account for how more advanced technology requires more capital to incorporate it into the input. Parameter η determines the productivity of firms when producing inputs.

We assume that in every period there is a large number of non-R&D firms capable of producing the input with the currently available technology in subsector i. However, in some subsectors, there is a R&D firm that was successful in improving the technology in the previous period and will have a productivity advantage in producing the input in this period. R&D and non-R&D firms differ in the value of this parameter. In particular, the successful R&D firm can produce inputs with a parameter $\eta = \eta_{R\&D} = 1$, while a non-R&D firm can produce inputs with a parameter $\eta = \eta_F$ with $1 < \eta_F < 1/\epsilon$.[6] Both types of firms compete *à la* Bertrand so that the equilibrium price of inputs corresponds to the marginal cost of the second most efficient producer. Thus, $p_{it}{=}\eta_F A_{it} r_t$. Replacing p_{it} in equation (2), we obtain the equilibrium quantity supplied from each intermediate input given by $x_{it}{=}\left(\frac{\epsilon}{r_t\ \eta_F}\right)^{\frac{1}{1-\epsilon}}$. Consequently, when the R&D firm is successful in improving the technology, it serves the whole market and obtains profits equal to:

$$\pi_{it} = (\eta_F - 1)\, A_{it} \left(\frac{\epsilon}{\eta_F\ r_t^{\epsilon}}\right)^{\frac{1}{1-\epsilon}} \tag{4}$$

[5]This specification (in combination with the previous ones) produces an aggregate production function that is homogeneous of degree one in capital and labor as is standard in the literature.

[6]This assumption ensures that at the equilibrium prices and quantities, the successful R&D firm meets the entire market demand for input i.

Profits are proportional to the technology used in each sector. Perfect access to foreign capital ensures that $r_t = r_{Bt} + \delta$ in equilibrium, where δ corresponds to the depreciation rate of physical capital.

2.2 The R&D market and R&D firms

In every period t, a new entrepreneur is born in each subsector i who starts an R&D firm in order to improve the current technology. R&D is risky. If the R&D firm is successful in adopting a new technology, it will become the new producer of input i in the second period. At the end of this period, the firm disappears at no cost; the adopted technology remains available to all non-innovating firms. However, if the R&D firm is not successful, it will become a non-innovative firm. A successful firm copies the technological frontier, $A_{\max,t}$, which is the most advanced technology available in the world at time t. To simplify, we assume that $A_{\max,t}$ is the same for each sector i.

The Schumpeterian growth models *a la* Aghion and Howitt specify that innovations randomly arrive at the rate, $n\lambda$, where λ is a parameter indicating the productivity of the research technology, and n corresponds to a production factor (typically R&D investment or labor used in research). Following this specification, we link the productivity parameter λ to institutions and a technological framework that enhances or diminishes the productivity of R&D activities. Second, we redefine the factor of production, n, as a combination of effective units of R&D investment ($i_{it} \equiv I_{it}/A_{\max,t}$) and domestic skills (S) used in the innovation process: $n = i^{\alpha} S^{\gamma}$.

We include skills as a production factor to account for the vast literature initiated by Nelson and Phelps that points out that human capital, in general, and education, in particular, plays an important role in increasing the capacity for innovation and adoption of new technologies. Implementing a new technology is not an automatic process. It requires specific skills in order to understand the foreign technology and also to implement it in a suitable way to a specific sector. This view is consistent with Schumpeterian models that include the number of (skilled) researchers (n) in the innovation process (Aghion and Howitt 1998). The inclusion of this variable is also supported by the empirical literature both macro (for example Barro and Sala-i-Martin, 1994) and micro (for example Bartel and Lichtenberg, 1987). Moreover, the complementarity between R&D and educational attainment is directly addressed by Benhabib and Spiegel (1994) and supported by the data. As in the basic model of Aghion and Howitt, we treat educational attainment as exogenous. Thus, the probability of success will be given by:

$$\phi_{it} \equiv {i_{it}}^{\alpha} {S_{it}}^{\gamma} \lambda^{1-\alpha-\gamma} \quad ; \quad \alpha+\gamma<1 \tag{5}$$

We scale total investment I_{it} by the technology that the firm will embed in input, and $A_{\max,t}$, to account for how the amount of resources needed increases with technological complexity; α is an intensity parameter.

The term S_{it} accounts for the role that domestic skills play in the adoption activity. Skills are obtained through a learning production process, $S_{it} = f(q, s_{it})$, which depends on the entrepreneurs years of education, s_{it}, and on the quality of the education system, q. In particular, we follow the Hall and Jones (1999) specification that is broadly used in the literature and is given by:

$$S_{it} = e^{q * s_{it}} \tag{6}$$

We assume that the entrepreneur has the average years of education in their country, thus $S_{it} = S_t$; q represents the marginal return of one additional year of education. We assume that this return depends on the quality of the education system, which in our model is exogenous and given to the entrepreneur.

The probability of successfully adopting a technology also depends on the economy's institutional framework that is related to the provision of incentives for the efficient use of existing and new knowledge. Parameter λ comprises all of these effects. This parameter is in the spirit of the barriers emphasized by Parente and Prescott (1994) and lies within the range $[0, 1]$. The lack of an appropriate institutional framework implies a value for $\lambda = 0$ and, conversely, a suitable level of institutions implies a $\lambda = 1$. This parameter can vary across countries. The relative importance of this institutional framework in shaping the probability of success is given by the intensity parameter $(1 - \alpha - \gamma)$.[7]

The entrepreneur decides the amount of R&D investment that maximizes her expected profits given by:

$$\begin{aligned} \max_{I_{it}} \phi_{it} W_{it} - & \quad (1+\tau) I_{it} \qquad \text{subject to} \\ I_{it} & \geq 0 \end{aligned} \tag{7}$$

With probability ϕ the firm succeeds in implementing the new technology, earning $W_i = \frac{\pi}{1+r_B}$, which is the present value of profits obtained in the second period. Adoption of the new technology involves the following activities. To start with, the entrepreneur opens a new firm. To open her firm, she has to spend resources and go through her country's legal and administrative system. We assume that these

[7] As λ is a constant parameter, $\lambda^{(1-\alpha-\gamma)}$ is a re-parametrization of another constant. However, we want to calibrate the intensity parameters to assess the relative importance of each factor in the development process.

resources are proportional to the firm's investments I_{it} by a factor of τ. In a broader sense, parameter τ accounts for all regulations, taxes, and costs that affect the entry and exit of firms and is associated with the economys microeconomic conditions. [8]

The maximization problem for any period t yields the first order condition presented in equation (8). We define w_{it} as the present value of the R&D firm's profits per unit of technology as $w_{it} \equiv W_{it}/A_{it}$. This expression depends only on aggregate factors. Thus, all sectors face the same profits adjusted by the level of technology and $w_{it}= w_t$.

$$I_{it} = I_t = A_{\max,t} \left[\frac{\alpha w_t S_t^{\gamma} \lambda^{(1-\alpha-\gamma)}}{(1+\tau)} \right]^{\frac{1}{1-\alpha}} \tag{8}$$

Investment in R&D is increasing with the level of the technological frontier, that is, as technologies become more advanced, countries must invest more in research and development to keep up with technological progress. The higher the level of skills, the greater the investment. The reason is that a higher level of entrepreneurial skills increases the probability of being successful, making R&D investment more profitable. A similar argument applies to the level of institutions. In this context, more suitable institutions, better property rights protection, and better regulation quality make it more likely that firms successfully implement frontier technologies. Finally, the more expensive it is to open a firm, the less profitable R&D investment will be. R&D firms will respond by lowering their investments. Investment in R&D has a direct impact on the probability of success. Recall that the probability of success depends positively on investment and skills and depends negatively on the cost of starting new firms. Since the sign of the impacts of these variables on

[8] Note that institutional arrangements like property right protection are captured by λ. Parameter τ captures specific barriers or cost to entries that are due to bureocratic regulations to establish a new firm.

investment is the same as on the probability of success, any direct impact of these variables on the probability of success will be amplified by their impact on R&D investment.

