When Does Domestic Saving Matter for Economic Growth?*

Philippe Aghion
Harvard University

Diego Comin
Harvard Business School

Peter Howitt
Brown University

Isabel Tecu
Brown University

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Abstract

Can a country grow faster by saving more? We address this question both theoretically and empirically. In our theoretical model, growth results from innovations that allow local sectors to catch up with frontier technology. In poor countries, catching up requires the cooperation of a foreign investor who is familiar with the frontier technology and a domestic entrepreneur who is familiar with local conditions. In such a country, domestic saving matters for innovation, and therefore growth, because it enables the local entrepreneur to put equity into this cooperative venture, which mitigates an agency problem that would otherwise deter the foreign investor from participating. In rich countries, domestic entrepreneurs are already familiar with frontier technology and therefore do not need to attract foreign investment to innovate, so domestic saving does not matter for growth. A cross-country regression shows that lagged savings is positively associated with productivity growth in poor countries but not in rich countries. The same result is found when the regression is run on data generated by a calibrated version of our theoretical model.

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1 Introduction

All long-run growth theories imply that a country can grow faster by investing more, in human or physical capital or in R&D, but that a country with international capital markets cannot grow faster by saving more - domestic saving is not an important ingredient in the growth process because investment can be financed by foreign saving. Thus the positive cross-country correlation between saving and growth that many commentators have noted[1] appears rather puzzling from the point of view of standard growth theory. Some writers have sought to explain the correlation as reflecting an effect of growth on saving. But this interpretation runs counter to mainstream economic theory in which, in response to expected growth, consumers raise their consumption and reduce savings,[2] hence the *negative* effect of growth on saving.[3]

That growth should be affected by domestic saving is suggested by the contrast between the high growth since 1960 in East Asia and the slow growth in Latin America, two middle-income regions with comparable levels of per capita GDP in the 1960s. This contrast could hardly be explained by differences in property right protection or in financial development. Moreover, most Latin American countries have subscribed to the so-called Washington consensus policies (namely, the idea of combining macroeconomic stability, trade and financial liberalization, and privatization), but so far to little avail. On the other hand, saving rates in East Asia have been much higher than in Latin America. Specifically, for the East Asian countries the average private saving rate from 1960 to 2000 was 25%, whereas for the Latin American countries it was only 14%.[4]

In this paper, we develop a theory of endogenous local saving and growth in an open economy with domestic and foreign investors. In our model, growth in relatively poor countries results mainly from innovations that allow local sectors to catch up with the current frontier technology. But catching up with the frontier in any sector requires the cooperation

[1] Houthakker (1961, 1965), Modigliani (1970) and Carroll and Weil (1994)

[2] See, for example, Tobin (1967) and Summers (1981).

[3] Thus for example Carroll, Overland and Weil (2000) depart from convention by developing a model of habit persistence which they argue is consistent with a wide body of evidence to the effect that increases in growth precede increases in saving. We have analyzed this alternative explanation in the working paper version.

[4] One exception in terms of growth performance in Latin America has been Chile. The average growth rate of GDP per worker in Chile between 1960 and 2000 has been almost 2 percent a year. Interestingly, its average saving rate has been 20 percent. See Prescott (2006) for more on the role of savings in the positive growth experience of Chile.

of a foreign investor who is familiar with the frontier technology and a domestic entrepreneur who is familiar with the local conditions to which the technology must be adapted. In such a country, domestic saving matters for technology adoption, and therefore growth, because it allows the local entrepreneur to take an equity stake in this cooperative venture, which mitigates an agency problem that would otherwise discourage the foreign investor from participating.

The theory also delivers predictions on when domestic saving should matter most for economic growth. In particular it focuses on the interaction between saving and the country's distance to the technological frontier. The main prediction of our model is that saving affects growth positively in those countries that are not too close to the technological frontier, but does not affect it at all in countries that are close to the frontier. The reason is that in a relatively poor country higher saving increases the number of projects that can be cofinanced by the local entrepreneur on terms that mitigate agency problems enough to make it worthwhile for a foreign investor to participate. However, in countries sufficiently close to the frontier the local firms are more likely themselves to be familiar with the frontier technology, and therefore do not need to attract foreign investment in order to undertake an innovation project; in such a case every ex ante profitable innovation project will be undertaken regardless of the level of domestic saving because there is no need for cofinancing when there is just one agent participating in a project.

We then confront the theory with the empirical evidence. First, in a cross-country panel regression, we find a large and significant positive coefficient of lagged saving on future growth in poor countries but not in rich. We also observe that, as predicted by the theory, the effect works not through capital accumulation but through TFP, and that the effect is not found if we divide countries according to their level of financial development instead of level of output per worker.

Because cross-country regressions are notorious for problem such as omitted variables, endogeneity, etc., we use these regression results not so much as a demonstration of our theory but as a benchmark for the quantitative evaluation of the model. We calibrate the non-standard parameters that govern the adoption process by requiring the model to match some cross-country adoption and growth patterns from the data. The policy functions and the associated transitional dynamics imply that the effects of savings on growth are quantitatively important. For a country with initial productivity half of the US level, moving from a saving subsidy of -100% to one of 100% raises the average growth rate from 0.77% to 4.17%.

To explore further the quantitative implications of the model, we estimate the reduced form relationship between saving and growth using data generated by the model in a Monte

Carlo exercise. We find that an increase in the average saving rate of 10 percentage points over the past ten years is associated with an increase in the average growth rate in output per worker of between 0.5 and 1.3 percentage points over the next ten years. This effect is only found for countries that are relatively far from the technology frontier.

Our theory shares some features of Dooley, Folkerts-Landau and Garber (2004), who stress the role of collateral, which is analytically equivalent to cofinancing, in the growth process of some countries. Specifically, they argue that capital flows from poor to rich countries may partly reflect poor countries' choices to transfer wealth to a "center or reserve currency country" in order to make it easier for foreigners to get their hands on that wealth should the poor countries expropriate the foreigners' capital; this in turn should encourage foreign direct investment in poor countries, thereby fostering development. However, Dooley et al. do not explore this idea in the context of a full-fledged endogenous growth model. Nor do they analyze its implications for the relationship between local saving and growth across countries with different levels of technological development.

