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Why Are Developing Countries So Slow in Adopting New Technologies?

The Aggregate and Complementary Impact of Micro Distortions

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Abstract

This paper explores how developmental and regulatory impediments to resource reallocation limit the ability of developing countries to adopt new technologies. An efficient economy innovates quickly; but when the economy is unable to redeploy resources away from inefficient uses, technological adoption becomes sluggish and growth is reduced. The authors build a model of heterogeneous firms and idiosyncratic shocks, where aggregate long-run growth occurs through the adoption of new technologies, which in turn requires firm destruction and rebirth. After calibrating the model to leading and developing economies, the authors analyze its dynamics in order to clarify the mechanism based on firm renewal. The analysis uses the steady-state characteristics of the model to provide an explanation for long-run output gaps between the United States and a large sample of developing countries. For the median less-developed country in the sample, the model accounts for more than 50 percent of the income gap with respect to the United States, with 60 percent of the simulated gap being explained by developmental and regulatory barriers taken individually, and 40 percent by their interaction. Thus, the benefits from market reforms are largely diminished if developmental and regulatory distortions to firm dynamics are not jointly addressed.

This paper—a product of the Macroeconomics and Growth Team, Development Research Group—is part of a larger effort in the department to understand the sources and policies for economic growth. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at nloayza@worldbank.org.

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The aggregate and complementary impact of micro distortions*

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1. Introduction

There is a large disparity among countries regarding the rate of adoption of even inexpensive technologies. To understand why, we focus on impediments to firm dynamics. When resource reallocation and firm renewal are not restrained, domestic enterprises are able to quickly incorporate the advances of a rising technological frontier. In contrast, when the firms' natural dynamics are obstructed (for instance by red tape or lack of human capital) a country's ability to adopt new technologies can be severely handicapped, with negative consequences for its long-run income potential. In this paper, we argue that a sizable fraction of the gap in income per capita between the U.S. and the typical developing country –over 50%-- is accounted for by these obstacles. Moreover, we find that not just removing the barriers, but removing them jointly is critical: about 40% of the estimated gap between the U.S. and the typical developing country is explained by the interaction of different barriers, and the rest by the sum of their individual effects.

Starting with the work of Hopenhayn and Rogerson (1993), Caballero and Hammour (1994), and Davis, Haltiwanger, and Schuh (1996), and more recently Restuccia and Rogerson (2008) and Hsieh and Klenow (2009), a large body of literature shows the key role of firm dynamics in driving microeconomic productivity and, consequently, aggregate growth. The entry and exit of firms, involving the reallocation of resources from less to more efficient economic units, explain a substantial share of productivity improvements in the economy. Resource reallocation, however, implies costly adjustment: it requires the adoption of new technologies and the assimilation of production inputs by expanding firms, and the shredding of labor and capital by declining firms. Without this costly process, economies would be unable to both reap the benefits of an expanding production possibilities frontier --the source of long-run growth - and absorb and accommodate negative shocks --the antidote to protracted recessions.

Some of the impediments to resource reallocation and firm renewal are related to the development status of the economy, such as poor governance and lack of human capital, which exacerbate the contractual, financial, and adaptation costs of new technologies (see Caballero and Hammour, 1998; and Acemoglu and Zilibotti, 2001). Other impediments result from government's distorting interventions in markets, such as excessive labor regulations, subsidies to inefficient sectors and firms, barriers to the establishment of new firms, and burdensome bankruptcy laws. These distortions, and their implied misallocation of resources, have been blamed for the observed differences in growth experiences across countries. In their influential book, Parente and Prescott (2000) argue that gaps in total factor productivity (TFP) among economies are produced by country-specific policies that restrict the set of technologies that individual production units can use. They ascribe them to monopoly-like denials of access to the best technology. Bernanke (2005) points to heavy regulatory burden as the reason why Europe lags behind the U.S. regarding productivity growth. Likewise, Nicoletti and Scarpetta (2003) conclude that the presence of government-owned firms with a degree of monopoly power, together with restrictions on the entry of new firms, diminishes competitive pressures that foster innovation and greater efficiency in the OECD. Also focusing on industrial countries, Gust and Marquez (2004) present empirical evidence that economies with highly regulated labor and product markets face greater difficulty in incorporating information technologies and suffer from lower productivity growth.

We analyze the process of technological innovation from the perspective of developing countries, that is, as an adoption process. In contrast to the papers focused on rich nations, we take into account not only the policy-induced regulatory obstacles to firm dynamics but also the shortcomings inherent to underdevelopment, such as poor education and faulty governance. Moreover, we analyze how these types of impediments interact with each other to affect firm dynamics and, consequently, technological adoption.[1] As we explicitly model the connection between micro distortions and technology adoption, we provide an explanation for endogenous productivity changes.[2]

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[1] Jovanovic (2009) provides an alternative explanation for the lack of technological innovation among developing countries. He argues that licensing costs keep technologies away from developing countries since their productivity is too low to warrant paying the fee.

[2] Although this paper is specifically concerned with the issue of technological innovation, the mechanism that we study (i.e., firm renewal to take advantage of exogenous shocks) can be applied to other externally generated events. One of them is related to trade prices. If world conditions induce a terms-of-trade shock, only countries that can shift resources towards the most profitable sectors will be able to take full advantage of the shock. The current world economic crisis is another example. It has created an increase in the U.S. demand for certain products --such as low-end retail merchandising or fuel-efficient

We first present some motivating evidence on the importance of developmental and regulatory characteristics for technological innovation. Using the availability of personal computers and the number of internet users as proxies of technological progress, we study how they are related to governance, schooling and regulatory freedom in a large cross-section of countries. We find that these characteristics not only exert a positive independent effect on technological innovation but also complement each other in this regard.

To understand these relationships, we then construct a stochastic general equilibrium model with heterogeneous firms. They differ with respect to their level of productivity, which is determined by their initial technology and history of idiosyncratic shocks. Old firms tend to become less productive than young firms with more advanced technologies, and eventually leave the market. In doing so, they release resources that may be then used to form new firms, which acquire the leading-edge technology and enter the market. The technological frontier expands according to a stochastic and exogenous process. This intends to capture the way developing countries relate to technological advances, that is, as takers and users rather than developers of new technologies. Modeling regulatory and developmental barriers to firm renewal as described below, our theory generates dynamics of adoption that are consistent with the data.[3]

As customary in this literature, regulatory barriers are modeled as entry taxes, such as red tape and registration fees. In turn, developmental barriers --such as poor governance and lack of education-- are modeled as a parameter that affects the adjustment cost of investment: the

automobiles-- that can benefit the most dynamic developing countries, even in the middle of an international crisis.

[3] Samaniego (2006) also studies technological adoption within general equilibrium. However, that paper focuses exclusively on policy distortions: subsidies that enable plants to survive longer allow more of them to enter the stage of their life at which renewing their technology becomes optimal. Nonetheless, the economy spends a lot of resources on keeping alive plants that would otherwise have shut down, and this results in a reduction in both output and employment on the aggregate. Restuccia and Rogerson (2008) use a similar model to account for cross-country differences in income per capita. They show that policies that create heterogeneity in the prices faced by individual producers can lead to sizeable decreases in output and measured TFP in the range of 30 to 50 percent. Hsieh and Klenow (2009), using micro data on manufacturing establishments, calculate manufacturing TFP gains of 30-50% in China and 40-60% in India if labor and capital inputs are allocated as in the U.S.

salvage value of capital. The intuition for this assumption is that in conditions of underdevelopment, the value of capital depends on the informal knowledge and institutional networks associated to a particular activity. In this case, capital cannot be easily transformed to serve as production factor elsewhere. As countries develop, however, the value of capital becomes more related to broadly applicable human capital (e.g., engineers that can work with a large variety of machines) and formal institutions (e.g., contracts that are enforced by the judicial system irrespective of economic activity, production sector, or geographic location). With higher development, capital can be retooled and reconverted, thus facilitating the process of technological adoption.

According to this theory, differences in income levels are accounted for by differences in the speed of technological adoption (which determines the rate of growth acceleration). The process is exacerbated when world knowledge expands continuously –economies that suffer from obstacles to innovation lag further and further behind the leading-edge technology, and thus, the leaders' income per capita. Using this framework, we calibrate the model economy to the U.S. and 107 developing countries around the world. The empirical counterpart of the chosen distortions is taken from the World Bank's *Doing Business* database.[4]

Then, we conduct simulation exercises to analyze the independent impact of developmental and regulatory barriers and the complementarity between them. Consistent with the data, the model implies a slow adoption of new technologies by developing economies and a complementarity between the developmental barrier and the policy distortion. That is, the effect of regulatory freedom on technological innovation – and on aggregate productivity and per capita GDP– is larger the higher the level of economic development, and *vice versa*. Our model accounts for over 50% of the income gap between the median LDC and the U.S, 60% of this gap is explained by the barriers individually and 40% by their complementarity.

From these results, a clear policy implication emerges: reforms must be implemented jointly. Economic reforms have been undertaken in developing countries during the last two

[4] Some recent papers use the *Doing Business* database to simulate the effect of entry or exit costs on aggregate productivity across countries in industry-dynamics models. These papers, however, do not stress innovation as a transmission mechanism, neither the complementarity between distortions. See Barseghyan and DiCecio (2010), Moscoso and Mukoyama (2010), and Poschke (2009).

decades. Frequently, however, they have been implemented without a comprehensive program, so when one reform is in place, other obstacles to reallocation remain. Our model suggests that the benefits from liberalizing international trade or privatizing publicly owned firms, for instance, are largely reduced when distortions are not uniformly eliminated.

The paper is organized as follows. Section 2 provides some motivating facts. Section 3 presents the model, and Section 4 discusses its calibration. Section 5 analyzes the dynamics of the model in order to highlight its firm dynamics mechanism. Section 6 uses the steady-state characteristics of the model to provide an explanation for long-run output gaps across countries. Section 7 concludes.