Replacing equation (8) in the definition of the probability of success (equation 5), we obtain the probability of success in equilibrium given by:

$$\phi_{it} = \phi_t = \left[\left(\frac{\alpha w_t}{1+\tau} \right)^{\alpha} S_t^{\gamma} \lambda^{(1-\alpha-\gamma)} \right]^{\frac{1}{1-\alpha}} \tag{9}$$

The probability of success is equal for all sectors. Consequently, in each sector i and in every period t, the technology embedded in input i will be upgraded to $A_{\max,t}$ with probability ϕ_t and will remain at its current level with probability (1-ϕ_t).

3 Aggregate implications

We now turn to the aggregate implications. An economy's development path depends on the law of motion for aggregate productivity, which in turn depends on the number of firms that adopt the technological frontier in every period. In the previous section, we derived the sector's probability of success in adopting the technological frontier. This probability is endogenous and depends on R&D investment (also endogenously determined), the entrepreneur's skills, the costs faced by new firms for entering the intermediate inputs markets, and the institutional framework of the economy. We assume that all risk is idiosyncratic and that successes are uniformly and independently distributed across sectors. Thus, the probability of success ϕ_t corresponds to the actual fraction of R&D firms that are successful in adopting the technological frontier at the aggregate level. It also measures the rate of creative destruction (rate of entry and exit of R&D firms) in equilibrium.

So, at the aggregate level, productivity improves to $A_{\max}$ in a fraction ϕ_t of sectors and remains at the current level in a fraction $(1-\phi)$ of them. The law of motion for aggregate productivity A_t evolves accordingly as

$$\int_0^1 A_{it+1} di = \phi_t A_{\max,t} + \int_0^1 (1-\phi_t) A_{it} di \tag{10}$$
$$A_{t+1} = \phi_t A_{\max,t} + (1-\phi_t) A_t$$

From this point, variables without subscript i denote the corresponding variable at the aggregate level, i.e., $X = \int_0^1 X_i di$. Variables in lowercase are defined in terms of the technological frontier, i.e. $x_t \equiv X_t / A_{\max,t}$.

Dividing equation (10) by the technological frontier $A_{\max,t}$ and replacing the equilibrium rate of creative destruction derived from equation (9), we obtain the law of motion of an economy's average productivity in relative terms:

$$a_{t+1} = \frac{a_t}{1+g} + \left[\left(\frac{\alpha w}{1+\tau} \right)^{\alpha} S^{\gamma} \lambda^{(1-\alpha-\gamma)} \right]^{\frac{1}{1-\alpha}} \frac{(1-a_t)}{1+g} \tag{11}$$

As we focus on the model's steady-state properties, we solve for the long-run expression of the variables of interest. In particular, in the long-run equilibrium, the economy grows at the growth rate of the technological frontier, g, and relative productivity corresponds to:

$$a = \frac{\left[\left(\frac{\alpha w}{1+\tau}\right)^{\alpha} S^{\gamma}\lambda^{(1-\alpha-\gamma)}\right]^{\frac{1}{1-\alpha}}}{\left[\left(\frac{\alpha w}{1+\tau}\right)^{\alpha} S^{\gamma}\lambda^{(1-\alpha-\gamma)}\right]^{\frac{1}{1-\alpha}} + g}. \tag{12}$$

Providing that the technological frontier grows at a positive rate, relative productivity is lower than one in steady state. Relative productivity depends negatively on the costs of opening new firms (τ) and positively on the institutional framework λ and the stock of skills. The greater the required skill intensity to adopt better technologies γ and the faster the technological frontier grows (the larger g is), the lower the steady-state productivity will be. As countries show different levels of development factors, countries will differ in the level of R&D investment and in the long-term entry and exit rate. Consequently, we will also observe different levels of TFP.

The amount of R&D resources invested is given by:

$$i = \left[S^{\gamma}\lambda^{(1-\alpha-\gamma)}\left(\frac{\alpha w}{1+\tau}\right)\right]^{\frac{1}{1-\alpha}}. \tag{13}$$

Consequently, the rate of entry/exit of R&D firms is

$$\phi = \left[\left(\frac{\alpha w}{1+\tau}\right)^{\alpha} S^{\gamma}\lambda^{(1-\alpha-\gamma)}\right]^{\frac{1}{1-\alpha}}. \tag{14}$$

4 Calibration and empirical evaluation

We construct a cross-section sample of 86 countries, using data availability as a selection criterion. We classify each country by its income level according to the

World Bank classifications.[9] We have 21 high-income countries (HIC), 32 upper-middle income countries (UMIC), 20 lower-middle-income countries (LMIC), and 13 low-income countries (LIC). Table 1 lists the countries in the sample.

[TABLE 1 ABOUT HERE]

We use values for ten parameters. Four are country specific factors that determine the economy's absorption capacity. The other six are common to every country. When available we set the values in line with previous literature; in all other cases, we calibrate them using the criteria described below. Table 2 presents the parameters used in the calibration and Table (13) describes all variables and sources used in the empirical section.

The upper panel of Table 2 presents the country-specific parameters. Factor λ measures the institutional environment. An efficient process of technology diffusion requires an adequate institutional framework. We measure the institutional framework of an economy using the index of Economic Incentives and Institutional Regime Framework constructed by the World Bank.[10] This index is the simple average of indexes comprised by the following variables: i) tariff and non-tariff barriers, ii) regulatory quality, and iii) rule of law. This index measures the extent to which the institutional framework provides incentives to the use of existing and new knowledge efficiently. Good policies that are favorable to market transactions, such as being open to free trade and foreign direct investment, helps R&D investment and the production of technological change. If the government protects property rights, it encourages entrepreneurship and knowledge investment.

[TABLE 2 ABOUT HERE]

[9] See, World Bank, Data & Statistics, Country Classification.

[10] Index extracted from the KAM Methodology developed by the World Bank.

The second factor behind the absorption capacity corresponds to barriers to opening new firms (τ), which are related to distortions, taxes, and administrative expenses for opening a new firm. We calibrate it by using the total number of days required to register a firm as a fraction of the number of days in a given year. This variable is reported by the World Bank in their *Doing Business* report. We assume that the firm loses the return over its investment during this period, and thus it is an implicit tax.

The third factor behind the absorptive capacity corresponds to skills acquired by the entrepreneurs. In the model, skills are exogenous, but heterogeneous among countries. These are modeled as a function of years of education and quality of the education system. For years of education, we use the average years of education as reported by Barro and Lee (2010). Measuring the quality of the education system is more challenging, and there are no direct measures in the data. One goal is to obtain a measure that allows for comparison of education systems across countries. We infer the educational quality by measuring the marginal returns of an additional year of schooling of an educated immigrant from that country in the United States. These returns are estimated by Schoellman (2012) for a large group of countries, controlling (to some extent) for country-specific factors different than quality, which might affect these returns as measured in the origin country.[11] Table 3 reports the median and the standard deviation of the four development factors by income group. As expected there is a high correlation between the median of each factor and development level. This is by no means evidence of causality; the table simply shows how the level of development factors that characterize different group of countries

[11]Schoellman (2012) discusses his estimation procedure in detail and how he deals with possible selectivity bias.

vary with the level GDP per capita. These medians will be used later to construct the representative country from each group.

[TABLE 3 ABOUT HERE]

Regarding common parameters used in the calibration, we assign a value of 0.62 to the material share of output ϵ and a value of 0.91 to the inverse of markups η both based on estimates of Norrbin (1993).[12] We set the growth rate of the technological frontier at 2.2%, which corresponds to the average per capita growth rate of the United States in the years 1960-2006. Finally, we set the long-run riskless interest rate at 3%, which corresponds to the average value of this rate for the United States for the period 1802-1998 as described by Mehra (2003).