The theory relates not only to the growth literature but also to an important debate in international finance around the so-called "Lucas puzzle", namely why poorer countries or regions, where capital is scarce and therefore the marginal productivity of capital should be high, do not attract investments that would make them converge towards the frontier countries or regions. Lucas (1990) points to the role of human capital externalities that would favor capital investments in richer countries. However, Gertler and Rogoff (1990), and more recently Banerjee and Duflo (2005), point to the importance of contractual imperfections (whether these result from local contractual enforcement problems or from ex ante moral hazard on the part on local investors). Gertler and Rogoff provide supporting evidence in favor of the contracting explanation, in particular the positive and significant correlation between the volume of private external debt and the log of per capita income in a cross-country regression. More recent evidence in Alfaro et al (2008) to the effect that private lending by foreign investors is correlated with various institutional indicators, in particular with a lower degree of corruption, is consistent with the contracting explanation, as is the evidence in Reinhart and Rogoff (2004) that poorer countries exhibit a higher rate of defaults on their foreign debt. The relationship between financial constraints and foreign investment flows is also emphasized in recent work by Antras, Desai and Foley (2009) that explains why we observe large and two-way FDI flows between countries with high levels of development, whereas capital flows between countries with uneven degrees of financial development are small and unbalanced. Also closely related to our analysis in this paper is Alfaro et al (2004) which shows, based on a cross-country sample, that FDI is more positively correlated with growth in countries with higher financial development. Our paper contributes to this literature by developing an endogenous growth model that shows how local saving impacts on foreign investment and thereby on growth in an economy with contractual frictions, and by confronting the predictions of this model with cross-country panel data.

Section 2 below develops our theoretical model. Section 3 shows the regression results on actual cross-country data. Section 4 discusses the calibration of our model and evaluates its quantitative significance. Section 5 concludes.

2 Theoretical model

2.1 Basic environment

We consider a discrete-time model of a small open economy, populated by two-period lived individuals. There is a constant population, which we normalize to equal 2. Individuals work and save when young to invest in innovation and consume when old. For the sake of clarity, we consider first an environment with an exogenous saving rate which we endogenize later in section 2.6.

There is a unique final good, which is produced under perfect competition using labor and a continuum of intermediate inputs, according to the production function:

$$y_t = L^{1-\alpha} \int_0^1 A_{it}^{1-\alpha} x_{it}^{\alpha} di,$$

where A_{it} is the productivity of input i at time t and L is the supply of labor. In equilibrium each young person supplies one unit of labor inelastically, so $L = 1$.

Intermediate goods are produced by local monopolists, using the final good as capital, with one unit of capital producing one unit of intermediate input. The amount of intermediate input x_{it} is chosen by producer i to maximize monopoly profits

$$p_{it} x_{it} - x_{it}$$

subject to the inverse demand schedule

$$p_{it} = \frac{\partial y_t}{\partial x_{it}} = \alpha (A_{it}/x_{it})^{1-\alpha},$$

where the numeraire is the final good. This yields

$$x_{it} = A_{it} (\alpha^2)^{\frac{1}{1-\alpha}} \equiv A_{it} \kappa,$$

with equilibrium profits equal to

$$\pi_{it} = \alpha(1-\alpha)\kappa^{\alpha} A_{it} \equiv \pi A_{it}.$$

Perfect competition in the labor market yields an equilibrium wage:

$$w_t = (1-\alpha)\,\kappa^{\alpha} A_t = \omega A_t.$$

where $A_t = \int_0^1 A_{it} di$ is average productivity.[5]

2.2 Growth and innovations

Productivity grows as a result of random innovations that allow the monopolists to access a global technology frontier. In each sector at each date there is one local entrepreneur capable of innovating. If she innovates then she will become the monopolist in that sector during that period, and her productivity will be given by the frontier productivity parameter $\overline{A}_t$ which grows exogenously at the constant rate $\overline{g}$:

$$\overline{A}_t = (1+\overline{g})\,\overline{A}_{t-1}$$

In order to innovate, the entrepreneur must first undertake a project. If she does, an innovation will occur with probability $\overline{\mu}$ if she spends effort and with probability $\underline{\mu}$ if she does not spend effort. In equilibrium she will always spend effort, as we shall see below. Thus productivity in any sector i where the entrepreneur has undertaken a project will be

$$A_{it} = \begin{cases} \overline{A}_t \text{ with probability } \overline{\mu} \\ A_{it-1} \text{ with probability } 1-\overline{\mu} \end{cases}$$

In sectors that do not undertake a project, $A_{it} = A_{it-1}$ with probability 1.

Suppose that a project is undertaken in a fraction λ_t of sectors, independently of the sector's lagged productivity A_{it-1}. (We endogenize λ_t below.) Integrating over i to compute average productivity, we see that it evolves according to:

$$A_t = \lambda_t \overline{\mu}\overline{A}_t + (1-\lambda_t\overline{\mu})A_{t-1}.$$

[5] Substituting from the above expression for x_{it} back into the aggregate production function shows that per-capita GDP is strictly proportional to productivity:

$$y_t = \kappa^{\alpha} A_t.$$

That is, the fraction $\overline{\mu}$ of the fraction λ_t of sectors that undertake a project will innovate, moving up to the frontier $\overline{A}_t$, while the remaining fraction will remain where they were, which on average, by the law of large numbers, is last period's economy-wide average productivity A_{t-1}.

Dividing the above difference equation through by $\overline{A}_t$, we obtain a difference equation in the country's proximity to the frontier $a_t = A_t/\overline{A}_t$

$$a_t = \lambda_t \overline{\mu} + \frac{1 - \lambda_t \overline{\mu}}{1 + \overline{g}} a_{t-1} \tag{1}$$

The country's productivity growth rate is

$$g_t = \frac{A_t}{A_{t-1}} - 1 = \frac{a_t (1 + \overline{g})}{a_{t-1}} - 1$$

Therefore

$$g_t = (\frac{1 + \overline{g}}{a_{t-1}} - 1)\overline{\mu}\lambda_t. \tag{G}$$

According to the growth equation (G), the country's growth rate is decreasing in proximity to the frontier and increasing in the fraction λ_t of sectors that undertake a project. If λ_t were constant then according to (1) proximity would converge to a steady-state value $a^* = \frac{\lambda\overline{\mu}(1+\overline{g})}{\lambda\overline{\mu}+\overline{g}}$ which is increasing in λ; provided that $\lambda > 0$, the country's growth rate would therefore converge to the world growth rate $\overline{g}$. The rest of our theoretical analysis will be devoted to endogenizing λ_t, showing in particular how it relates to the country's saving rate, and our empirical analysis explicitly recognizes that λ_t is a function of the saving rate.