2. Some facts

The differences across countries regarding technological adoption are quite large. Studying 115 technologies in 150 countries, Comin, Hobijn, and Rovito (2006) conclude that the average dispersion of technology across countries is 3 times larger than the dispersion of income per capita, and for 68 percent of the technologies their cross-country dispersion is larger than that of income per capita. What explains these technological gaps? Most technologies have quite long gestation and adaptation processes, which makes it hard to identify the causes underlying their cross-country variation. The technologies related to the information revolution, however, offer an interesting exception: a little over two decades ago, they were practically nonexistent almost everywhere; since then, they have been adopted at different rates throughout the world. This may allow us to characterize the effect of certain initial conditions on recent adoption levels of these technologies.[5] Before proceeding to the econometric exercise, let's consider some stylized facts about these technologies. To maximize data quality and coverage across countries, we work with two indicators: the number of personal computers per 1,000 people as proxy for technological progress in production and management processes; and the number of internet users per 1,000 people as proxy for the advance in telecommunications and information

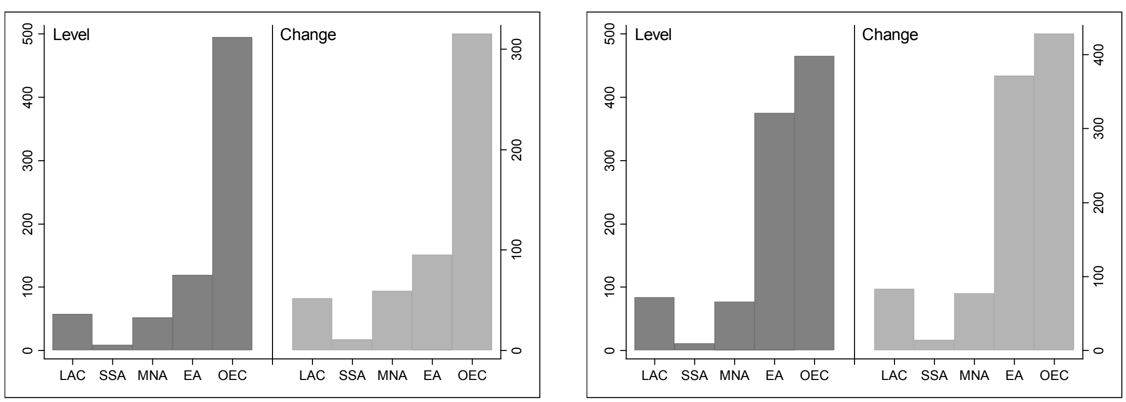
[5] As mentioned above, the empirical exercise is reported only as motivation and suggestion of the type of results the model should be directed at.

gathering. Figure 1 presents some regional comparisons on these technologies, both in levels as of 2003-04 and in changes between 2003-04 and 1994-96.

Since these technologies are rather recent, the comparisons based on levels and changes are quite similar. The OECD far surpasses any developing region. The typical OECD country has 5 times more personal computers per capita than the typical East Asian developing country, 10 times more than the typical Latin American or Middle Eastern countries, and about 50 times more than the typical Sub-Saharan African country. Regarding internet usage, the gaps are smaller but still considerable. The typical OECD country leads the typical East Asian developing country by 25%, while the other regions --Latin America, the Middle East, and specially Sub-Saharan Africa-- lag much farther behind.

Figure 1. Technological Innovation per World Region

Personal Computers (per 1,000 people) **Internet Users (per 1,000 people)**



Notes: 1. LAC: Latin America and the Caribbean; SSA: Sub-Saharan Africa; MNA: Middle East and North Africa; EA: ASEAN+2 (South Korea and China) excluding LICs; OEC: OECD. 2. Median value of each country group. 3. Level indicates an average of 2003-2004 by country, and change means the difference between the periods 2003-2004 and 1994-1996. 4. Data on Personal Computers and Internet Users are from World Development Indicators.

These regional differences are clearly related to income levels, providing some evidence on the importance of the developmental barriers mentioned above. What about regulatory barriers? Figure 2 shows some evidence that they are also potentially important. Using the Fraser index of business regulatory freedom, we divide countries into three groups. For each of them, we plot the group average of both personal computers and internet users per population for each year in the period 1990-2004. Countries in the top quartile of regulatory freedom (countries with lower regulations) have much higher levels and speeds of adoption of both technology indicators. Countries in the middle (inter-quartile) range of regulatory freedom also experience an increase over time but, having started their rise much later, show levels of technology adoption in the mid 2000s that are between one-third and one-half of those in the top quartile. Finally, countries in the bottom quartile of regulatory freedom start the adoption process much later and slowly than the others, resulting in enormous technology gaps with respect to the leaders.

The evidence presented above is suggestive that both developmental and regulatory barriers play a role in explaining technological differences across countries. For more careful empirical support, we now turn to cross-country regression analysis. This will allow us to ascertain whether each proposed determinant of technological adoption exerts a statistically significant impact, even after controlling for the effects of the other determinants. Moreover, this analysis will help us understand to what extent the proposed determinants complement each other regarding their effect on technological adoption.

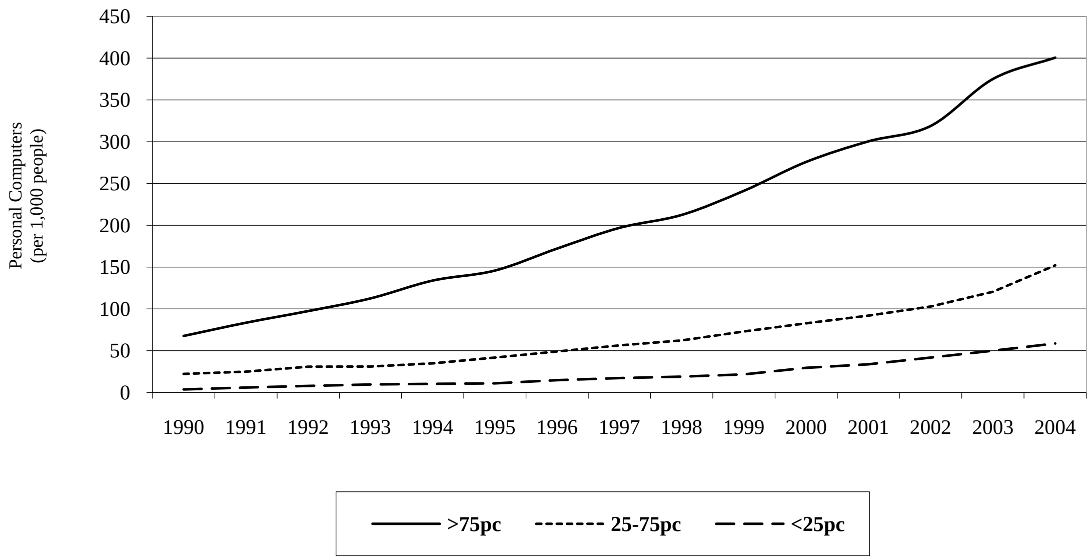
Table 1 presents information and results of the cross-country regression analysis. The dependent variables are the two indicators of technological innovation, that is, personal computers and internet users, both normalized by population. The explanatory variables are intended to capture the most relevant developmental and regulatory characteristics --the first represented by governance and schooling, and the second one, by business regulatory freedom.[6] Specifically, for the quality of public institutions and governance, we use an index based on International Country Risk Guide indicators on the rule of law, bureaucratic quality, and absence of official corruption. For education and human capital, we use the Barro and Lee (2001) measure of average schooling years of the adult population. For regulatory stance, we use the

[6] We make this selection based on the received literature on growth and technological innovation --see De Soto (1989) and Parente and Prescott (2000) on regulatory freedom; Olson (1982) and Acemoglu, Johnson, and Robinson (2005) on institutions and governance; and Lucas (1988) and Glaeser et al. (2004) on human capital and schooling.

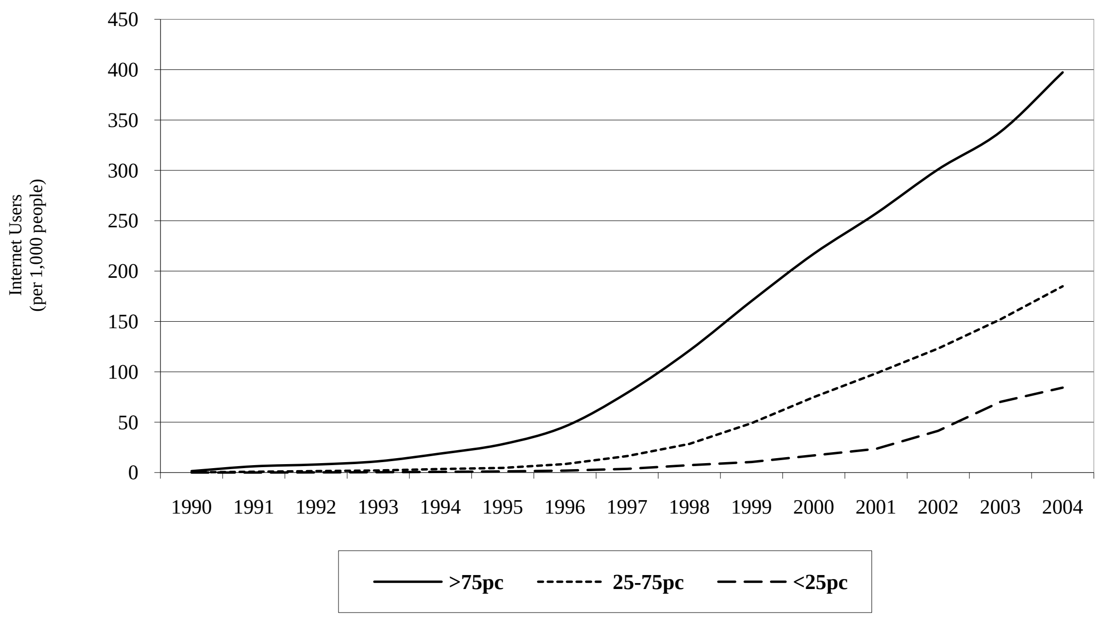
Fraser Institute Index of Regulatory Freedom. Appendix 1 provides additional information on definitions and sources of the three explanatory variables.