Finally, we need to estimate parameters α and γ, which define how intensively the adoption activity uses R&D resources and skills. As there is no previous reference for the value of these parameters, we obtained them from the solution of:

$$\underset{\alpha,\gamma}{min}\sum_{j}(y_{j,sim} - y_{j,data})^2 \tag{15}$$

where $y_{j,sim}$ represents the simulated value of relative GDP per worker estimated within the model and data $y_{j,data}$ represents the value of relative GDP per worker obtained from the data. As we are interested in analyzing the narrowing of GDP per worker of different countries with the leading economy (in this case the United States), we construct relative measures by dividing each GDP per worker value by the corresponding value for the United States. We construct actual data for GDP per worker by using total GDP (PPP) from Penn World Tables 9.0 divided by

[12] There are several papers discussing the value of both parameters. See for example Basu and Fernald (1994), and Hall (1990) among others. Our results do not vary significantly when choosing values in the neighborhood.

employment, also obtained from Penn World Tables. Simulated GDP per worker for each country j is constructed following the next equation:

$$y_{j,sim} = A_{j,sim} k^{\epsilon}_{j,data}, \text{ where} \tag{16}$$

$A_{j,sim}$ is simulated using equation (12) to obtain a, which is divided by the value for the US, and k_j corresponds to capital per worker for each country j, where capital stocks and employment data are taken from Penn World Tables 9.0. All actual data are obtained for year 2014, or most recently available. The minimization problem gives values for α and γ equal to 0.74 and 0.12, respectively.[13]

4.1 Fit of the model

Before using the model to disentangle productivity bottlenecks, we evaluate its goodness of fit by comparing its results with various statistics in the data. We measure all variables of interest relative to their values in the United States.

The model was calibrated to minimize the squared distance of relative GDP per worker generated by the model and the GDP per worker data from the World Bank. The distribution of relative GDP per worker across countries spawned by the model resembles the one of actual data. Figure 1 compares both distributions. The Kolmogorov-Smirnov (KS) test does not reject the hypothesis that the two

[13] As complementary evidence in favor of the plausibility of the values of these parameters, note that according to equation (13), the elasticity of innovation to human capital is

$$\gamma/(1-\alpha) = 0.1246/(1-0.7378) = 0.475$$

This value is in line with other elasticities estimated in the literature. For instance, Dakhli and De Clercq (2004) estimate an elasticity of R&D investment (as a share of GNI) respect to an index of human capital in a range between 0.56 and 0.32. De Ferranti et. al. (2003), based on Park (2002), reports an elasticity of private R&D respect to educational variables around 0.33.

samples (the actual data and the one generated by the model) come from the same distribution.[14] When dividing the sample by income level, we get a good fit for each group as presented in columns 2 and 3 of Table 4.

[FIGURE 1 ABOUT HERE]

Next, we check how well the model fits some moments of other endogenous variables that were not targeted in the calibration. Specifically, we are interested in the fit of R&D investment and firms' entry rate for each group of countries. Table 4 presents the steady state values for each variable and group of countries relative to the United States. Note that we do not have data for R&D investment and entry rate for all countries in the sample. Therefore, for these variables, we evaluate the fit in a sub-sample of 46 countries.

[TABLE 4 ABOUT HERE]

Columns 4 and 5 show the fit for R&D investment and columns 6 and 7 show the entry rate. Average R&D in the data is 0.54 versus 0.52 for the model. Looking across the group of countries the fit is reasonable, with a little tendency to overestimate the actual value for low-middle and low-income countries. It is important to note that the number of countries in the low-income group is particularly small, and the quality of this data is less reliable. Therefore, the results for this group should be analyzed with caution.

The average relative entry rate in the data is 0.67; the model predicts a value of 0.58. This is surprisingly close as it is difficult to find an empirical counterpart of the probability of success for an R&D firm and consequently the average entry/exit rate at the aggregate level. The proxy that we use for this variable is the number of

[14] The corrected combined p-value of the KS test is equal to 0.974.

newly registered corporations divided by the number of total registered corporations published by the World Bank.

Table 5 shows the fit of GDP per worker for each income group at the 25th and 75th percentiles of the distribution (non-targeted moments). We focus only on GDP per worker since observations for R&D investment and entry rate are too few to have an accurate analysis of the distribution within the groups. NResults shows that, again, the model is close in each income group.

[TABLE 5 ABOUT HERE]

5 Disentangling TFP gaps

This section is motivated by three related issues, namely: identifying the most binding factors for closing existing per capita GDP gaps between different types of countries and the United States; finding the patterns, if any, in the relationship between each bottleneck and the development level; and discussing why similar reforms have different effects on productivity depending on the countrys stage of development.

In order to address these issues, we build a representative economy for each income group. Then we use this economy to run some policy experiments, which consist of improving each development factor to the level of the United States to quantify its effect of the technology gap. We explore the complementarities among the components of the absorptive capacity in the development process. As we are interested in the relative steady-state TFP between the representative economy and the United States, a relative TFP of one indicates that there is no gap.

5.1 Construction of representative countries

The TFP of each representative country is constructed using the median of each development factor according to the values presented in Table 3. Figure 2 plots the relationship between each development factor and GDP per worker, highlighting the position of the representative economy in each group. The red crosses correspond to the median parameters of each group.

FIGURE 2 ABOUT HERE

When looking at the correlation between GDP per worker and the development factors, we found that all parameters increase with the level of GDP per capita. However, there are some interesting features worth mentioning. Upper-middle-income countries and lower-middle-income countries show similar values for education system quality and entry costs. Moreover, median years of schooling are not significantly different between these two groups, suggesting that the discriminating factor between them is the institutional framework that favors the adoption of new technologies.

Second, the positive correlation between factors and GDP per worker is stronger for institutional framework and years of schooling than for educational quality and entry barriers. In addition, while the two former variables show an almost linear relationship with development level, educational quality and entry barriers do not show similar pattern at each level of development.

5.2 Closing the gap with the leading economies

In this section, we address the contribution of each development factor in closing the gap with the United States and study whether this contribution differs among country groups. To this end, we quantify the impact of improving each development factor up to the level of the United State while maintaining the other parameters at their current levels for each representative economy.

Table 6 exhibits the contribution of each factor in closing the TFP gap (columns 1-4). The values in column 5 are calculated by subtracting the sum of all individual effects from the value of the calibrated gap. This residual captures complementarities across factors.[15] Column 6 shows the steady-state gap for each representative economy at the actual parameter values. The high-income representative economy has a TFP gap of 16% in a steady state, while the gap of the representative economy for the poorest group is 78%.

[TABLE 6 ABOUT HERE]

Several interesting results are shown in Table 6. Institutional framework is the only variable that has a monotonically decreasing effect on the gap as income increases. In the case of low-income countries, an improvement in this variable closes 26 percentage points of the gap, while for the rest of the economies the contribution ranges from 3 to 20 percentage points. This result might be expected as poorer countries simply have a larger gap. Surprisingly, however, this is not what we observe for the rest of the variables. All other three factors quality and quantity of education and barriers in opening new firms show a lower absolute impact on the TFP gap

[15] In the next section, we discuss in detail the effect of these complementarities on the TFP gap and the relevance of taking that effect into account when assessing economic impacts of policy reforms.

for the poorest countries compared to the higher income ones. For example, these three factors account for 75% of the gap between the high-income economy and the United States, while they constitute only 17% for the low-income group. [16]

The effect we call *complementarities* refers to the impact of the overall absorptive capacity of a particular reform. It happens because the effect of changing a factor is not orthogonal to the level exhibited by the other variables. For example, the effect of changing educational quality depends on the average years of schooling, the level of barriers to opening new firms, and the level of institutional framework (see equation 11). This explains why poor countries show low impacts from individual reforms; the overall absorptive capacity is poor and any single reform has a poor basis to impact. Consequently, complementarities are important for this group. Thus poor countries need bigger or more multifaceted reforms to close the gap with leading economies [17]. The other interesting feature is that the effect of these complementarities monotonically decreases with income level. This result shows precisely how higher income economies may upgrade specific factors without needing to perform other reforms simultaneously.

How do changes in development factors impact other endogenous variables? Table 7 reports the results for R&D investment and entry rate gaps. We found exactly the same pattern. Single reforms do not significantly impact R&D and entry rate in low-income countries. The counterpart is a high value for *complementarities*, a figure that decreases as income increases. Although the gap between high-income economies and the leading economy is small, it is interesting to notice that a reduc-

[16] Not surprisingly, the findings for the quality of human capital are in line with Okoye (2016) in the sense that the degree of factor complementarity matters in the productivity of human capital. This could explain why this development factor is more important for middle-income than for low-income countries.