2.3 Innovation technology

As in Howitt and Mayer-Foulkes (2005), we assume that local firms can access the frontier technology on their own, although at a cost which increases with the distance between the local and the frontier productivities. In addition, we introduce the possibility that local entrepreneurs might turn to a foreign investor who has mastered the frontier technology in order to access that technology at a potentially lower cost. Both accumulated savings and the country's distance to the technological frontier will affect the feasibility or the attractiveness of this latter type of arrangement relative to the former innovation technology.

Consider the entrepreneur in some sector. If she undertakes a project and successfully innovates then she will become the local monopolist, and according to the results of section

2.1 above she will receive a monopoly profit equal to

$$\pi_t = \pi \overline{A}_t$$

The total cost of a project is the entrepreneur's effort cost, which only she can incur, plus an "investment cost," which can be shared with anyone. The effort cost is

$$c\overline{A}_t$$

where c is a random variable, independent across time and sectors, distributed uniformly on the interval $[0, \bar{c}]$. The entrepreneur can avoid this cost by choosing not to spend effort, a choice that cannot be observed by anyone else.

The investment cost depends on whether the entrepreneur undertakes the project with or without a foreign investor. Specifically, if she partners with a foreign investor the cost is

$$\phi\overline{A}_t$$

whereas if she undertakes the project alone the cost will depend on proximity to the frontier, according to

$$\phi_0 (a_{t-1}) \overline{A}_t$$

The dependence on lagged proximity is motivated by the idea that entrepreneurs that grew up near the frontier will be more familiar with frontier technology and thus will have a lower cost of innovating alone.[6]

Assume for concreteness that:

$$\phi_0 = \overline{\phi}_0 / a_{t-1} \text{ and } \overline{\phi}_0 < \phi$$

The second part of this assumption guarantees that no one can innovate at less cost than someone going alone in a country where all sectors were on the frontier last period ($a_{t-1} = 1$).

A project is "worthwhile" if the expected monopoly profit $\mu\pi$ that it generates is at least equal to the effort cost plus the investment cost. We make the following assumptions.

Without effort no project is worthwhile

$$\underline{\mu}\pi < \overline{\phi}_0 \tag{A1}$$

[6] This assumption captures the lower stock of knowledge of entrepreneurs in countries that are farther from the frontier. This stock could be cumulated either by adopting new technologies or by producing using them. In both cases the stock of knowledge would be proportional to A_t.

With effort, some joint project is strictly worthwhile

$$\overline{\mu}\pi > \phi \tag{A2}$$

Not all projects are worthwhile

$$\overline{\mu}\pi < \overline{\phi}_0 + \overline{c} \tag{A3}$$

2.4 The contract in a joint project

If an entrepreneur E partners with a foreign investor F, they will agree to a contract (x, y) where x is the amount that F contributes to the investment cost and y is the amount of monopoly profit that F will receive if the project is successful (that is, if it results in an innovation). Thus E will contribute $\phi - x$ to the investment cost and will receive $\pi - y$ if the project is successful.

Let σ be the fraction of wage income that E saved when young. Assume that all the expected surplus of a joint venture goes to E. (This assumption does not affect the existence of a mutually agreeable contract.) Then she can profitably undertake a project with F if and only if there exists a contract that satisfies the following four constraints:

1. Joint participation constraint

$$c \leq \overline{\mu}\pi - \phi$$

2. Foreign participation constraint

$$\overline{\mu}y = x$$

3. Incentive compatibility constraint

$$c \leq \left(\overline{\mu} - \underline{\mu}\right)(\pi - y)$$

4. Entrepreneurial equity constraint

$$\phi - x \leq \frac{1 + r}{1 + \overline{g}}\sigma\omega a_{t-1}$$

The joint participation constraint just states that the project must be worthwhile. The foreign participation constraint states that F must break even in expected value. The incentive compatibility constraint states that E must receive at least as much expected payoff if she spends effort as if she doesn't (because assumption A1 guarantees that the project will not be worthwhile otherwise). The entrepreneurial equity constraint states that E's contribution cannot exceed her net worth[7] (both normalized by $\overline{A}_t$).

2.5 Fraction of sectors that undertake a project

Define the "public surplus" of a joint project as

$$v = \overline{\mu}\pi - \phi > 0$$

(the inequality follows from assumption A2) and the public surplus of a solo project as:

$$v_0 \left(a_{t-1}\right) = \overline{\mu}\pi - \overline{\phi}_0 / a_{t-1}$$

Let δ denote the proportional effect of effort on the probability of success:

$$\delta = \frac{\overline{\mu} - \underline{\mu}}{\overline{\mu}}$$

and let s denote the productivity-adjusted saving of an entrepreneur:

$$s = \frac{1+r}{1+\overline{g}}\sigma\omega \tag{2}$$

A project can be undertaken profitably without a foreign investor in any sector where the effort cost is less than the public surplus:

$$c \leq v_0 \left(a_{t-1}\right) \tag{3}$$

Likewise, Appendix A shows that, according to the analysis of section 2.4, a project can be undertaken profitably with a foreign investor in any sector where:

$$c \leq v \text{ and } c \leq \delta \left(v + s a_{t-1}\right) \tag{4}$$

The first part of (4) requires the effort cost to be small enough to make the project worthwhile, and the second part requires saving to be large enough relative to the effort cost so that the incentive compatibility constraint can be satisfied. The fraction λ_t of sectors in which a project is undertaken is the fraction in which the effort cost satisfies either (3) or (4).

[7] Recall that her wage income was $w_{t-1} = \omega a_{t-1} \overline{A}_t / \left(1+\overline{g}\right)$, of which she saved the fraction σ, which grew by the interest factor $1+r$.