Figure 2. Technological Innovation and Regulatory Freedom

Personal Computers by Level of Regulatory Freedom



Internet Users by Level of Regulatory Freedom



Notes: 1. Lines show average per group (top quarter, inter-quartile range, bottom quarter) according to Regulatory Freedom as of mid 90s. 2. Data on Personal Computers and Internet Users are from World Development Indicators. Data on Regulatory Freedom are from the Fraser Institute.

The explanatory variables are all measured at the period 1994-96, while the dependent variables are measured at 2003-04. We lag the explanatory variables sufficiently to be able to consider them as pre-determined while still connected to the dependent variables. The resulting samples consist of 83 and 90 countries for the regressions on personal computers and internet users, respectively.

For each dependent variable, we run three analogous regressions. The first estimates only linear effects, while the second and third allow for multiplicative interactions. The linear regression results show that *all* explanatory variables carry positive and statistically significant coefficients, indicating that each of them independently is a relevant determinant of technological innovation. More regulatory freedom, better governance, and higher schooling all lead to faster technological adoption. Moreover, the results suggest that *both* developmental and regulatory barriers should be considered in any attempt to explain cross-country differences of technological innovation and, in particular, the backwardness suffered by some developing countries.

In exercises not reported here, we included per capita GDP in the mid-1990s as an additional explanatory variable. In the regression featuring only linear effects, the variables on regulatory freedom, governance, and schooling retained their sign and significance. In the regressions featuring the multiplicative term, the coefficients on the interaction between regulatory freedom and each of the developmental indicators remained positive and significant. To some extent, per capita GDP captures all the measures of regulatory and developmental characteristics whose individual and interactive effects we want to disentangle. Including per capita GDP in the regression would mostly obscure the interpretation of the direct and complementary effects, and this is why we decided to exclude it from the basic regressions.

To assess both the direct effects of developmental and regulatory characteristics and whether they complement each other, we now consider the regressions where the regulatory freedom variable is interacted with, in turn, the governance and schooling variables. These regressions show a clear and robust pattern: the coefficients on all the multiplicative interactions for both dependent variables are positive and statistically significant. That is, governance and schooling complement regulatory freedom, compounding each other's effect on the availability of personal computers and internet usage.

Table 1. Technological innovation

Method of estimation: Ordinary Least Squares with Robust Standard Errors

	Personal Computers (per 1,000 people)			Internet Users (per 1,000 people)		
Regulatory Freedom	25.48*	-132.01**	-67.26**	26.44**	-77.05**	-12.42
(index of Credit, Labor and Business Regulation, by The Fraser Institute: higher, less regulated; country average)	[1.97]	[3.09]	[2.25]	[2.06]	[2.66]	[0.51]
Governance	110.07**	-138.22*	102.11**	83.02**	-73.24	81.66**
(simple average of ICRG Law and Order, Bureaucracy Quality and Corruption indices: higher, better governance; country average)	[7.39]	[1.74]	[6.86]	[5.04]	[1.59]	[5.02]
Schooling	28.96**	33.94**	-41.49	26.08**	28.53**	-4.41
(average schooling years in the population aged 15 and over, from Barro and Lee (2001); country average)	[3.66]	[4.70]	[1.42]	[3.07]	[3.61]	[0.21]
Regulatory Freedom * Governance		39.85**			26.20**	
		[3.27]			[3.44]	
Regulatory Freedom * Schooling			12.67**			5.41*
			[2.56]			[1.68]
No. of observations	83	83	83	90	90	90
R-squared	0.78	0.82	0.81	0.75	0.77	0.75

Notes: 1. t-statistics are presented below the corresponding coefficients. * and ** denote significance at the 10 percent and 5 percent levels, respectively. Constant terms are included but not reported. 2. Dependent variables are measured as average of the period 2003-04. Explanatory variables are measured as of mid 1990s. 3. Data on dependent variables are from World Development Indicators and on explanatory variables, as indicated below each variable.

We can use the estimated coefficients to evaluate the effect of an increase in regulatory freedom on technological innovation. For this purpose, we need to consider the coefficients on both the interaction term and regulatory freedom itself.[7] Given that the total impact depends on

[7] The regression with interaction terms implies the following formula for the point estimate of the total effect of a change of regulatory freedom on either proxy of technological innovation,

$$\Delta Tech = (\beta_{REGFREE} + \beta_{INT}\, DEV)\, \Delta REGFREE$$

Where *Tech* represents either personal computers or internet users, *DEV* represents either governance or schooling, *REGFREE* indicates regulatory freedom, the symbol Δ denotes change, and the parameters $\beta_{REGFREE}$ and β_{INT} are the estimated regression coefficients on, respectively, regulatory freedom and the

the values of the variables with which regulatory freedom is interacted, it is not informative to provide a single summary measure of the effect. Instead, we show how this effect varies with governance and schooling.

Figure 3 presents the total effect on both personal computers and internet users of a one-standard-deviation change in the regulatory freedom index as a function of the values of either governance or schooling. In addition to the point estimates, the figure shows the corresponding 90% confidence bands (constructed from the estimated variance-covariance matrix of the corresponding parameters). It shows that if governance and schooling are very low, an increase in regulatory freedom may not lead to higher levels of technological innovation. However, as countries advance in governance, institutions, schooling and human capital, they are more likely to take advantage of larger regulatory freedom to speed up the process of technological adoption.[8] What explains this pattern of complementarity between regulatory and developmental characteristics to achieve technological innovation? The mechanism we propose in this paper is based on the incentives and costs of firm renewal. We develop this mechanism in our model, to which we turn now.

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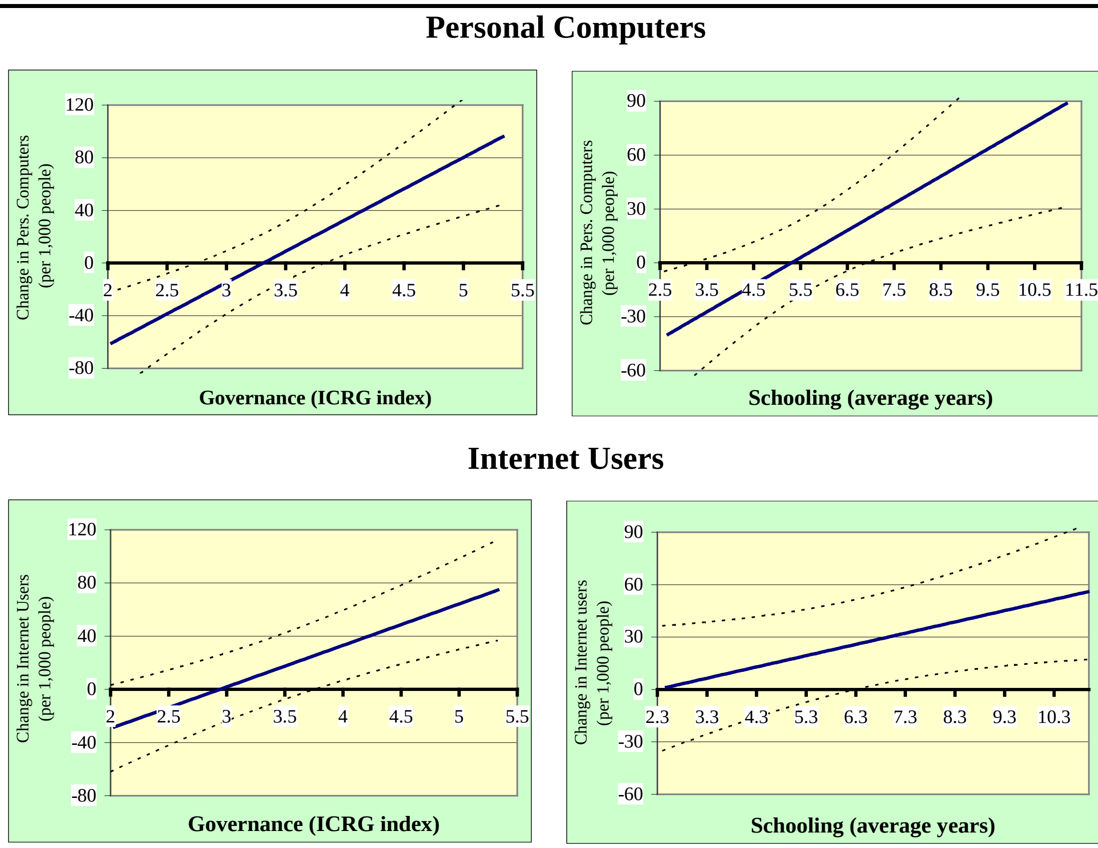
interaction between regulatory freedom and governance or schooling. Note that $\Delta REGFREE$ is an arbitrary constant, which we set to equal one sample standard deviation of the regulatory freedom index, and *DEV* corresponds to any point in the set of values given by the sample range of either governance or schooling. $\Delta REGFREE$ and *DEV* can thus be treated as constants. Then, variance of the point estimates (of the effect of a given change of regulatory freedom on personal computers or internet users) can be obtained as follows,

$$\text{Var}[\Delta Tech] = \{\text{Var}(\beta_{REGFREE}) + DEV^{2}\,\text{Var}(\beta_{INT}) + 2\,DEV\ \text{Cov}(\beta_{REGFREE}, \beta_{INT})\}\ \{\Delta REGFREE\}^{2}$$

Using this variance, we construct the confidence intervals shown in Figure 3.

[8] The panels of Figure 3 show that for very low levels of governance or schooling, the effect of an increase of regulatory freedom on computer and internet adoption seem to be negative. In additional exercises, we explored whether this negative result may be due to a non-linearity in the interaction. Indeed, when we interacted regulatory freedom with not only the linear term but also the square term of the corresponding developmental indicator, we found an upward-concave shape for the effect of regulatory freedom on technological adoption. For very low levels of governance or schooling the slope of the effect of regulatory freedom on technological adoption was flat and close to zero; as the levels of governance and schooling increased, the slope of this effect increased markedly. For simplicity we only present here the simple linear interaction specification.