[17] Note that what we call *complementarities* is similar to the notion in Chang et al., 2009 and Bergoeing et al., 2015.

tion in the barriers to opening new firms contributes 31% and 25% to closing the gap in R&D investment and entry rate respectively. This factor is also the most important in explaining R&D investment and entry rate gaps in the case of upper-middle-income countries. These results are in line with Bergoeing et al. (2015), although their estimated impacts of firms exit and entry rates are much larger as they do not consider other factors.

[TABLE 7 ABOUT HERE]

5.3 Complementarities and the level of development

The results presented in the previous section reflect the trade-off between the level of absorptive capacity determinants and the technology gap, which are the empirical counterparts of equation (11). A reform that improves one of the development factors to the level of the leading economy has different effects on the steady-state productivity gap and per worker income gap when it is undertaken by countries at different stages of development. There are two opposing effects at play. On one hand, the gains of undertaking any reform increase with the initial distance to the technological frontier since the incentives for investing in technology improvement are larger. On the other hand, economies have larger distance to the technological frontier when they have low values of the parameters behind the absorption capacity so improving only one of them has a small effect on closing the technology gap.

Table 8 shows the non-linearities described here. It is straightforward to see that, for example, increasing years of schooling will close the gap depending on the level of the actual gap and the level of all parameters reflected in the productivity level. To further explore these nonlinearities, we evaluate the marginal effect derived in

Table 8 using the initial value of each parameter by income group. Then to capture complementarities with other development factors, we modify the values of the other parameters within a range comprised of plus/minus one standard deviation within income group.

[TABLE 8 ABOUT HERE]

Figures 3 to 6 summarize each factor's marginal effects by income group and by varying the values for the other factors. In each graph, the y-axis shows the marginal effect on the relative TFP gap of changing a specific factor behind the absorptive capacity. The x-axis shows the deviation of the other factors in respect to their initial value; thus, $x = 0$ corresponds to the marginal effect calculated using Table 8 keeping the current value of the other parameters at their initial values. Values of x between -0.5 and 0.5 correspond to the effect of simultaneously changing all the other parameters by plus/minus 0.5 standard deviations. For example, in Figure 3 at $x = 0$ the effect of increasing schooling rates by one year increases the TFP ratio in respect to the leading economy by 2 percentage points for the poorest group to 6 percentage points for the upper-middle income group. As the other development factors simultaneously improve, the effect of increasing years of schooling become larger for all groups except for the high-income economies. This is due to the fact that the gap $(1-a)$ becomes small. This can be easily appreciated in the downward trend of the marginal effect for the rich economies that contrasts with the upward-slope of the marginal effect for the other three groups.

Figure 4 plots the marginal effect o of increasing educational quality on the TFP gap. The pattern of this factor's marginal effects is similar to that in the previous graph. The poorest economies exhibit the lowest marginal effect; their upward slope shows the importance of the other development factors. In other words, the complementarity effect is stronger for those groups. The marginal effect increases as the value of the other development factor increases for all the groups except for rich economies.

Figure 5 exhibits the marginal effect of reducing the barriers to opening new firms on the TFP gap. What is surprising here is that, in the case of upper-middle-income economies, the marginal effect does not change much when the other development factors change. If anything, the marginal effect decreases when the level of other factors improves. The pattern for the other groups is the same as in previous graphs.

In all three effects analyzed until this point, there is a common pattern, upper-middle-income economies show the largest marginal effect and the low-income economies tend to show the lowest for each factor analyzed. This finding is in line with the results previously shown in Table 6, which indicate that low-income economies require larger scale reforms.

Finally, Figure 6 shows the effect of improving the institutions that favors technology adoption. This effect is larger for the two lowest income groups. The marginal effect is particularly strongly increasing in the level of the other factors for the poorest economies. For this group, this is the only factor that has a significant impact on the TFP gap even when the other factors are kept at their initial level. For the other three groups, the pattern is almost flat, meaning that complementarities between this factor and the rest are less important.

[FIGURES 3 TO 6 ABOUT HERE]

In summary, the complementarities among factors are more important for the low-income groups, which is seen in the upward slope, showing a reform's effect as a function of the rest of the factors. A similar, but not as strong conclusion can be made for lower-middle income countries. For the two richest groups the evidence suggests that the impact of improving one factor is not overly affected by the level of the others since they are already high.

5.4 Comparison with development accounting

The model presented here differs respect to the typical production function approach for development accounting, where human capital is substitute with physical capital in the production process. Here the human capital interact with other factors to affect the probability of success in adopting a new technology. The TFP is obtained from a model and not from growth accounting. So, one way to see it is what part of the residual could be accounted from this model

Following Caselli (2005) let′s define

$$y = A^* y^* \tag{17}$$

$$y^* = k^\alpha h^{1-\alpha} \tag{18}$$

where y is output per worker, A^* is TFP from growth accounting, k is the capital-labor ratio, h is per worker human capital and α is the share of capital income on total income. Using the data from Penn World Tables 9.0 from Feenstra et al (2015) we estimate two measures of what Caselli calls

$$success_1 = \frac{Var(log(y^*))}{Var(log(y))} \tag{19}$$

and

$$success_2 = \frac{\frac{y^{90*}}{y^{10*}}}{\frac{y^{90}}{y^{10}}} \tag{20}$$

where x^p represents the $p-th$ percentile of the distribution of x.

Our paper differs from Caselli (2005) in two dimensions: the sample of economies included and the way that TFP is obtained. We will use our sample to estimate both measure of success. Another issue to be considered is that the construction of $log(y^*)$ depends on the human capital estimation. We use three measures of human capital: PWT9.0, *a la* Hall and Jones, and *a la* Schoellman. The contribution of the variance of $log(y^*)$ in our sample of countries is 29% (PWT 9.0), 35.1% (H&J) and 50.9% (Shoellman). In other words, the contribution of TFP accounts for something between 49% and 71% to the variance of $log(y)$. Using our model, the $Var(log(A)$ explains 27% the variance of $log(y)$. It seems small, but the factors on technology adoption included in the model accounts for 55% to 38% of the unexplained part of the variance of $log(y)$. [18]

The second measure, $success_2$, applied to our sample, gives a value of 0.33 (with data from PWT 9.0). This result is comparable to the value of 0.35 reported in Caselli (2005). It is important to emphasize our contribution here. In our sample, the 90th-percentile is Denmark (HIC) and the 10th-percentile is Zimbawe (LIC). This paper offers a measure of the importance of the different development barriers and the complementarities among development factors to explain the results of $success_2$. Looking at Table 6, we can conclude that complementarities among the different

[18] But, it is important here to recognize that A also affects the marginal productivity of factors and, therefore, the covariances betwwen A and k and h are not zero in the data.

factor and the particular factor pro-adoption institution are the key inputs to explain the gap between the 90-th and the 10-th percentile of our country distribution. [19]

6 Robustness checks

In this section, we measure the development factors using alternative definitions to check the robustness of our results.

In the first exercise, we analyze the effects of changing the measure of entry costs. In the benchmark model, we use the number of days needed to open a new firm, which reflects the bureaucratic costs. Now, we use the fees required to open a new firm which measure the financial costs. We measure these fees as percentage of GDP per capita in each country. The second and third columns of Table 9 show the median and standard deviation of this variable, respectively. As shown, the cost as percentage of per capita GDP varies considerably by country group, ranging from 3% in the group of high-income countries to 78% in the group of low-income countries. However, if the cost is measured in absolute terms, the cost in middle and low-income economies is 2 to 3 times higher than in high-income countries. The results of the robustness exercise are shown in Table 10. The implications remain qualitatively unaltered. Institutional framework and complementarities remain the most significant factors in explaining TFP gaps for the two poorest groups; in the case of upper-middle income countries, educational quality is the most important

[19] Caselli and Coleman (2006) also note that they need barriers for adoption to explain the differences between potential frontiers for each economy. This paper endogenize those barriers. In this sense, our results complements the findings of Caselli and Coleman regarding the importance of human capital in the choice of the technology to adopt.

factor. Entry costs and educational quality are the binding factors for high-income countries.[20]

[TABLE 9 ABOUT HERE]

[TABLE 10 ABOUT HERE]

In the second robustness exercise we construct the stock of skills with the definition used by Hall and Jones (1990), which has been widely used in the literature. Under this definition, all countries have same returns from schooling, but returns vary by years of schooling in the following way: 0.134 for the first 4 years of education, 0.101 for the following 4 years, and 0.068 from there on. The sixth and seventh columns of Table 9 report the median and standard deviation of this new measure of human capital, respectively. Figure 7 plots the stock of human capital used in our benchmark model versus the one *a la* Hall and Jones. The solid line corresponds to the 45-degree line. In general, the human capital stock *a la* Hall and Jones is larger than the one in the reference model using Schoellman's educational returns. This is especially true for low-income countries, which have high returns for the first years in the Hall and Jones specification, but much lower values in the Schoellman's estimates. Table 11 presents the results of this exercise. The contribution of educational quality is zero as Hall and Jones use the same educational returns for all countries. Results hold qualitatively, but the effect of human capital on the TFP gap is quantitatively lower under this measure as it ignores differences in educational quality.