Since $\phi > \overline{\phi}_0$, therefore $v_0(1) > v$. By construction $v_0(0) = -\infty$. Since v_0 is an increasing function, it follows that there is a critical proximity $\overline{a} \in (0,1)$ that determines whether or not an entrepreneur would prefer to partner with a foreign investor:

$$v_0(a) \gtreqless v \text{ as } a \gtreqless \overline{a}$$

Assume that whenever an entrepreneur would prefer to take on a foreign partner, incentive compatibility is the binding constraint in the condition (4) that determines whether this can be done:

$$v \geq \delta(v + sa) \text{ for all } a \text{ such that } v \geq v_0(a) \tag{5}$$

Then, as Figure 1 shows, there is another critical proximity $\widehat{a} \in (0, \overline{a})$ where:

$$\delta(v + s\widehat{a}) = v_0(\widehat{a})$$

There are two cases to consider

1. Whenever $a_{t-1} \leq \widehat{a}$ an entrepreneur would prefer to partner with a foreign investor (since $\widehat{a} \leq \overline{a}$), and will do so whenever her effort cost is low enough to satisfy the incentive compatibility constraint. But if the effort cost is too high to satisfy the incentive compatibility constraint then it will also be too high for a project without a foreign investor to be worthwhile, since as Figure 1 makes clear, $v_0(a_{t-1}) \leq \delta(v + sa_{t-1})$ in this case. So in this case λ_t will be the fraction of sectors in which $c \leq \delta(v + sa_{t-1})$

2. Whenever $\widehat{a} \leq a_{t-1}$ then λ_t will be the fraction of sectors in which $c \leq v_0(a_{t-1})$ because if this inequality holds then a project without a foreign investor can be undertaken profitably whereas if it does not hold then not only is a project without a foreign investor not profitable but also

   (a) if $a_{t-1} \leq \overline{a}$ then a project with a foreign investor is not incentive compatible, since $\delta(v + sa_{t-1}) \leq v_0(a_{t-1})$ in this case (see Figure 1), or

   (b) if $\overline{a} \leq a_{t-1}$ then a project with a foreign investor is not profitable since $v \leq v_0(a_{t-1})$ in this case.

It follows that λ_t is given by the function:

$$\lambda_t = \widetilde{\lambda}(s, a_{t-1}) = \left\{ \begin{array}{cc} \delta(v + sa_{t-1})/\overline{c} & \text{for } a_{t-1} \leq \widehat{a} \\ v_0(a_{t-1})/\overline{c} & \text{for } \widehat{a} \leq a_{t-1} \end{array} \right\} \tag{6}$$

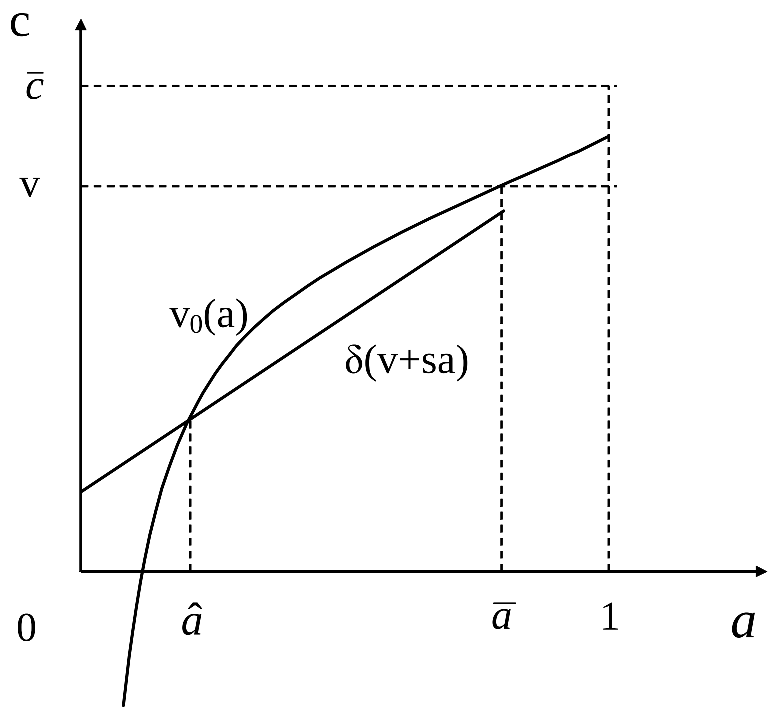

Figure 1: Saving affects innovation below $\widehat{a}$ but not above

Since the incentive-compatibility constraint that determines whether a project will be undertaken below $\widehat{a}$ depends on saving but the profitability constraint that matters above $\widehat{a}$ does not, we have:

Proposition 1 *There is a critical proximity* $\widehat{a} \in (0, 1)$ *such that*

$$\frac{\partial \widetilde{\lambda}}{\partial s} \left\{ \begin{array}{ll} > 0 & \textit{if } a < \widehat{a} \\ = 0 & \textit{if } a > \widehat{a} \end{array} \right\}$$

2.6 Growth and saving

By substituting the equilibrium fraction $\widetilde{\lambda}$ of equation (6) into the growth equation (G) we get the equilibrium growth rate

$$g_t = (\frac{1 + \overline{g}}{a_{t-1}} - 1)\overline{\mu}\widetilde{\lambda}(s_{t-1}, a_{t-1}). \tag{7}$$

where we have put the time subscript on s to indicate that it is last period's saving that matters. Below we estimate this equation both with actual and simulated data. Applying Proposition 1 to equation (7) we see that growth is affected positively by saving below the critical proximity $\widehat{a}$ but not above.

Any interpretation of the empirical growth-saving relationship must allow for the possibility of reverse causation - that saving is endogenous to the growth process. In section 4 below where we calibrate and simulate the model, we endogenize saving by supposing that every individual at time $t-1$ maximizes a Kreps-Porteus intertemporal utility function with an elasticity of intertemporal substitution equal to unity and a coefficient of relative risk aversion equal to zero:

$$u = \ln(C_1) + \frac{1}{1+\rho}\ln\left(E\left(C_2 - ce\overline{A}_t\right)\right)$$

where $\rho > 0$ is the constant rate of time preference, C_1 and C_2 are consumption when young and old, E is the expectations operator and $e \in \{0,1\}$ is entrepreneurial effort.