Figure 3: Innovation Effect of an Increase in Regulatory Freedom as Function of Governance and Schooling



Notes: 1. The solid lines show the effect of a one-standard-deviation increase in the index of regulatory freedom on personal computers and internet users, respectively; 2. The x axis represents the .05-.95 percentile range of, respectively, governance and schooling in the sample; 3. Dotted lines are 90% confidence bands.

3. A model of plant selection

We develop a general equilibrium model of heterogeneous production units, vintage capital, and idiosyncratic shocks, based on Hopenhayn (1992), Campbell (1998) and Bergoeing, Loayza and Repetto (2004). There exists a distribution of plants characterized by different levels of productivity. In each period, plant managers decide whether to exit or stay in business. If a plant stays, the manager must decide how much labor to hire. If the plant exits, it is worth a sell-off value. Every period the incumbents receive an idiosyncratic productivity shock. In addition, new plants enter every period. The initial technology level of a newcomer is random, although increasing in the leading edge production technology. New plants are produced by a "construction" firm with a constant return to scale technology.

In this context, the economy is characterized by an ongoing process of plant entry and exit, and the corresponding creation and destruction. Plants exit if economic prospects loom negative. They may also exit if their current technology becomes obsolete and, by selling their capital off, owners gain access to the leading-edge technology –Schumpeter's process of creative destruction. However, exiting is costly as capital loses some of its value in the process. These investment irreversibilities, as modeled by Caballero and Engel (1999), combined with idiosyncratic uncertainty, generate an equilibrium solution where plant owners rationally delay their exit decisions.

We allow for exogenously imposed rigidities. In particular, we study the effect of policy-related and developmental barriers that alter firms' decisions to leave or stay in the market. Governments are willing to impose such policies to reduce the volatility and short-run social and political costs associated to the entry – exit process or simply to collect revenues. As mentioned above, we interpret the loss due to capital irreversibility as indicative of the economy's level of development. Thus, micro dynamics are affected both by government and developmental barriers. The larger these are, the lower the rate of technology adoption that developing economies engage in, and the larger their income gap with rich economies. Our simulation results are consistent with this fact: as the leading edge technology expands, barriers to the extensive margins dampen the reallocation process reducing short-run output losses at the cost of lowering adoption, productivity gains, and output trend.

To relate our model to the existing micro dynamics literature, we refer to production units as "plants." However, we do not provide a theory of the firm or the plant. In our model the size of the firm as a collection of production units is indeterminate, and, therefore, the modeled entry-exit dynamics can occur either within or across *actual* firms or plants. Nevertheless, to the extent that a firm or plant activities tend to consist of interrelated production units (or investment projects), we expect that there is a considerable correlation between production dynamics in the model and actual plant dynamics.

The gap between the definition of production units in the model and in the data implies that our model abstracts from reality in other dimensions that are also relevant for the specification of parameters as well as for the interpretation of our results. First, in the model only new plants invest, while in the data investment is carried out by both new and old plants. Second, in the model technological adoption requires firms to close down, while in the data incumbent plants may also adopt new technologies. Thus, we conjecture that the magnitude of entry and exit implicit in the model is an upper bound of those in reality.

In what follows we describe our model in detail.

The model economy: The economy is populated by a continuum of heterogeneous plants. A plant needs labor (*n*) and capital (*k*) for production of the unique good, which can be used for consumption or investment. This production good is the numeraire.

Each plant's production function is given by

$$y_t = A n_t^{\alpha} \left(e^{\theta_t} k_t(\theta_t) \right)^{1-\alpha} \tag{1}$$

where A is aggregate productivity common to all the establishments (a scale factor), and θ_t is the idiosyncratic productivity at period *t*. The notation $k_t(\theta_t)$ reflects the fact that the technology θ_t is embodied in the plant.

Since technologies are characterized by constant returns to scale, we can restrict the size of all the plants to be equal to one unit of capital. Thus, capital goods are identified with plants so that investing one unit of the aggregate good yields a unit mass of plants. Then, from now on $k_t(\theta_t)$ will represent the density of plants with embodied technology θ_t as well.

The aggregate production function of this model economy is:

$$Y_t = A N_t^{\alpha} \left[\int_{-\infty}^{\infty} e^{\theta_t} k_t(\theta_t) d\theta_t \right]^{1-\alpha} = A N_t^{\alpha} \overline{K}_t^{1-\alpha} \tag{2}$$

where $\overline{K}_t = \int_{-\infty}^{\infty} e^{\theta_t} k_t(\theta_t) d\theta_t$ is the aggregate effective capital stock.

Capital embodying relatively low level of technology is scrapped as its productivity lags behind that of the leading edge technology. When a plant is retired, a unit of capital that is scrapped has salvage value $s < 1$. The total amount of salvaged capital in period *t* is then

$$S_t = (1-\delta)s\int_{-\infty}^{\overline{\theta}_t} k_t(\theta_t)d\theta_t \quad (3)$$

where $\overline{\theta_t}$ is the endogenous cut-off level of productivity that determines the exit decision of plants and δ is the capital's depreciation rate.

Units of the production goods not consumed -- which are made up of investment and part of last period's scrapped capital -- are transformed into new units of capital embodied with the leading edge technology. That is, the initial productivity level of a plant born in period *t* is a random variable with a normal distribution $\theta_{t+1} \sim \mathrm{N}(\mathrm{z}_t,\ \sigma^2)$, where z_t represents the level of leading edge technology. This stochastic variable follows a random walk with a positive drift μ_z according to

$$z_{t+1} = \mu_z + z_t + \varepsilon^z_{t+1}, \qquad \varepsilon^z_{t+1} \sim \mathrm{N}(0,\ \sigma^2_z). \quad (4)$$

This drift is the only source of long-run aggregate growth in our economy.

Capital that is not scrapped receives an idiosyncratic shock to its productivity level before next period production process starts, according to

$$\theta_{t+1} = \theta_t + \varepsilon^\theta_{t+1}, \qquad \varepsilon^\theta_{t+1} \sim \mathrm{N}(0,\ \sigma^2_\theta) \quad (5)$$

This idiosyncratic shock has zero mean and, thus, it does not affect the economy´s long-run growth rate. The random walk property of the stochastic process ensures that the differences in average productivity across units of capital persist over time. Thus, at any *t*, the units of capital with more advanced technology have a lower probability of shutting down.

Summarizing, there are two sources of uncertainty: first, an idiosyncratic productivity shock, ε^θ_t , that determines the plant level decisions of incumbents. This shock does not alter the aggregate equilibrium allocation. Second, a leading edge idiosyncratic productivity shock, ε^z_t , that governs the economy's aggregate growth. Notice that plants, as they decide to stay or leave, choose between the following distributions:

$$\theta_{t+1} \sim \mathrm{N}(\theta_t,\ \sigma^2_\theta) \quad (6)$$

$$\theta_{t+1} \sim \mathrm{N}(\mathrm{z}_t,\ \sigma^2) \quad (7)$$

Plants last only one period. At the beginning of the period, firms decide production and hiring. The wage rate in period *t* is ω_t, and the beginning and end of period prices of a plant with productivity θ_t are $q_t^0(\theta_t)$ and $q_t^1(\theta_t)$, respectively. Within this setting, given the number of units of capital with productivity θ_t, $k_t(\theta_t)$, the employment assigned to each plant is given by

$$n_t(\theta_t) = N_t^{\alpha} e^{\theta_t} / \overline{K}_t \tag{8}$$

After production, firms decide which plants should be scrapped and which ones should be maintained in business. Firms sell their production units and salvaged capital to the consumer and to a construction firm that produces capital embodying the leading edge technology. The construction firm, which buys I_t^C units of the aggregate good from the producer, incorporates the leading edge technology at zero cost, and then sells it to consumers at the end of the period at a price per unit q_t^{1i} . Profit maximization requires the price of the construction project *i* to be equal to the cost of inputs. That is,

$$q_t^{1i} = 1 \ . \tag{9}$$

This is the ex-ante price cost of capital, that is, before the realization of the productivity shock.

The distribution of capital evolves according to the law of motion

$$k_{t+1}^0(\theta_{t+1}) = \int_{-\infty}^{\infty} \frac{1}{\sigma_\theta} \phi\left(\frac{\theta_{t+1} - \theta_t}{\sigma_\theta}\right) k_t^1(\theta_t) d\theta_t + \phi\left(\frac{\theta_{t+1} - z_t}{\sigma}\right) I_t^c, \quad \textit{for all } \theta_{t+1} \tag{10}$$

Since asset prices equal discounted expected dividend streams, increases in the level of productivity raise these prices; and since the scrap value of a plant is independent of its productivity, only plants with productivity level below the threshold $\overline{\theta_t}$ exit the market. Thus, the marginal plant, that is, the one with productivity level $\overline{\theta_t}$, must have a market value given by the scrap value. The following equation states this condition.

$$s = q_t^1(\overline{\theta_t}) \tag{12}$$

Finally, the purchasing price of a unit of capital is determined not only by its marginal productivity, less any operating costs, but also by the price at which the capital left after depreciation may be sold at the end of the period. Thus, for each θ_t, the purchase and sale decisions of capital units must be characterized by the zero profit condition:

$$q_t^0(\theta_t) = (1-\alpha)\left(\frac{\overline{K}_t}{N_t}\right)^{-\alpha} e^{\theta_t} - \pi_t + (1-\delta)\left[1\{\theta_t < \overline{\theta}_t\}s + 1\{\theta_t \geq \overline{\theta}_t\}q_t^1(\theta_t)\right] \tag{13}$$

where 1{·} is an indicator function that equals one if its argument is true and zero otherwise. This condition restricts the beginning of period price to be the return from using the capital plus the price at which it can be sold at the end of the period. The parameter π is a cost (fee and/or tax) per plant that the firm has to pay to be able to operate. Notice that π is independent of the productivity of the particular plant. With this we try to capture the impact of policy regulatory restrictions such as legal fees, government permits, and bureaucratic process, whose cost firms must suffer regardless their size or productivity.

The entry cost π follows an AR(1) process with autocorrelation coefficient ρ^{π} and variance σ_{π}^2. The government´s budget constraint is guaranteed to be satisfied by imposing a lump-sum transfer to consumers.