[FIGURE 7 ABOUT HERE]

[20] Another source of barriers to entry is financial frictions a la Midrigan and Xu (2014). We conducted an exercise using interest rate spreads as a proxy for financial frictions as entry cost. The conclusion regarding the relative contribution of each factor in explaining TFP differences does not change significantly. These results are available upon request.

[TABLE 11 ABOUT HERE]

In the last robustness exercise, we use a different measure of institutions. Instead of using the institutional framework, we evaluate the effects on the TFP gap of using the type of technological infrastructure existing in each country. This alternative variable could be endogenous with the level of development. However, in this context, we are looking for an indicator of a favorable environment for technology adoption. The proxy for this variable is the Information and Communication Technology Index constructed by the World Bank, by simply averaging the following variables: i) telephones per 1,000 people in 2007, ii) computers per 1,000 people in 2007, and iii) internet users per 1,000 people. Descriptive statistics for this variable are presented in the forth and fifth columns of Table 9. The existence of technological infrastructure facilitates the dissemination and processing of knowledge. Although the technological infrastructure and institutional framework measure different aspects of the economic environment, their medians (calculated from Table 3 and Table 9) are relatively similar across country groups. Table 12 reports the results with this alternative measure, and they are quantitatively and qualitatively similar to those in Table 6.

[TABLE 12 ABOUT HERE]

7 Concluding remarks

Technology adoption is a key vehicle for improving productivity in both developed and developing economies. This process requires that economies be capable of absorbing and implementing technologies that are developed elsewhere. We identify factors that are essential for shaping this absorptive capacity: skills, which are determined by i) years of education, and ii) the quality of the educational system; iii) the institutional framework that favors or hinders technology diffusion; and iv) the ease of opening new firms.

In this paper, we build an analytical model of technology adoption including all these factors, providing a steady-state TFP gap between any economy with respect to a benchmark country. We calibrate the model for a sample of 86 countries generating a world distribution of TFP in respect to the United States (the benchmark). The model matches the empirical TFP distribution and also other endogenous variables like entry rates and R&D investment rates. Afterwards, we group countries into four income categories and then use this model to disentangle and to quantify the relative weight of these factors in explaining the TFP gaps of the income groups with the United States.

The individual impact of factors positively depends on the initial TFP gap and the level of all other factors shaping the absorptive capacity of the economy, and their impact differs greatly by income level. Poor countries, which are far from the technological frontier (with much to gain) usually have a poor absorptive capacity (diminishing the impact of reforms). Thus our findings show that low-income economies require large-scale, multifaceted reforms as complementarities among multiple reforms enhance their overall effect. However, if a poor economy had to choose one reform, improving the economy's institutional framework produces the largest impact on TFP. However, as economies develop, educational quality becomes increasingly important in closing TFP gaps and at high stages of development, the barriers for entering new markets become important.

These assessments contain certain nuances as there are important non-linearities in the relationships between productivity and the corresponding factors. These non-linearities reflect the complementarities among the different factors and the different initial TFP gaps. For example, when improving all factors but one, we find heterogeneous effects for the different income groups. For all groups but the high-income one, the impact of that one factor increases with the higher levels of the other factors. This reflects that the effect of a better absorptive capacity offsets the effect of a smaller gap induced by the better factor. The contrary is true for high income countries. The exercise conducted here has important implications, since most papers quantify the average effect of a specific development factor on closing TFP gaps. This average effect, however, hides significant heterogeneities for economies at different stages of development that are relevant to address.

The contribution of the paper is to quantify the role played by different development factors and the complementarities among them. It has also shown how the effect of each development factor depends on the countrys income level and, thus may help to draw conclusions for economies in different stages of development. Nevertheless, it is impossible to not recognize that different production structures will generate a different level of aggregate TFP. This could be the reason why we found that complementarities among factors is so important in poor countries and less important as income increases.

At the light of the literature on sectoral productivity differences (Acemoglu and Zilibotti (2001), Restuccia et al (2008)) and intersectoral misallocations (Hsieh and Klenow (2009), Bento and Restuccia (2017)) and as a further research, it would be interesting to analyze the case when A_{max} differs across sectors. There would be different weight for the factors that generate differences in productivity and it would help to understand why low-tech sectors or agriculture is behind in less developed countries. In this context, policy that generates misallocations of factors in favor of low distance to the frontier would affect the potential growth of an economy.

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Tables and Figures

Table 1: Country sample, by income group

	High income countries	*Upper-middle income countries*	*Lower-middle income countries*	*Low income countries*
	Australia	Algeria	Albania	Bangladesh
	Austria	Argentina	Bolivia	Cambodia
	Belgium	Brazil	Cameroon	Ghana
	Canada	Bulgaria	China	Haiti
	Denmark	Chile	El Salvador	Kenya
	Finland	Colombia	Fiji	Lao PDR
	France	Costa Rica	Guyana	Nepal
	Germany	Croatia	Honduras	Senegal
	Hong Kong	Czech Republic	India	Sierra Leone
	Ireland	Egypt	Indonesia	Sudan
	Italy	Greece	Jamaica	Uganda
	Japan	Guatemala	Morocco	Vietnam
	Netherlands	Hungary	Nicaragua	Zimbabwe
	New Zealand	Iran	Pakistan	
	Norway	Israel	Paraguay	
	Singapore	Jordan	Peru	
	Spain	Korea	Philippines	
	Sweden	Latvia	Sri Lanka	
	Switzerland	Lithuania	Syria	
	United Kingdom	Malaysia	Yemen	
	United States	Mexico		
		Panama		
		Poland		
		Portugal		
		Romania		
		Slovak Republic		
		South Africa		
		Taiwan		
		Thailand		
		Turkey		
		Ukraine		
		Uruguay		
Number of observations (1)				
Full sample: N=86	21	32	20	13

Notes. (1) Countries selected by data availability.

Table 2: Calibration Parameters

Country specific parameters			
	Definition		*Source*
Exogenous			
λ	Institutional framework		World Bank
τ	Cost of opening new firms		Doing Business
S	Av. Years of schooling		Barro and Lee (2010)
q	Educational quality		Schoellman (2010)

Common parameters across countries			
	Definition	*Value*	*Source*
Exogenous			
ϵ	Material share	0.620	Norrbin (1993)
η	Inverse of markup	0.910	Norrbin (1993)
r	Riskless Interest rate	0.030	Mehra (2003)
g	Growth rate of technology frontier	0.022	World Bank
Calibrated			
α	R&D intensity	0.7378	
γ	Skill intensity	0.1246	

Table 3: Descriptive statistics: Medians and standard deviations (sd). Development factors and economic outcomes.

	Years of schooling		*Educational quality*		*Entry costs*		*Institutions*		*GDP per worker(1)*	
Type of Economy	median	sd	median	sd	median	sd	median	sd	median	sd
High income countries	10.8	1.2	0.083	0.020	0.036	0.067	0.88	0.05	0.77	0.10
High-to-middle income countries	9.2	1.9	0.050	0.024	0.093	0.072	0.67	0.14	0.31	0.13
Middle income countries	7.5	2.2	0.051	0.021	0.133	0.091	0.39	0.11	0.13	0.04
Low income countries	4.9	1.5	0.024	0.025	0.139	0.150	0.20	0.07	0.05	0.01
Average	8.7	2.5	0.055	0.029	0.099	0.101	0.61	0.26	0.25	0.29

(1)Relative to US values. *Source:* Authors' calculations.