The individual's saving when young is

$$S = (1+\tau)(w_{t-1} - C_1). \tag{8}$$

where τ is a subsidy to saving, which we introduce in order to have an exogenous source of variation in saving rates. The second period budget constraint is

$$C_2 + T = S(1+r) + R$$

where R is the individual's rent from an innovation project and T is a lump sum tax used to finance the saving subsidy. We assume that the tax-subsidy scheme does not affect a young individual's net worth. Thus

$$T = (1+r)\tau(w_{t-1} - C_1). \tag{9}$$

The individual takes as given both the lump sum tax T and the subsidy rate τ.

The individual's lifetime utility maximization problem would be completely routine except for the fact that the rent R as well as the effort cost $ce\overline{A}_t$ are both random variables whose distribution will be affected by the choice of C_1, since, as we have seen, the prospect of attracting a foreign investor if she becomes an entrepreneur when old will depend on her saving rate:

$$s_{t-1} = \frac{(1+r)(w_{t-1} - C_1)}{(1+\overline{g})A_{t-1}\kappa^{\alpha}} \tag{10}$$

which is also the saving variable that enters into the growth equation (7). To simplify the analysis we assume that each individual will become an entrepreneur with probability one, but that she does not learn her effort cost c until she is old.

Under those assumptions, we show in Appendix B that the young person's expectation of rent net of effort cost when old equals

$$E\left(R - ce\overline{A}_t\right) = \overline{A}_t\widetilde{z}\left(s_{t-1}, a_{t-1}\right)$$

and that her consumption when young will equal

$$C_1 = \beta\left(w_{t-1} + \frac{1}{1+r}\overline{A}_t\widetilde{z}\left(s_{t-1}, a_{t-1}\right)\right) \tag{11}$$

where the function $\widetilde{z}$ is increasing in both arguments,[8] and the propensity to consume out of wealth when young is

$$\beta = \frac{1+\rho}{2+\rho+a_{t-1}^{-1}\partial\widetilde{z}/\partial s_{t-1}+\tau}.$$

3 Cross-country regressions

We now explore whether the relationship between savings and growth is consistent with the main prediction of our model, namely that saving is more strongly associated with growth for countries with lower productivity.[9] Our exploration is based on a cross-country non-overlapping panel over the period from 1960 to 2000. We use a sample of 118 countries, all those for which there exist data on per-worker GDP and on the saving rate. Data on income per worker and saving come from the Penn World Tables 6.1.

Just to be clear, the cross-country regressions are not meant to be a proof of the mechanisms presented in the model.[10] Its purposes are more modest. First, we intend to see if there is any empirical evidence on the reduced form relationships predicted by the model between savings and growth. More importantly, the estimates from these regressions constitute a benchmark used later on in the quantitative evaluation of contending theories that imply a relationship between savings and growth.

To explore in the data the main empirical implication of our model, we classify countries each year in two groups depending on whether the log-income gap with the highest income per capita country is above or below a relative productivity threshold. Based on a regression tree analysis described below, we set this threshold at 70% of the US labor productivity level. Since our theory probably is not suited to explain why extremely poor countries do not grow, we eliminate the poorest 25% of the country-decade observations (which correspond

[8] Appendix B derives a closed-form solution for $\widetilde{z}$.

[9] See Aghion et al. (2006) for a more comprehensive exploration of this hypothesis.

[10] We are perfectly aware of all the potential problems that reduce form regressions have and will expand on that below.

to a relative productivity level below 9% of the US level). As a result, we are left with two samples: the sample of poor countries (i.e. those with productivity between 9% and 70% of the US level) and the rich countries (i.e. those with productivity of at least 70% of the US).

3.1 Econometric specification

The baseline specification used to investigate the relationship between savings and growth -regression (12) below- follows closely equation (7) in our model. In this specification, the dependent variable is a measure of growth of productivity between year t and year $t+10$. We experiment both with the growth rate of income per worker and the growth rate of total factor productivity (TFP). We choose a difference of ten years because the mechanism embedded in our model is more relevant in the medium term than in the very short term.

$$\ln(y_{it+10}/y_{it})/10 = \alpha_0 + \alpha_1 \ \ln y_{it} + \beta \bar{s}_{it,t-9} + \epsilon_{it}. \tag{12}$$

The independent variable of interest is the average saving rate in the ten-year period between $t-10$ and t denoted by $\bar{s}_{it,t-9}$. The saving rate variable, which includes public as well as private saving, is defined as one minus the ratio of private consumption to GDP minus the ratio of government purchases to GDP.[11]

Using a ten-year average of savings instead of the annual saving rate at t serves three purposes. First, it reduces the measurement error present in annual data. Second, it better captures the notion that collateral is a stock not a flow. Third, by using lagged measures of the independent variable we reduce the possibility of reverse causality. Of course, the ideal empirical counterpart to the saving rate in the model would be some measure of collateralizable domestic assets. Unfortunately, this variable is unavailable for a panel such as ours and we have to use a noisy proxy such as the average saving rate for the last ten years.

In our regressions, we follow the convergence literature (and equation (7)) and allow for the initial log-level of income per worker ($\ln y_{it}$) to have an effect on the subsequent growth rate.

Our empirical strategy consists in estimating regression (12) for three samples, the sample of all countries, the sample of poor countries and the sample of rich countries. Therefore, the speed of convergence may in principle differ by productivity group.

[11] If the economy were in a steady state, this would correspond to $\bar{g}s_{t-1}/\kappa^{\alpha}$, where s_{t-1} is the argument of the theoretical growth equation (7).

3.2 Lagged savings and productivity growth

The first three columns in Table 1 report the OLS estimates from (12) in our three samples when the dependent variable is the growth rate of labor productivity. Column 1 covers all the country-years; column 2 restricts the sample to country-year pairs below 70% of US productivity, that is, poor countries, while column 3 restricts the sample to rich countries. In the full sample we observe some very slow convergence in income per worker. As predicted by our model, we find a significantly positive association between savings and productivity growth in the ten years going forward. A more interesting prediction of our model is that the effect of savings on growth should be larger for countries far from the technology frontier than for countries close to the frontier. This prediction is borne by the data. Comparing the coefficients of savings in columns 2 and 3 we can observe how for poor countries the coefficient of savings in the growth regression is 4.6% while for rich countries it is -4.7%. The association between lagged average savings and productivity growth for poor countries is statistically significant while for rich countries the t-statistic is just 1.07. The difference in the coefficient of savings between the two samples is statistically significant at the 5 percent level. The estimated effect of lagged savings on growth in poor countries is quantitatively important; an increase in the average saving rate between $t-9$ and t of 10 percentage points is associated with an increase in the average growth rate in output per worker of 4.6 tenths of one percentage point over the next ten years.