The remainder of the model is standard. There is a continuum of identical infinitely lived consumers who own labor and equity. Their preferences are given by

$$E_0\left[\sum_{t=0}^{\infty}\beta^t\left(\log(c_t)+\kappa(1-n_t)\right)\right] \tag{14}$$

where c_t and $1-n_t$ are consumption and leisure, respectively, and β and κ ∈ (0,1) are, respectively, the subjective time discount factor and the marginal utility of leisure. Every period, consumers have a time endowment equal to 1. Notice that we assume that the utility function is linear in leisure.[9] Following Hansen (1985) and Rogerson (1988), this can be interpreted as an environment in which consumers, with standard utility functions, can work only a fixed number of hours or none at all, and they can trade employment lotteries. Thus, n_t is interpreted as the fraction of the population that works.

[9] If we run the numerical simulations using a standard log utility function for leisure, the main results remain qualitatively unchanged.

Definition of the equilibrium: A *Competitive Equilibrium* in this economy is a set of decision rules $\left\{I_t, c_t, \{n_t(\theta_t), k_t(\theta_t), y_t(\theta_t)\}_{\forall\theta_t}\right\}_{t=0}^{\infty}$, stochastic variables $\{c_t, I_t, Y_t, \overline{K}_t, N_t, S_t\}_{t=0}^{\infty}$, contingent prices $\{\omega_t, q_t^1, q_t^0, q_t^{1i}\}_{t=0}^{\infty}$, and a vector $\{\overline{\theta}_t\}_{t=0}^{\infty}$ such that, given contingent prices, the transfer T_t, and production and government stochastic processes $\{z_t, \theta_t, \pi_t\}_{t=0}^{\infty}$, at each period t:

1) Given the initial holding of capital, the representative consumer maximizes utility subject to a budget constraint and the law of capital accumulation,

$$E_0\left[\sum_{t=0}^{\infty}\beta^t\left(\log(c_t)+\kappa(1-n_t)\right)\right]$$

$$c_t + I_t^c q_t^{1i} + \int_{-\infty}^{\infty} q_t^1(\theta_t)k_t^1(\theta_t)d\theta_t = \omega_t n_t + \int_{-\infty}^{\infty} q_t^0(\theta_t)k_t^0(\theta_t)d\theta_t + T_t$$

$$k_{t+1}^0(\theta_{t+1}) = \int_{-\infty}^{\infty}\frac{1}{\sigma_\theta}\phi\left(\frac{\theta_{t+1}-\theta_t}{\sigma_\theta}\right)k_t^1(\theta_t)d\theta_t + \phi\left(\frac{\theta_{t+1}-z_t}{\sigma}\right)I_t^c$$

$k_0^0(\theta_0)$>0 given

2) The producer of the consumption good satisfies (firm's first order conditions),

$$n_t(\theta_t) = N_t^{\alpha}e^{\theta_t}/\overline{K}_t$$

$$\omega_t = \alpha A\left(\frac{\overline{K}_t}{N_t}\right)^{1-\alpha}$$

$$q_t^1(\overline{\theta}_t) = s$$

$$q_t^0(\theta_t) = (1-\alpha)\left(\frac{\overline{K}_t}{N_t}\right)^{-\alpha}e^{\theta_t} - \pi_t + (1-\delta)\left[1\{\theta_t < \overline{\theta}_t\}s + 1\{\theta_t > \overline{\theta}_t\}q_t^1(\theta_t)\right]$$

3) The intermediary satisfies,

$$I_t^i = q_t^{1i}I_t^c$$

4) The government budget constraint satisfies,

$$\pi_t \int_{-\infty}^{\infty} k_t(\theta_t) d\theta_t = T_t$$

5) Markets clear,

$$c_t + I_t = Y_t + S_t \qquad (15)$$

4. Numerical evaluation

We analyze steady states under alternative distortions (produced by policy-related and developmental barriers) and, for each distortion, the transitional path following a leading-edge technology shock. To approximate actual experiences and to assess the robustness of the results we simulate equilibria for a wide range of policy values.

Numerical equilibria are solved using a three-step strategy. First, we compute the non-stochastic steady state equilibrium variables. Second, we log-linearize the system of equations that characterize the solution around the long-run values of the equilibrium elements. Third, we apply the method of undetermined coefficients described in Christiano (1998) in order to recover the coefficients of the individual policy functions. Because the economy exhibits unbounded growth most of the variables are not stationary. Thus, when solving the equilibrium we scale the non-stationary variables by the long-run growth rate. Then, a mapping takes the solution from the scaled objects solved for in the computations to the unscaled objects of interest.

We can separate the parameters in four types: aggregate parameters $\{\beta, \delta, \kappa, \mu_z, \alpha\}$, plant specific parameters $\{\sigma, \sigma_\theta\}$, a policy parameter $\{\pi\}$, and a developmental parameter $\{s\}$.

In what follows time is measured in years. We use a discount factor of $\beta = 0.95$, consistent with a net real interest rate of 5% yearly; the depreciation rate is set at $\delta = 0.06$; and the share of labor incomes to output is set at $\alpha = 0.7$, following Gollin (2002). The aggregate parameters are calibrated as in a representative firm economy. Long-run growth is given by $\mu_z(1-\alpha)/\alpha$, which, since population is stationary, also represents the growth rate of income per capita. Thus, to have an annual trend growth rate of 2%, given α, we set μ_z equal to 4.5%. The marginal utility of leisure, κ, determines the fraction of available time allocated to labor. We choose κ consistently with N equal to 0.33 in the steady state.

Plant specific parameters are proportional to those used in Campbell (1998) for the U.S. There are two reasons to do so. First, long series of plant level data are not available for a large sample of countries. Second, economies in our model are equal in all respects except specific parameters related to policies and development. We use the U.S. as our undistorted long-run developed benchmark. The parameters used by Campbell (1998) do a good job generating a distribution of firm's productivities for the U.S. economy, but they fail to capture the larger dispersion of individual productivities observed in developing economies (as reported by Bartelsman, Haltiwanger, and Scarpetta, 2004). Hence, in order to find meaningful values for the productivity threshold (i.e., values of $\bar{\theta}$ with strictly positive measure) we must use a substantially larger variance. We choose values for σ_θ and σ twice as large as those used by Campbell (1998).

Regarding the policy-related and developmental barriers, we calibrate their corresponding parameters, π and s, to match data from the World Bank Doing Business database.[10] We choose to use data for 2007 (in part to ensure that GDP figures are not preliminary). Two specific indexes are of interest for the purpose of our paper: the cost of starting a business and the percentage of the initial investment that is preserved (or recovered) when a firm exits the market. The mapping between these indexes and the model's parameters, π and s, is not exact, but we believe it is reasonably appropriate. The mapping is quite close when we interpret the model in a limited perspective, according to which π and s simply represent entry and exit costs, respectively. Admittedly, the mapping becomes weaker when we interpret the model and its parameters more broadly, that is, when we associate π with policy barriers and s with developmental constraints. In reality, both indicators from *Doing Business* have elements of policy and development imbedded in them. However, the design of the *Doing Business* indicators makes the entry costs mostly driven by policy barriers, that is, dictated by *de jure* regulations, while the recovery rate is determined to a large extent by the confluence of *de facto* governance and human capital factors. We acknowledge that the indicators from *Doing Business* are neither complete nor exclusive proxies of the model parameters. However, for the purpose of

[10] On entry costs, this is the same source used by the Fraser Institute to construct their index of regulatory freedom.

the application and interpretation of the model, they are the best in terms of representing, first, the entry and exit margins, and, second, the policy and developmental barriers to firm dynamics.

Table 2. Selected Statistics, *Doing Business*

	Entry		Exit
	Fees (% of GDP pc)	Time (days)	Recovery rate (cents per 1$)
Average	106.3	46.2	30.8
Median	24.3	34.0	27.3
Minimum	0.0	2.0	0.0
Maximum	6,375.5	694.0	92.7
St. deviation	491.3	59.6	24.9
P90	203.9	87.5	75.3
P10	3.21	11.7	0.0
U.S.A.	0.8	6	77*
Median LDC (Egypt)	68.8	19	16.6*
Median LAC (Brazil)	9.9	152	12.1*

Source: World Bank, *Doing Business*, 2007
*In the simulations, the recovery rates of the U.S., Egypt, and Brazil are rounded to the nearest number used in the simulation grid. As shown in Table 3, they are, respectively, 77.5, 17.5, and 12.5.

Table 2 presents selective statistics on entry barriers and recovery rates for the 183 countries included in the *Doing Business* database. It also presents the values corresponding to the U.S. (our benchmark efficient economy) and the median LDC (according to income per capita). Differences across countries are large. The most entry-regulated economies (90th percentile) have a direct cost to start a business of about 200% of GDP. That is around 60 times larger than the cost of the least entry-regulated ones (10th percentile). Recovery rates after exiting are 0% and 75% for the least advanced (10th percentile) and most advanced (90th percentile), respectively.

Table 3. Parametric specification		
Aggregate parameters	***Parameter***	***Value***
Discount factor	β	0.95
Fraction of steady state hours worked	N	0.33
Labor share	α	0.7
Depreciation rate	δ	0.06
Leading edge technology drift	μ_ζ	0.045
Plant level parameters		
St. deviation of shock to incumbents	σ_θ	0.06
St. deviation of shock to startups	σ	0.06
Simulation parameters		
Leading edge technology shock	ε_ζ	0.045
Efficient economy – US		
Recovery rate (development level)	s	0.775
Entry barrier (policy regulation)	π	0
Developing economies		
Median LDC – Egypt		
Recovery rate (development level)	s	0.175
Entry barrier (policy regulation)	π	0.2 (0.74 GDP pc)
Median LAC – Brazil		
Recovery rate (development level)	s	0.125
Entry barrier (policy regulation)	π	0.15 (0.52 GDP pc)

The link between the recovery rates from *Doing Business* and the parameter *s* in the model is direct and correspond one-to-one. Both represent the fraction of initial investment that is not lost when the firm closes. On the other hand, the connection between the entry barrier data from *Doing Business* and the parameter π in the model is more involved. First, we need to convert the two measures (fees and time) into the same unit. As an approximation, we do it by assuming that the fraction of days in a year that takes to open a business corresponds to the fraction of GDP per capita lost in the process. Then, we add this measure to the fees, already expressed as ratio to GDP per capita. The second step is to transform this cost as ratio to GDP per capita to a cost in terms of the price of capital (see equation 13). The transformation is not linear and depends, among other things, on the prevailing recovery rate *s*. For instance, an economy with a recovery rate of 0.175 and an entry barrier of 0.74 of GDP (corresponding to the median LDC) would have a parameter π equal to 0.2. The U.S., having about 0.02 of GDP as entry barrier and 0.775 of recovery rate, would have $\pi = 0$.[11]

Table 3 summarizes the main parameters used in the calibration and simulations presented below. In particular, it presents the corresponding values for the entry barrier π and the recovery rate *s* for the U.S., as the benchmark efficient economy; for the median LDC according to income per capita, which in 2007 happens to be Egypt, and the median Latin American and Caribbean (LAC) country, which in 2007 is Brazil.