Table 4: Model vs Actual data. Means. GDP per worker, R&D Investment and Entry Rate. Figures relative to US values(1)

	GDP per worker		*R&D investment*		*Entry rate*	
Type of Economy	Model	Data	Model	Data	Model	Data
High income countries	0.81	0.82	0.78	0.84	0.79	0.81
Upper-middle income countries	0.51	0.53	0.45	0.32	0.49	0.64
Lower-middle countries	0.32	0.32	0.18	0.13	0.22	0.41
Low income countries	0.22	0.20	0.23	0.22	0.26	0.35
Average	0.50	0.50	0.52	0.54	0.58	0.67

(1) Sample for R&D Investment and Entry rate is restricted by data availability and comprises the following countries: Argentina, Austria, Belgium, Australia, Bulgaria, Bolivia, Brazil, Canada, Switzerland, Chile, Colombia, Croatia, Czech Republic, Denmark, Spain, Finland, France, Great Britain, Germany, Greece, Cuba, Hungary, India, Indonesia, Ireland, Israel, Italy, Japan, Kenya, Luxembourg, Mexico, Norway, New Zealand, Poland, Portugal, Romania, Senegal, Singapore, Slovakia, Sweden, Thailand, Turkey, Ukraine, United States, South Africa, and Zimbabwe.
Source: Author's calculations. Actual data based on data of The World Bank.

Table 5: Model vs Actual data. 25th and 75th Percentiles. GDP per worker. Figures relative to US values(1)

Type of Economy	Model	Data
Percentiles P 25 and P 75 (1)		
High income countries *P 25*	0.77	0.75
High income countries *P 75*	0.92	0.85
Upper-middle income countries *P 25*	0.41	0.42
Upper-middle income countries *P 75*	0.60	0.60
Lower-middle countries *P 25*	0.28	0.28
Lower-middle countries *P 75*	0.39	0.36
Low income countries *P 25*	0.18	0.17
Low income countries *P 75*	0.26	0.23

(1) Observations for Entry rate and R&D investment are too few to make an accurate analysis of the within income groups distribution.

Source: Author's calculations. Actual data based on data of The World Bank.

Table 6: Absolute contribution to closure TFP gaps, by development factor and country group. Gap points.

	Absolute contribution					
Type of Economy	*Years of Schooling*	*Education Quality*	*Entry costs*	*Institutions*	*Complementarities*	*TFP Gap*
High income countries	0.040	0.040	0.042	0.027	0.015	0.164
Upper-middle income countries	0.035	0.101	0.111	0.097	0.133	0.477
Lower-middle countries	0.040	0.054	0.118	0.196	0.245	0.652
Low income countries	0.018	0.037	0.079	0.259	0.390	0.783
Average	0.033	0.058	0.088	0.145	0.195	0.519

Source: Author's calculations based on data of The World Bank, Penn World Tables, Schoellman (2010).

Table 7: Absolute contribution to closing various development gaps: R&D investment and Entry rate. Gap points. Variables relative to US values.

	Effects on R&D investment gap					
Type of Economy	*Years of schooling*	*Educational quality*	*Entry costs*	*Institutions*	*Complementarities*	*R&D investment gap*
High income countries	0.042	0.042	0.060	0.029	0.020	0.194
Upper-middle income countries	0.033	0.096	0.147	0.092	0.171	0.538
Lower-middle countries	0.034	0.047	0.149	0.173	0.305	0.709
Low income countries	0.015	0.031	0.097	0.223	0.455	0.822
Average	0.031	0.054	0.113	0.129	0.238	0.566
	Effects on Entry rate gap					
Type of Economy	*Years of schooling*	*Educational quality*	*Entry costs*	*Institutions*	*Complementarities*	*Entry rate gap*
High income countries	0.043	0.043	0.045	0.029	0.018	0.178
Upper-middle income countries	0.035	0.103	0.112	0.099	0.155	0.504
Lower-middle countries	0.038	0.052	0.116	0.193	0.276	0.676
Low income countries	0.017	0.035	0.075	0.250	0.423	0.800
Average	0.033	0.058	0.087	0.143	0.218	0.539

Source: Authors' calculations based on data of The World Bank, Penn World Tables, Schoellman (2010).

Table 8: Analytical derivatives

	x	$\frac{\partial a}{\partial x}$
Years of schooling	s	$a(1-a)\ \frac{\gamma}{1-\alpha}\ q$
Educational quality	q	$a(1-a)\frac{\gamma}{1-\alpha}\ s$
Entry costs	τ	$-a(1-a)\frac{\alpha}{1-\alpha}\frac{1}{1+\tau}$
Institutions	λ	$a(1-a)\frac{1-\alpha-\gamma}{1-\alpha}\frac{1}{\lambda}$

Table 9: Descriptive statistics for variables used in robustness exercises: Medians and standard deviations (sd).

	Entry costs as % GDP per capita		*Technological Infrastructure*		*Human Capital a la Hall & Jones(1)*	
Type of Economy	median	sd	median	sd	median	sd
High income countries	0.029	0.062	0.913	0.043	0.868	0.207
Upper-middle income countries	0.146	0.210	0.617	0.186	0.525	0.170
Lower-middle income countries	0.512	0.736	0.324	0.140	0.449	0.145
Low income countries	0.782	3.997	0.251	0.140	0.365	0.087
Average	0.173	1.755	0.539	0.274	0.516	0.228

Source: Authors' calculations. (1)Stocks of human capital are reported relative to US values.

Table 10: Robustness exercise 1: Cost of opening new firms as percentage of US GDP per capita, PPP. Absolute contributions to closing the gap by development factor and country group.

Type of Economy	*Years of schooling*	*Educational quality*	*Entry costs*	*Institutions*	*Complementarities*	*TFP Gap*
High income countries	0.047	0.030	0.041	0.024	0.013	0.154
Upper-middle income countries	0.034	0.118	0.066	0.098	0.107	0.422
Lower-middle countries	0.048	0.059	0.070	0.219	0.193	0.589
Low income countries	0.023	0.046	0.024	0.321	0.313	0.727
Average	0.038	0.063	0.050	0.165	0.156	0.473

Source: Authors' calculations.

Table 11: Robustness exercise 2: Human capital constructed *a la* Hall and Jones (1999). Absolute contribution to closing the gap by development factor and country group.

Type of Economy	*Years of schooling*	*Educational quality*	*Entry costs*	*Institutions*	*Complementarities*	*TFP Gap*
High income countries	0.034	-	0.044	0.029	0.004	0.111
Upper-middle income countries	0.058	-	0.134	0.118	0.044	0.354
Lower-middle countries	0.068	-	0.142	0.234	0.136	0.579
Low income countries	0.083	-	0.096	0.311	0.247	0.736
Average	0.061	-	0.104	0.173	0.108	0.445

Source: Authors' calculations.

Table 12: Robustness exercise 3: Institutional framework using the Technological Infrastructure Index. Absolute contribution to closing the gap by development factor and country group.