Columns 4 through 6 show the robustness of the larger effect of savings on growth for poor than for rich countries to using TFP growth as dependent variable. In this case, the coefficient of savings on growth for poor countries is 4.0% while for the rich countries it is -7.5% , a quantitatively important if not statistically significant difference. By contrast, columns 7 through 9 show that there is no significant effect of saving on capital accumulation in the whole sample or in either subsample. These findings are consistent with models such as ours that emphasize the effect of saving on technology adoption. In addition, they help distinguish our theory from those based on the effect of saving on investment through a financial multiplier a la Bernanke and Gertler (1989).

It is important to note that this differential effect between rich and poor countries is the opposite of what we would have expected to have resulted if measurement error was a major issue, given that the quality of data in the Penn World Tables is generally lower for poor countries than rich. In particular, higher measurement error in saving rates probably caused more attenuation of its estimated effect in poor countries than rich.

A related issue may arise if the savings rates are measured with more error than per capita income levels. Since lagged savings is likely to be correlated with income at t, part of the effect of savings on growth may be captured by income. Since income should enter negatively due to convergence and savings positively, this bias will result in lower estimates of the effect of savings and higher estimates of the effect of income. (i.e. the estimated coefficient on both income and savings will be biased towards 0). This bias, however, cannot explain our findings that lagged savings seems to have a stronger effect on growth for poor countries.

3.3 Robustness checks

The empirical finding uncovered with the simple cross-country regressions is the larger coefficient of lagged savings on growth in poor than in rich countries. This appears to be a robust finding. Table 2 shows that it also holds when using time trends or year dummies in the estimating equation, and when including country fixed effects. Table 3 shows that it is robust to using other cutoffs to divide the sample between poor and rich countries. We also find that the regression results are robust to dropping outliers; i.e., observations more than 2 standard deviations from the regression line.

An alternative interpretation of our results is that income per capita is a proxy for financial development. According to this interpretation, financial development is needed to attract foreign investment, so in less financially developed countries the investments underlying economic growth must be financed with domestic saving -[12] thus saving has an effect in poor countries only because per-capita income and financial development are positively correlated. To test this alternative interpretation, we split the sample not by labor productivity but by financial development, measured by the ratio of private credit to GDP. Our regression tree analysis then suggested splitting the sample at the 87th percentile of financial development. As columns 1 through 3 of Table 4 indicate, this resulted in an estimated saving coefficient that was almost the same across the two samples, in contradiction to the alternative hypothesis. Columns 4 through 6 verify that including country fixed effects does not rescue the financial development hypothesis.

Comin and Nanda (2009) provide even more direct evidence against a differential role of financial development in the adoption of technologies in poor countries. They find that financial development accelerates more the speed of diffusion of technologies for countries that are closer to the technology frontier than for countries that are far from the frontier. In contrast, in Aghion et al. (2006), we find that the effect of savings on growth that works through FDI and through the import of "high tech" manufacturing goods is significantly larger for countries that are far from the frontier.[13]

[12] Note that, since the effect of lagged savings on growth works through TFP growth and not through capital accumulation savings must be relevant because it helps adopting technologies.

[13] Obviously, our goal is not to explain cross-country FDI flows since there are many other determinants in

3.4 Relation to the literature

The positive relationship that we have documented between lagged savings and subsequent growth may seem at odds with some results in the literature. For example, Caroll and Weil (1994), CW henceforth, use a specification that is closest to ours and estimate the effect of lagged savings on growth to be negative. Next, we explore the reasons for this apparent discrepancy with the literature. For concreteness, we initially focus on CW and later expose reasons why our results may also differ from other significant papers in the literature.

Our specification differs from CW in a number of dimensions but, as we show next, the key one is that they do not control for initial income. To illustrate this, Table 5 moves from our specification to CW's step by step. In column 1 of Table 5, we start with the full sample and the 10-year intervals that we use in Table 1. One difference between our regressions and CW's is that they have fewer sample years and use five- rather than ten-year time intervals. In column 2 we restrict the time period to 1953-1993, and in column 3 we further change to 5-year intervals, in order to align our sample years to CW's. The coefficient in lagged savings remains almost constant, however. Thus the fact that we find a positive significant effect of lagged savings on growth is not driven by our time period or horizon.

CW also use fewer countries than we do, because at that time less data was available, and because they exclude very small, communist, and oil-dominated countries. We therefore restrict our sample in column 4 to approximate the countries used by CW, and the coefficient on savings in fact increases. The larger sample per se does not drive our findings.

Column 5 shows that our results are robust to country fixed effects, which CW include in their main specification. While maintaining country fixed effects for the subsequent columns, we add lagged growth as an additional control variable in column 6. Lagged growth seems more or less uncorrelated with lagged savings, holding initial income fixed. Only if we do not control for initial income does the effect of lagged savings drop to zero (column 7). The fact that we control for initial income therefore explains why we find a positive effect of lagged savings and growth while CW find the opposite.

Column 8 assimilates CW's estimation even further by using data from version 5 of the Penn World tables. This change results in a negative and significant coefficient on the savings variable, just as CW found.

Even if we adopt a specification which controls for lagged growth rather than initial income, as CW do, the effect of savings on growth is still more positive in poor countries than in rich. Suggestive evidence for this is already contained in Carroll and Weil's paper, where the effect of savings on growth is more negative for OECD countries only. In Table

addition to domestic private savings. The evidence from Aghion et al. suggests that FDI to rich conuntries carries a much lower transfer of technology than FDI to developing countries.

6, we show that the difference between poor and rich is also visible for our definition of rich countries. This table repeats the regression in column 6 of Table % separately for poor and rich countries. The coefficient on savings in the poor sample is about .04 and statistically significant, while in the rich sample it is -.003 and indistinguishable from zero. The difference between the two coefficients has a p-value of 6% despite the small sample size and large standard errors in the rich sample.