5. Dynamics: A mechanism based on firm renewal

In this section, we simulate the dynamics of the model for the efficient economy (the U.S.) and for two developing countries, the median LDC (Egypt) and the median LAC (Brazil). Our purpose is to clarify the mechanism through which both development and regulatory barriers affect growth and output per capita levels. As emphasized in the paper, this mechanism consists of technological adoption through firm renewal.

Figure 4 shows the impulse response of firm entry, firm exit, aggregate capital, aggregate labor, TFP, and output to a positive shock of 4.5% to the leading technology (a shock of a one-drift size, equivalent to a permanent increase in long-run growth rate of about 2 percentage points). The impulse responses are presented for the U.S. and the two developing economies, Egypt and Brazil. Firm entry and exit are calculated as ratio of entry/exit net capital over GDP, and their impulse responses correspond to the after-shock percentage point deviations of this ratio. For the remaining variables, the impulse response is presented as the after-shock deviation with respect to the original steady-state growth rate.

Firm entry jumps more rapidly and remains at a significantly higher level in the efficient economy than in the typical developing economies for the first 10 periods, slowly converging to the initial ratio with respect to GDP. Firm exit shows a similar pattern, but in this case the

[11] The full mapping is not provided here to save space but is available upon request.

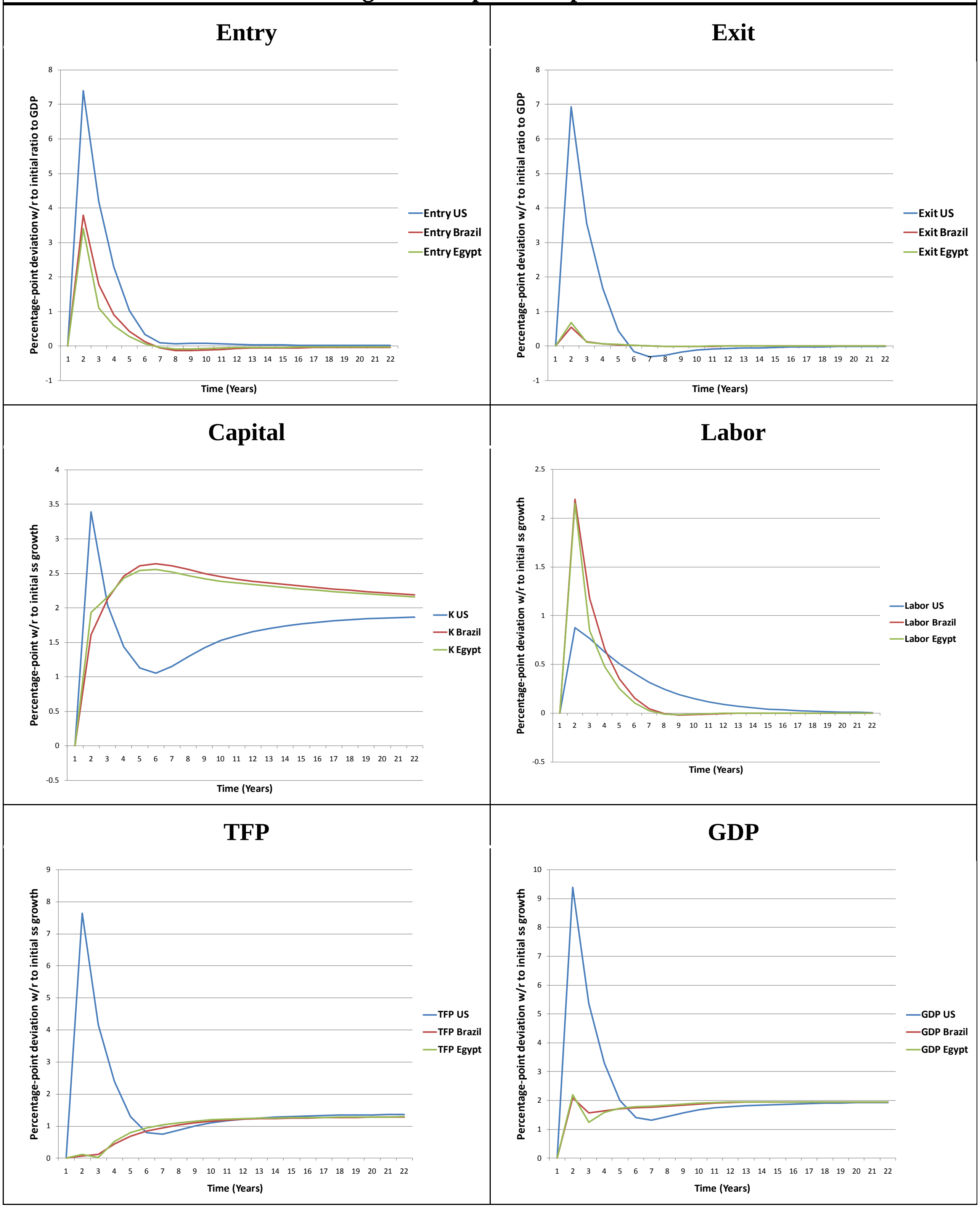
differences between the U.S. and the developing economies are much more pronounced. Firm exit in the U.S. is much larger than in the typical developing economies and for a longer period of time. The stronger response of firm exit than entry is in part due to the larger difference regarding (after exit) recovery rates than entry barriers between the two types of countries.

The result of the more active firm dynamics in the efficient economy can be seen in the remaining panels. Capital grows substantially more in the efficient economy than in the developing ones but only in the first few periods. Since at the end both types of economies fully adopt the new technology, more adoption through capital accumulation occurs later on in the developing economies.[12] Interestingly, labor response is more intense in the developing than the efficient economy during the first few periods. This reverses after approximately 5 periods, gradually converging towards the new steady state. The stronger labor response in developing economies is partly to compensate for their weaker capital and productivity response.

The effect of the more active firm renewal is strikingly seen in the impulse response associated to TFP. In fact, TFP grows substantially higher in the efficient than in the developing economies for the first periods. Later on, the latter economies have somewhat higher TFP growth, as they catch up on the adoption of the new technology. The impulse response of GDP reflects the responses of the components of the production function, with some predominance of the TFP response. GDP grows much more rapidly in the efficient than developing economies during the first periods, with a reversal of smaller magnitude in the following years. The difference in GDP growth rates in favor of the efficient economy is less pronounced than the corresponding difference in TFP growth rates. This is due to the stronger initial response of labor in developing countries, as well as their stronger response of capital in subsequent periods.

[12] The "inevitable" full adoption of new technologies is implicit in the assumption that long run growth (μ_z) is exogenous and equal in both economies. We think that this assumption reflects accurately the sources of growth, since, sooner or later, all technological innovations are worldwide adopted.

Figure 4: Impulse Responses



6. Steady-state: Explaining long-run per capita output gaps

Our theory proposes a partial explanation for the observed differences in output (income) per capita across countries –some countries are poorer than others because their economies suffer from barriers to the adoption of new technologies. [13] Some barriers are the product of the country's underdevelopment itself, while others consist of policy regulations that reduce competition and raise the costs of firm formation. In our theory, any policy that affects current and expected productivity by interfering with the natural process of birth, growth, and death of firms, will have a detrimental effect on aggregate growth.

As the cost of entering and exiting the economy increases, the distribution of firms is altered such that too many inefficient firms remain in the market and too few potentially more efficient firms enter the market. As a result, both the reshuffling of resources from less to more efficient firms and the adoption of the leading-edge technology are impeded. The mechanism does not require new technologies to be fully blocked since slowing down this adoption process is enough to render significant income differences across countries. New technologies are eventually fully adopted by all countries, but what matters to account for income disparities at a moment in time is the difference in the speed at which they are adopted.

In order to illustrate the potential impact that the barriers to technological adoption can have on long-run output differences across countries, we use the model and its calibration to simulate the steady-state output of a set of economies with given policy and developmental barriers relative to the output of the U.S., our benchmark efficient economy. The results are illustrated in Figure 5.

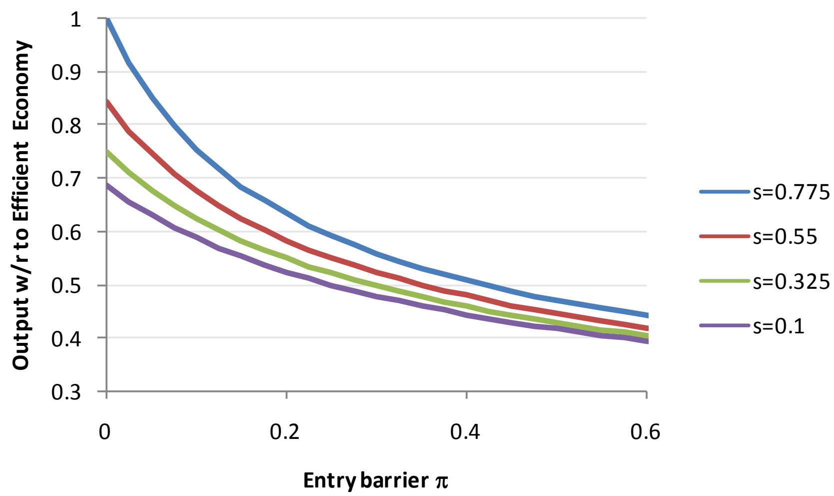
Three results deserve to be highlighted. First, worsening entry barriers (higher π) or poorer recovery rates (lower s) decreases steady state output with respect to the leader, with this effect being larger when the corresponding parameters are close to those of the efficient

[13] We indistinctly refer to income and output as GDP. And, unless otherwise noted, GDP is presented in per capita terms. As it is evident from the feasibility condition in equation (15), the analogous to GDP per capita in our model economy is $Y+S$, not Y by itself. That is, the "transformation" of plants back into the *numeraire* is a production process itself, which entails the loss of $1-s$ parts of the original components of the plant. Thus, we refer to GDP per capita as Y+S in the model economy.