Type of Economy	*Years of schooling*	*Educational quality*	*Entry costs*	*Infrastructure*	*Complementarities*	*TFP Gap*
High income countries	0.041	0.042	0.043	-0.003	0.011	0.133
Upper-middle income countries	0.034	0.100	0.109	0.107	0.138	0.488
Lower-middle countries	0.037	0.050	0.111	0.219	0.259	0.676
Low income countries	0.021	0.042	0.090	0.227	0.372	0.752
Average	0.033	0.058	0.088	0.138	0.195	0.512

Source: Author's calculations

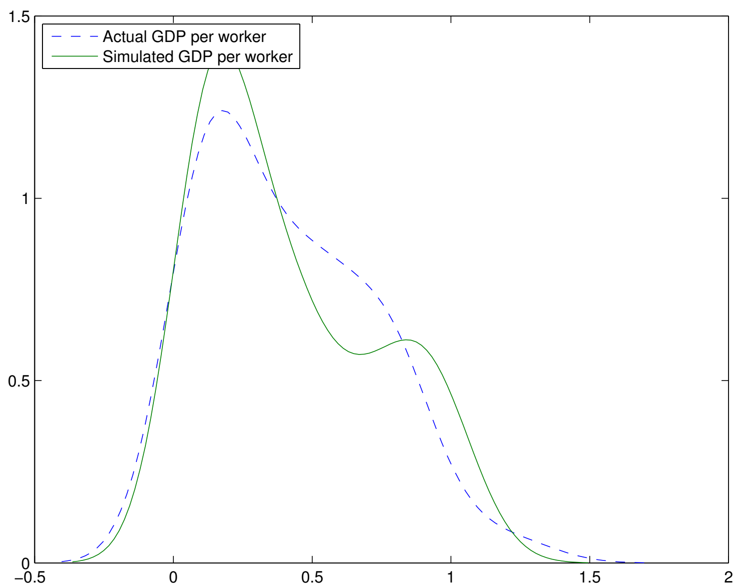
Table 13: Data Appendix

Variable	Year	Description	Source
Capital stock	2014 or most recent available	Capital stock at current PPPs (2011US$)	Penn World Tables 9.0
Educational Quality	See paper	Marginal returns of an additional year of schooling of an educated immigrant from that country in the United States.	Schoellman (2012)
Employment	2014 or most recent available	Number of persons engaged	Penn World Tables 9.0
Entry and exit rate	2009 or most recent available	Number of newly registered corporations divided by the number of total registered corporations	Entrepreneurship Survey and database, The World Bank
Entry cost in fees	2010	Cost (as fraction of GNI per capita) to complete all procedures officially required, or commonly done in practice, for an entrepreneur to start up and formally operate an industrial or commercial business.	Doing Business, The World Bank.
Entry cost in days	2010	Number of days required to open a new business divided by 365 days and multiplied by the annual GNI per capita.	Doing Business, The World Bank.
GDP PPP, level	2010 or most recent available	Output-side real GDP at current PPPs, to compare relative productive capacity across countries at a single point in time	Penn World Tables 9.0
Human Capital a la Hall and Jones	2010 or most recent available	Methodology following Hall and Jones (1990). Barro and Lee (2010) for average years of schooling.	Hall and Jones (1990) for metodology.

Table 13: Data Appendix (cont)

Variable	**Year**	**Description**	**Source**
Institutional Framework	2010 or most recent available	index of Economic Incentives and Institutional Regime Framework constructed by the World Bank. Simple average of following indexes: i) tariff and non-tariff barriers, ii) regulatory quality, and iii) rule of law.	The World Bank, all indexes
R&D investment	2010 or most recent available	Research and development expenditure (% of GDP)	World Development Indicators, The World Bank
Technological infraestructure	2009	The proxy for this variable is the Information and Communication Technology Index constructed by the World Bank, by averaging the following variables: i) telephones per 1,000 people in 2007, ii) computers per 1,000 people in 2007, and iii) internet users per 1,000 people.	The World Bank, KAM Methodology
Years of schooling	2010 or most recent available	Average years of education	Barro and Lee (2010)

Figure 1: GDP per worker distribution(1): model versus data

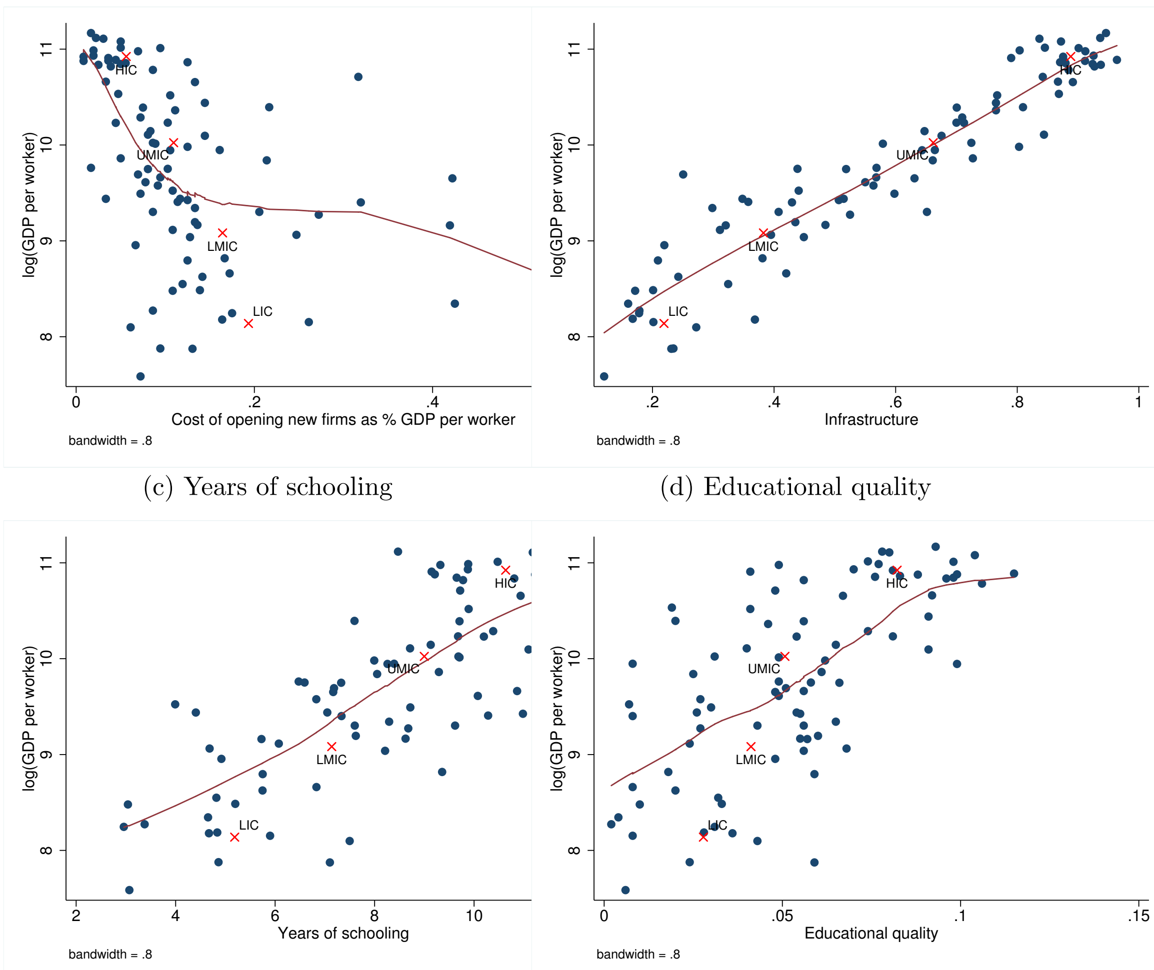


(1) Kernel density distributions. *Source:* Authors' calculations.

Figure 2: Development factors and GDP per worker(1)

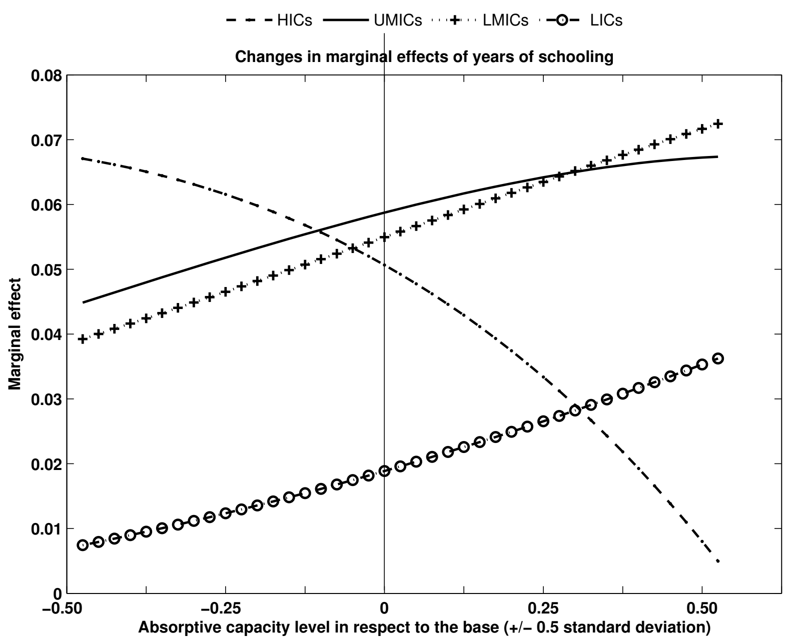
(a) Costs for opening new firms (b) Institutions