Other papers studying the relationship between savings and growth have focused on even shorter horizons (annual growth) finding little conclusive evidence that savings (or investments) Granger-cause growth, either positively or negatively (Blomström, Lipsey, and Zejan (1996), Attanasio, Picci, and Scorcu (2000)). Following their specification, we do not find a differential impact of savings on growth for poor versus rich countries at an annual horizon. This is not surprising since the link between savings and growth that we propose – technology adoption – is unlikely to operate over horizons as short as a year. Planning and implementing the adoption of new technologies typically takes several years. Given that, we find supportive of our model the finding that lagged savings is positively associated with growth over five and 10-year horizons but not over one-year horizons. The relationship between savings and growth at one-year horizons, with all security, is dominated by other mechanisms. Carrol, Overland and Weil (2000), for example, hypothesize that habit formation may play an important role.[14]

Besides its particular relevance for poor countries over long time horizons, the link between savings and growth that we propose operates through TFP growth rather than capital accumulation. To the best of our knowledge, this distinction has not been explored in the literature. We find that the differential effect of savings on growth in poor countries operates entirely through TFP and not through capital accumulation (see Table 1). Though savings and investment are correlated contemporaneously, savings over the last decade is not correlated with average investment over the next decade, after controlling for initial income.

The relationship between savings and growth has also been discussed in the context of "growth miracles". Several authors have argued that high savings has followed very fast growth rather than vice-versa.[15] To assess the relevance of this observation for our findings, in Table 7, we estimate our main specification for the subsample of poor countries splitting further the data depending on whether average annual productivity growth (over the next decade) was above or below 5%.[16] This definition yields 28 "growth miracle"

[14] In simulations we conduct in the working paper version, we show that indeed, habit only plays a quantitative role over the very short term and plays no role in the growth-savings relationship over the frequencies we explore in this paper.

[15] See Williamson (1979), Rodrik (2000), Hayashi (1986).

[16] For the rich country sample, no observations with growth above 5% exist.

observations. For the subsample of growth miracles, the relationship between lagged savings and subsequent growth is negative but insignificant. This seems consistent with the literature and in particular with Hausmann, Pritchett, Rodrik (2005) who conclude that such periods of accelerated growth remain in large part explained by idiosyncratic factors. In contrast, for the non-miraculous episodes, we obtain a strong positive relationship between lagged savings and subsequent growth that is consistent with the mechanisms in our model. Thus, we conclude that while our model does not seem key to understand growth miracles it seems relevant to explain growth in regular scenarios which represent the ample majority of growth episodes.

4 Calibration and model evaluation

To make further progress in evaluating the quantitative importance of the mechanism described in our model, we find instructive to conduct some simulations of our model and compare them to the data. To this end, we calibrate the model and conduct a Monte Carlo exercise. Our model contains nine parameters. Five of them $(\bar{\mu}, \bar{\phi}_0, \bar{c}, \delta, \phi)$ are related to the process of technology adoption arnd therefore they are not standard in the RBC literature. To calibrate these new parameters we use five moments which ensure that the model conforms with some basic cross-country patterns.[17] Specifically, we can calibrate the parameters $\bar{\mu}, \overline{\phi}_0$ and $\bar{c}$ by matching:[18]

- the relationship between the adoption expenditures and the proximity to the frontier a for rich countries
- the convergence dynamics for rich countries, and
- the profit rate in the US.

These moments contain important information. The first allows us to estimate how fast adoption costs decrease with the proximity to the technology frontier. The second moment calibrates the extent to which adoption costs affect growth in rich countries. These two moments capture elasticities of adoption costs and growth with respect to proximity, but do not pin down the level of adoption or their costs. The third moment allows us to pin down the level by requiring the profit rate of the firms in the frontier to be consistent with the US post-war profit rate.

[17] Next subsection and Appendix C provide all the details about the calibration.

[18] Recall that these parameters denote the percent increase in the probability of success in adoption from exerting effort $(\bar{\mu})$, the parameter in the cost of adopting solo $(\overline{\phi}_0)$ and the upper bound in the distribution of the cost of effort $(\bar{c})$.

In addition, we can calibrate the costs of adoption with a foreign investor, ϕ, (for a given value of δ)[19] from the proximity threshold at which firms are indifferent between going solo and seeking foreign help. Following Durlauf and Johnson (1995), we pin down this threshold by conducting a regression tree analysis. The idea of this exercise is to split the sample so as to maximize the combined R^2 for the regressions run on the two subsamples. Reassuringly, the threshold we obtain is consistent with the micro evidence that even in relatively developed countries foreign help is often sought when adopting frontier technology.

The final restriction comes from several constraints that delimit the range of feasible values of the pair (δ, ϕ). The condition that the cost of adopting solo is lower than with the help of a foreign investor when the country is on the technology frontier, sets a lower bound for ϕ. The assumption that all projects that are incentive compatible are profitable with a foreign investor, determines an upper bound in ϕ, for a given δ. This interval of feasible values for the pair (δ, ϕ) turns out to be quite narrow and the results are robust for the values in the interval as well as for reasonable parametrizations outside the interval.

We deferr the details of the calibration of the non-standard to Appendix C. Our model also contains four parameters $(\alpha, r, \rho, \overline{g})$ that are standard to the RBC literature. We follow Cooley and Prescott (1995) to assign them values. Given the OLG nature of our model, we interpret a period in the model to be 10 years.[20] The specific values used in our simulations are listed in Table 8.[21]

Finally, since proximity a in the model is defined relative to the world technology frontier, we have to take a stand on where this frontier is. We assume that the US is in the frontier. Effectively, this means that, within ten years, the US adopts all the state of the art technologies.[22]

4.1 Model evaluation

Next, we evaluate the quantitative importance of the main mechanism described in our model: namely, the role of domestic saving as collateral that allows countries far from the frontier to benefit from the knowledge of foreign investors to successfully adopt the frontier technology. We do that in two ways. First, we compute the policy functions and the resulting transitional dynamics to see the effect of saving subsidies on saving, technology adoption and growth. Second, we conduct a Monte Carlo exercise and estimate the same regressions we

[19]Recall that δ is the percentage increase in the probability of successful adoption from exerting effort.