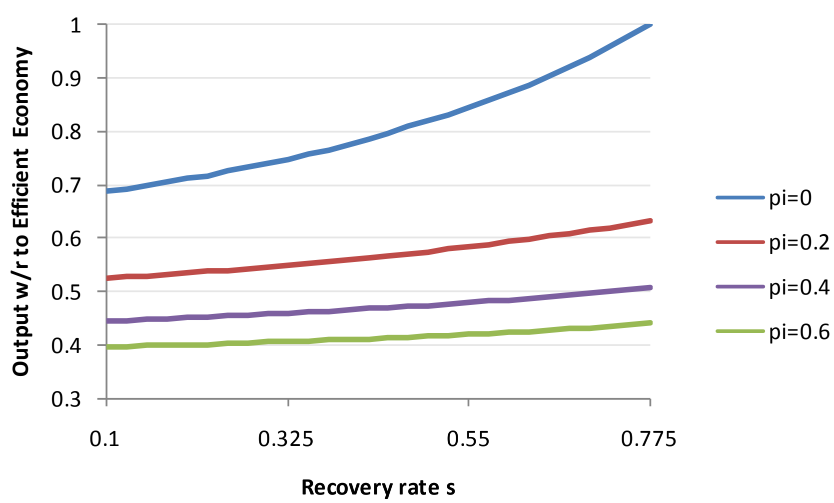
economy. In other words, when the situation with respect to either entry barriers or recovery rates is already bad, worsening them would have smaller negative impact.

Figure 5: Output Relative to Efficient Economy (U.S.)

For given recovery rate (s)



For given entry barrier (π)



The second result is that the model generates substantial income heterogeneity. With respect to the efficient economy ($\pi = 0$ and $s = 0.775$), movements in the entry barrier or the recovery rate can lead to output ratios as low as 40%. This is obtained considering a limited range for the policy and developmental parameters; were we to increase this range, considering the extreme cases found in the world sample, the differences with respect to the leader would be predicted to be much larger.

The third interesting result can be associated with the complementarity between policy and developmental barriers (or, more literally in the model, the interaction between different distortions to efficient technological adoption). In Figure 4, we plot the effect of entry barriers (upper panel) and the effect of recovery rates (bottom panel) for four different values of each other parameter. This shows that improving a country's developmental characteristics (increasing *s*) when its policy barriers (π) are kept at a high level has almost no impact on GDP per capita. Likewise, reducing policy barriers when the economy exhibits a low level of development has a small impact on GDP per capita. On the other hand, either reducing policy barriers when the economy has a high level of development *or* improving developmental characteristics when policy barriers are low has a sizable effect on GDP per capita.

Table 4. Changes in output with respect to the initial level

s / π	**0.9**	**0.7**	**0.5**	**0.3**	**0.1**
0.9 to 0.7	10.4%	9.5%	9.3%	9.0%	8.7%
0.7 to 0.5	13.5%	12.6%	12.1%	11.4%	10.9%
0.5 to 0.3	19.4%	18.4%	16.9%	15.7%	14.7%
0.3 to 0.1	35.8%	32.6%	28.2%	24.9%	22.6%
0.1 to 0	39.2%	29.6%	23.4%	19.4%	16.8%

Table 4 provides additional evidence of this positive interaction between developmental and policy margins. It presents the impact of parameter changes on output as a proportion of its original level. The higher the s and the lower π, the higher the output gains are, as a proportion of the original output level. For instance, starting from an economy with $\pi = 0.1$ and s = 0.9, moving towards an economy with no entry barriers generates a 39.2% output gain. But if s = 0.1, the same entry barrier change would produce a gain of only 16.8% of the original output level. Moreover, since an economy with lower π and higher *s* has larger output level, the potential absolute and proportional gains in output are larger the closer to the leading edge technology the economy is.

The output effect of the change in policy or developmental barriers is true everywhere: the better one margin, the larger the value of the theoretical derivative of output with respect to the other margin. This complementarity is consistent with the empirical findings presented in Section 2. A policy implication follows: the benefits from reforms can be considerably reduced if they are not uniformly addressed.

Having analyzed the theoretical effect of policy and developmental barriers on potential output, we can next quantify their effect on explaining the observed output gaps between the benchmark efficient economy (the U.S.) and developing countries around the world. First, using the model and each country's observed entry cost and recovery rate, we simulate its predicted output gap with respect to the U.S. Second, we compare the simulated with the actual output gap per country in order to assess the model's ability to account for observed income differences. Finally, we analyze the contribution of policy barriers, developmental constraints, and their complementarity in explaining the simulated output gap between each developing country and the benchmark economy.

For the interested reader, Appendix II presents the country-specific results on long-run output gaps corresponding to 107 developing countries. Here, for brevity, we discuss only the results related to the median LDC (Egypt) and median LAC (Brazil). They are summarized in Table 5.

Table 5 (and the accompanying Appendix II) presents some interesting results. From them, two deserve special attention. First, despite the model's narrow emphasis on growth through technological adoption and firm renewal, its mechanism can explain a substantial fraction of the GDP gap of developing countries with respect to the U.S. In fact for the typical less-developed country, the model explains over 50% of the actual GDP gap with respect to the leading developed economy. Considering the full sample of developing countries, the median explanation performance of the model is nearly 50%.

A second finding is not less interesting. About 40% of the simulated gap is accounted for by the complementarity of policy and developmental barriers. This is the case for the typical LDC and typical LAC. It is also very similar to the median contribution from the interaction of policy and developmental barriers obtained from the full sample of developing countries. The remaining 60% is, of course, explained by each barrier separately. Their proportional contribution varies from country to country, depending on the relative importance of entry barriers and recovery rates. For the median LDC, entry barriers are somewhat more important than recovery rates, accounting for 37% and 22%, respectively. This is approximately the same as the median values obtained from the full sample of developing countries.

Table 5. Explaining Long-Run Output Gaps

	Median LDC (Egypt)	Median LAC (Brazil)
Simulated GDP gap with respect to U.S.*	0.47	0.44
Simulated / Actual GDP gap with respect to U.S.	52%	56%
Contribution to simulated output gap:		
Individual effects		
Recovery rate (development level)	22%	29%
Entry barrier (policy regulation)	37%	31%
Complementarity	42%	40%

* Proportional output gap with respect to the U.S. $\left(\frac{Output_{US} - Output_i}{Output_{US}}\right)$ obtained from the model.

7. Concluding comments

This paper links microeconomic rigidities and technological innovation in order to provide a theory, albeit partial, of aggregate economic development. Since world knowledge expands continuously, economies that keep obstacles to innovation permanently lag the leading-edge technology, and thus, the leaders' income per capita. In particular, when government-imposed regulations or developmental barriers deter the ongoing process of resource reallocation and firm creation and destruction, then technological adoption becomes sluggish and the economy fails to generate enough growth to close the developed-developing gap. Even though all economies end up fully adopting the new technologies, poor economies are always behind.

These regulatory and developmental barriers not only exert an independent effect on technological innovation but also complement each other in this regard: policy-induced regulatory obstacles to firm dynamics limit reallocation, and the shortcomings inherent to underdevelopment, such as poor education and faulty governance, exacerbate the costs of firm renewal. That is, the effect of regulatory freedom on technological innovation is larger the higher the level of development, and vice versa.

In spite of its single focus on technological adoption and firm renewal, our model explains a substantial fraction of the per capita GDP gap between leading and less developed countries. For instance, it explains over 50% of the income per capita gap between the U.S. and the typical LDC, with 60% of this simulated gap being explained by policy and developmental barriers individually and 40% by their complementarity.

These results suggest further research on other policy issues, such as the timing of the reforms. Economic reforms have been extensively undertaken by developing economies during the last two decades. However, most reforms are implemented sequentially, so when one reform is in place other obstacles to reallocation remain. Our theory suggests that the benefits from these market reforms have been substantially reduced when distortions have not been uniformly eliminated. A corollary follows –since resource reallocation implies costly adjustment, sequentially implemented reforms may end up being reverted in developing economies.

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Appendix 1. Definitions and sources of explanatory variables

Variable	Definition and Construction	Source
Regulatory Freedom	An index ranging 0 to 10 with higher values indicating less regulated. It is a comprehensive index that captures three areas of regulatory restraints: (i) Domestic credit market; (ii) Labor market; and (iii) Business activities. Each area also has five sub-components. The area of credit market is composed of (a) Ownership of banks; (b) Competition; (c) Extension credit; (d) Avoidance of interest rate controls and regulations that lead to negative real interest rates; and (e) Interest rate controls. The measure of labor market regulations is based on (a) Impact of minimum wages; (b) Hiring and firing practices; (c) Share of labor force whose wages are set by centralized collective bargaining; (d) Unemployment Benefits; and (e) Use of conscripts to obtain military personnel. Regulation of business activities is composed of following indicators: (a) Price controls; (b) Administrative Conditions/Entry of New Business; (c) Time with government bureaucracy; (d) Starting a new business; and (e) Irregular payments. A score of 1995 by country is used.	Gwartney and Lawson (2006), The Fraser Institute. Data retrieved from www.freetheworld.com.
Governance	An index ranging 0 to 5.5 with higher values indicating better governance. It is a simple average of Law and Order (6 points), Bureaucracy Quality (4 points) and Corruption (6 points) indices. Law and Order are assessed separately, with each sub-component comprising 0 to 3 points. Assessment of Law focuses on the legal system, while Order is rated by popular observance of the law. The rating of Bureaucracy Quality is based on the strength and established mechanism of the bureaucracy to govern without drastic changes in policy and to be autonomous from political pressure. Corruption covers a wide range of forms of corruption in the political system, from bribes to excessive patronage, nepotism and secret party funding. An average of 1994-1996 by country is used.	ICRG. Data retrieved from www.icrgonline.com.
Schooling	Average schooling years in the population aged 15 and over. A score of 1995 by country is used.	Barro and Lee (2001).