(c) Years of schooling (d) Educational quality



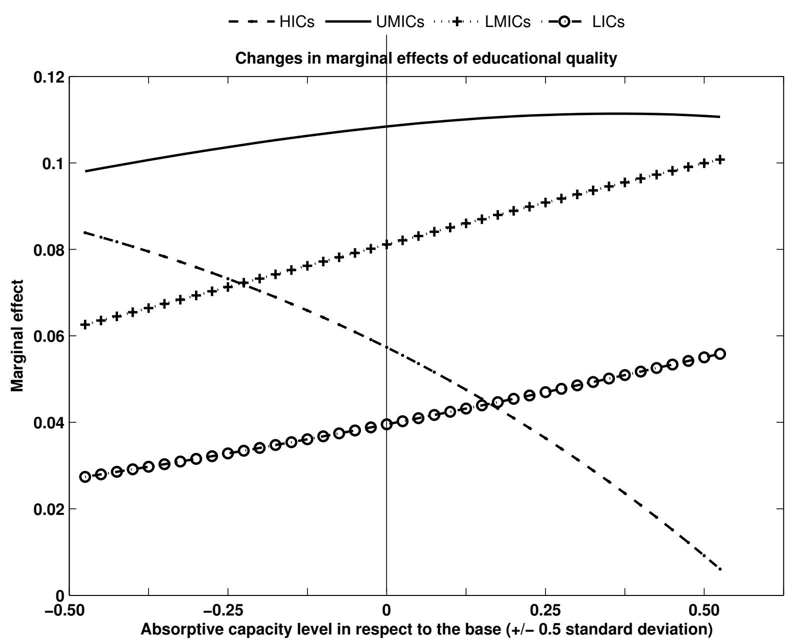
(1). Solid lines correspond to locally weighted scatter plot smoothing. HIC: High income countries; UMIC: Upper-middle income countries; LMIC: Lower-middle income countries; LIC: Low income countries.
Source: Authors' calculations based on data on Doing Business, Penn World Tables, World Bank, and Schoellman (2010).

Figure 3: Effects on TFP gap of increasing Years of schooling for different values of the absorptive capacity(1) by income group



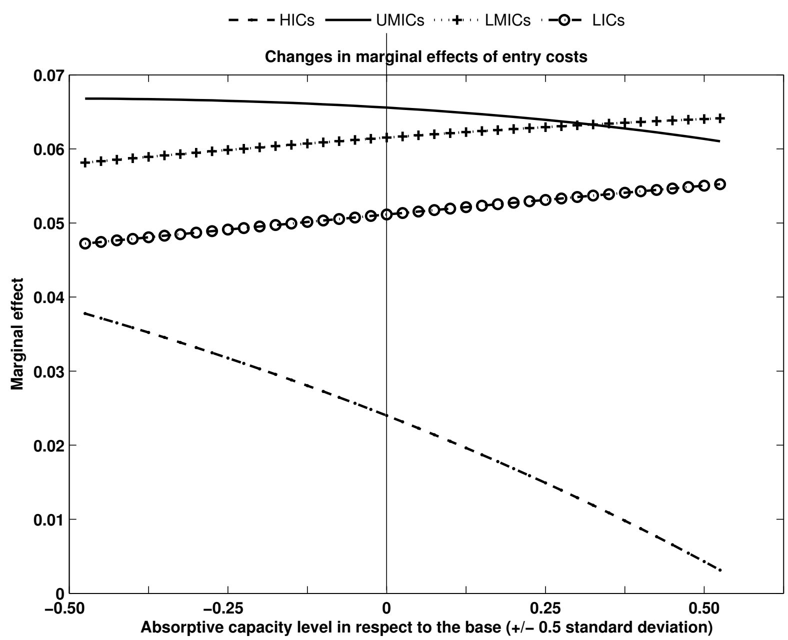
(1) The absorptive capacity corresponds to the set of policy and economic parameters that shape the economic environment. For each income group, this exercise varies the values of Educational quality, Institutions, and Entry costs jointly by +/- 0.5 standard deviation of each development factor.
Source: Authors' calculations.

Figure 4: Effects on TFP gap of increasing the Educational quality for different values of the absorptive capacity(1) by income group



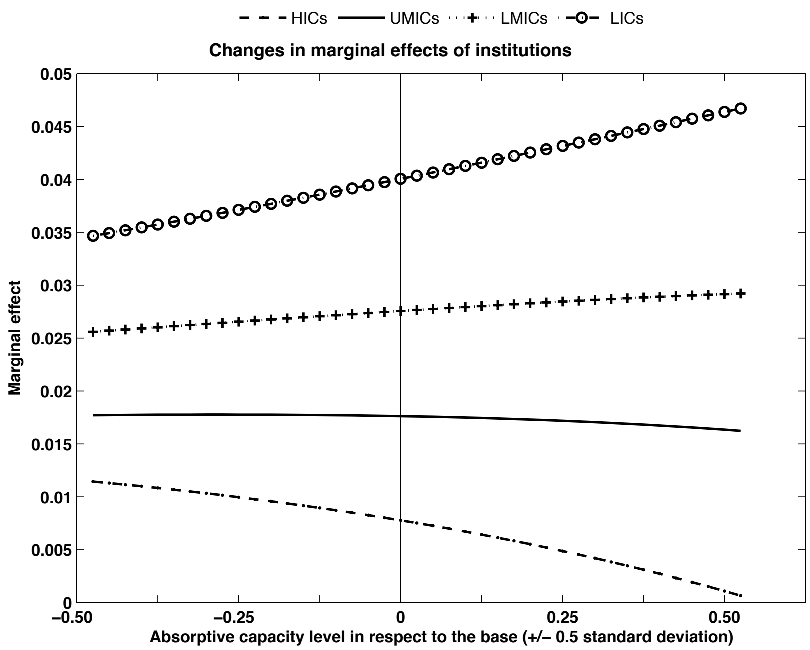
(1) The absorptive capacity corresponds to the set of policy and economic parameters that shape the economic environment. For each income group, this exercise varies the values of Years of schooling, Institutions, and Entry costs jointly by +/- 0.5 standard deviation of each development factor.
Source: Authors' calculations.

Figure 5: Effects on TFP gap of reducing Entry costs for different values of the absorptive capacity(1) by income group



(1) The absorptive capacity corresponds to the set of policy and economic parameters that shape the economic environment. For each income group, this exercise varies the values of Years of schooling, Educational quality, and Institutions jointly by +/- 0.5 standard deviation of each development factor.
Source: Authors' calculations.

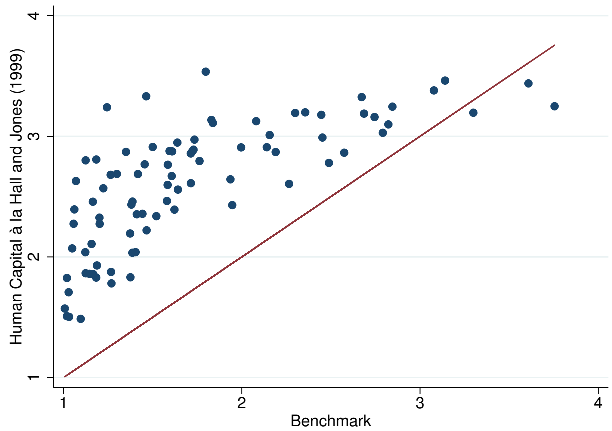
Figure 6: Effects on TFP gap of increasing the level of Institutions for different values of the absorptive capacity(1) by income group



(1) The absorptive capacity corresponds to the set of policy and economic parameters that shape the economic environment. For each income group, this exercise varies the values of Years of schooling, Educational quality, and Entry costs jointly by +/- 0.5 standard deviation of each development factor

Source: Authors' calculations.

Figure 7: Human capital in the benchmark model versus Human Capital *a la* Hall & Jones



Source: Authors' calculations.