Appendix II: Explaining Output Differences between the U.S. and Developing Countries

Country	Recovery Rate (s)	Entry Barrier (π)	Simulated Output Gap*	Percentage Simulated Over Actual Output Gap	Percentage Contribution To Simulated Output Gap: s	π	complementarity
Algeria	0.425	0.075	0.33	39%	38%	35%	28%
Angola	0.100	0.900	0.65	74%	5%	52%	42%
Argentina	0.350	0.075	0.34	49%	41%	30%	29%
Armenia	0.425	0.025	0.26	29%	67%	17%	16%
Azerbaijan	0.325	0.075	0.35	42%	42%	28%	29%
Bangladesh	0.250	0.175	0.44	46%	23%	38%	39%
Belarus	0.325	0.125	0.40	52%	29%	37%	35%
Belize	0.625	0.200	0.40	47%	9%	72%	20%
Benin	0.225	0.475	0.57	59%	8%	50%	41%
Bolivia	0.375	0.400	0.53	59%	8%	56%	35%
Bosnia and Herzegovina	0.350	0.150	0.41	49%	24%	41%	35%
Botswana	0.600	0.125	0.34	47%	16%	62%	22%
Brazil	0.125	0.150	0.44	56%	29%	31%	40%
Bulgaria	0.350	0.050	0.32	41%	52%	23%	24%
Burkina Faso	0.275	0.325	0.52	53%	12%	48%	40%
Cameroon	0.250	0.350	0.53	55%	11%	48%	41%
Chile	0.225	0.050	0.34	49%	56%	18%	25%
China	0.325	0.075	0.35	40%	42%	28%	29%
Colombia	0.575	0.100	0.32	39%	22%	55%	23%
Congo, Dem. Rep.	0.100	0.900	0.65	66%	5%	52%	42%
Congo, Rep.	0.200	0.350	0.53	58%	12%	46%	42%
Costa Rica	0.175	0.125	0.42	55%	33%	30%	38%
Cote d'Ivoire	0.350	0.350	0.52	54%	10%	53%	37%
Djibouti	0.150	0.500	0.58	61%	9%	48%	43%
Dominican Republic	0.100	0.150	0.44	53%	29%	30%	41%
Ecuador	0.175	0.150	0.44	52%	28%	33%	39%
Egypt, Arab Rep.	0.175	0.200	0.47	52%	22%	37%	42%
El Salvador	0.300	0.225	0.47	54%	17%	45%	39%
Ethiopia	0.325	0.150	0.42	42%	24%	40%	36%
Fiji	0.200	0.125	0.42	46%	32%	31%	37%
Gabon	0.150	0.125	0.42	61%	33%	29%	38%
Gambia, The	0.175	0.600	0.60	62%	7%	51%	42%
Georgia	0.275	0.050	0.33	37%	55%	20%	25%
Ghana	0.250	0.200	0.46	47%	20%	40%	40%
Guatemala	0.275	0.175	0.44	49%	22%	39%	38%
Guinea	0.175	0.425	0.56	57%	10%	47%	43%
Guyana	0.175	0.275	0.50	54%	16%	41%	43%
Haiti	0.100	0.625	0.61	62%	7%	49%	44%
Honduras	0.200	0.200	0.46	51%	21%	38%	41%
India	0.125	0.225	0.48	52%	20%	37%	43%
Indonesia	0.125	0.275	0.51	55%	16%	40%	44%

* Proportional output gap with respect to the U.S. $\left(\frac{Output_{US} - Output_i}{Output_{US}}\right)$ obtained from the model.

Appendix II: Explaining Output Differences between the U.S. and Developing Countries

Country	Recovery Rate (s)	Entry Barrier (π)	Simulated Output Gap*	Percentage Simulated Over Actual Output Gap	Percentage Contribution To Simulated Output Gap: s	π	complementarity
Iran, Islamic Rep.	0.200	0.050	0.35	46%	57%	18%	25%
Jamaica	0.650	0.050	0.21	26%	30%	55%	16%
Jordan	0.275	0.200	0.46	51%	20%	41%	39%
Kazakhstan	0.400	0.050	0.30	40%	50%	26%	24%
Kenya	0.325	0.175	0.43	45%	21%	42%	37%
Kyrgyz Republic	0.150	0.050	0.36	38%	58%	16%	25%
Latvia	0.350	0.025	0.28	43%	70%	14%	16%
Lebanon	0.200	0.275	0.50	65%	15%	42%	42%
Lesotho	0.375	0.175	0.43	44%	20%	45%	35%
Liberia	0.100	0.900	0.65	66%	5%	52%	42%
Lithuania	0.500	0.050	0.27	42%	45%	34%	22%
Macedonia, FYR	0.150	0.050	0.36	44%	58%	16%	25%
Malawi	0.125	0.500	0.58	59%	9%	47%	44%
Malaysia	0.375	0.100	0.36	52%	32%	36%	32%
Maldives	0.175	0.050	0.35	40%	58%	17%	25%
Mali	0.225	0.475	0.57	58%	8%	50%	41%
Mauritania	0.100	0.350	0.54	56%	13%	42%	45%
Mauritius	0.350	0.075	0.34	46%	41%	30%	29%
Mexico	0.650	0.075	0.26	37%	21%	62%	17%
Micronesia, Fed. Sts.	0.100	0.325	0.53	57%	14%	41%	45%
Moldova	0.300	0.075	0.36	38%	43%	27%	30%
Mongolia	0.175	0.050	0.35	38%	58%	17%	25%
Montenegro	0.425	0.050	0.29	40%	49%	28%	23%
Morocco	0.350	0.050	0.32	35%	52%	23%	24%
Mozambique	0.150	0.300	0.52	52%	15%	42%	44%
Namibia	0.425	0.150	0.40	46%	21%	46%	32%
Nepal	0.250	0.225	0.47	48%	18%	42%	40%
Nicaragua	0.350	0.350	0.52	55%	10%	53%	37%
Niger	0.150	0.800	0.64	65%	6%	53%	42%
Nigeria	0.275	0.200	0.46	48%	20%	41%	39%
Pakistan	0.400	0.100	0.36	38%	31%	38%	31%
Panama	0.325	0.100	0.37	50%	34%	33%	33%
Papua New Guinea	0.225	0.125	0.41	43%	31%	32%	37%
Paraguay	0.150	0.375	0.54	60%	12%	45%	44%
Peru	0.250	0.150	0.43	51%	26%	36%	38%
Philippines	0.100	0.125	0.43	46%	34%	27%	39%
Poland	0.275	0.100	0.38	60%	36%	30%	34%
Romania	0.200	0.025	0.32	43%	74%	10%	16%
Russian Federation	0.275	0.050	0.33	49%	55%	20%	25%
Samoa	0.150	0.150	0.44	49%	28%	32%	40%
Senegal	0.325	0.325	0.51	53%	11%	51%	38%
Serbia	0.225	0.050	0.34	43%	56%	18%	25%
Sierra Leone	0.100	0.900	0.65	66%	5%	52%	42%

* Proportional output gap with respect to the U.S. $\left(\frac{Output_{US} - Output_i}{Output_{US}}\right)$ obtained from the model.

Appendix II: Explaining Output Differences between the U.S. and Developing Countries

Country	Recovery Rate (s)	Entry Barrier (π)	Simulated Output Gap*	Percentage Simulated Over Actual Output Gap	Percentage Contribution To Simulated Output Gap: s	π	complementarity
Solomon Islands	0.225	0.250	0.49	52%	16%	42%	41%
South Africa	0.350	0.050	0.32	40%	52%	23%	24%
Sri Lanka	0.500	0.075	0.31	34%	34%	41%	25%
St. Lucia	0.425	0.100	0.35	45%	30%	40%	30%
Suriname	0.100	0.675	0.62	73%	7%	50%	44%
Swaziland	0.375	0.175	0.43	48%	20%	45%	35%
Syrian Arab Republic	0.300	0.100	0.38	42%	35%	32%	33%
Tajikistan	0.225	0.250	0.49	51%	16%	42%	41%
Tanzania	0.225	0.250	0.49	50%	16%	42%	41%
Thailand	0.425	0.050	0.29	36%	49%	28%	23%
Togo	0.275	0.575	0.59	60%	7%	55%	39%
Tonga	0.250	0.075	0.37	40%	45%	25%	31%
Tunisia	0.500	0.050	0.27	32%	45%	34%	22%
Turkey	0.175	0.100	0.40	56%	38%	26%	35%
Uganda	0.400	0.275	0.48	49%	12%	53%	35%
Ukraine	0.100	0.050	0.37	43%	59%	15%	26%
Uruguay	0.425	0.175	0.42	56%	18%	49%	33%
Uzbekistan	0.175	0.075	0.38	40%	46%	22%	31%
Vanuatu	0.400	0.200	0.44	48%	17%	49%	34%
Venezuela, RB	0.100	0.175	0.46	63%	26%	32%	42%
Vietnam	0.175	0.125	0.42	44%	33%	30%	38%
Yemen, Rep.	0.275	0.525	0.58	61%	7%	54%	39%
Zambia	0.250	0.125	0.41	42%	31%	33%	36%
Sample Median	0.250	0.150	0.43	49%	24%	39%	37%
Typical LDC (Egypt)	0.175	0.200	0.47	52%	22%	37%	42%
Typical LAC (Brazil)	0.125	0.150	0.44	56%	29%	31%	40%

* Proportional output gap with respect to the U.S. $\left(\frac{Output_{US} - Output_i}{Output_{US}}\right)$ obtained from the model.