[20]Since the adoption investment is a sunk cost while output is a flow, we interpret ϕ and ϕ_0 as the annualized costs of adoption.

[21]The value of α implies that $\kappa^{\alpha} = 1/3$ and $\pi = 0.074$.

[22]We have conducted complementary calibrations where US productivity was an additional parameter to be estimated in the convergence regressions described below and our estimates supported this assumption.

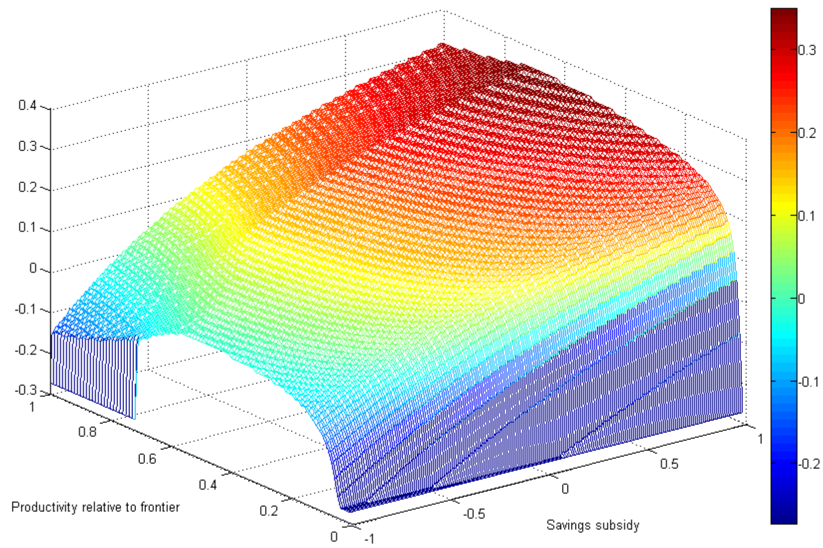

Figure 2: Saving rate as a function of a_{t-1} and τ.

have run in Section 3 on the simulated data to see whether the magnitude of the estimated relationships between saving and growth for the subsamples of poor and rich countries are comparable with the estimates we have obtained above. These exercises should provide us with a good sense of the strength of our mechanism.

4.1.1 Policy function and transitional dynamics

Saving rates

Combining (10) and (11), we can define the saving rate in our model as the value of s that solves the following equation:[23]

$$s = \frac{\left[(1-\beta) - \frac{\beta \tilde{z}\left(\frac{1+r}{1+\bar{g}} s, a_{t-1}\right)}{\kappa^{\alpha}(1+r)a_{t-1}}\right]}{(1-\alpha)} \tag{13}$$

Figure 3 displays the resulting saving rate as a function of the proximity level, a_{t-1}, and the saving subsidy, τ.

The range of feasible saving rates goes from -27% to 35%. [24]As one would expect, there

[23]Note that this expression for the saving rate has the implicit assumption that the saving subsidies at $t-1$ and t are the same. This allows us to avoid the hassle of having to track down past subsidies at the same time as identifying the subsidies in the data. It also has the advantage that we do not have to make assumptions about the subsidies at period -1. Given the very high persistence of saving subsidies, this seems a reasonable shortcut.

[24]Though quite wide, this range does include the most extreme values of the saving rate observed in our

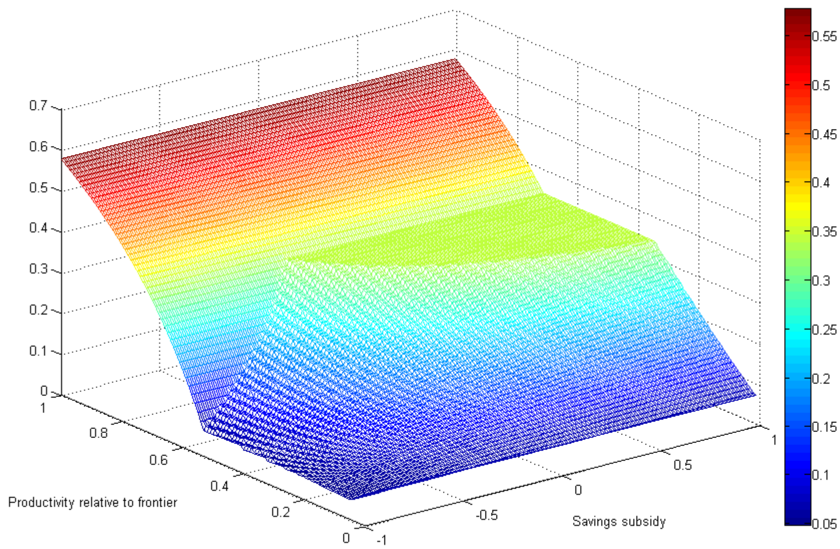

Figure 3: λ as a function of a_{t-1} and τ.

is a strong positive effect of the saving subsidy on the saving rate. For example, for a country with $a_{t-1} = 0.5$, the saving rate goes from -1 to 33% when the saving subsidy goes from -1 to 1. The saving rate is also increasing with the proximity to the frontier for low initial proximity levels. This is the case because future gains from innovation are proportional to $\bar{A}$ while current output is proportional to A_{t-1}. As we lower a_{t-1}, the gap between permanent income and current income increases and, as a result consumers want to borrow more (internationally) against their future income to smooth out consumption.

Share of sectors attempting to adopt new technologies

The share of sectors that try to adopt new technologies is given by the function λ. Figure 4 plots λ in terms of initial productivity and the subsidy to saving. As anticipated above, for $a_{t-1} > \hat{a}$ (i.e. larger than 0.7) λ is independent of τ and hence of savings. For lower values of a_{t-1}, λ steeply increases with the subsidy to saving. This effect is quantitatively important in our calibration. For example, for a country with a productivity level relative to the frontier of 0.5, the share of sectors that adopt frontier technology within a period increases from 7% to 34% as we increase the saving subsidy from the minimum to the maximum. Once the saving rate becomes sufficiently large, so that $\delta(v + s'a) > v$, the incentive constraint for projects is no longer binding and consequently λ becomes independent of saving.[25]

Growth

panel.

[25]Savings rates for which this happens are quite high and occur only rarely in our panel.

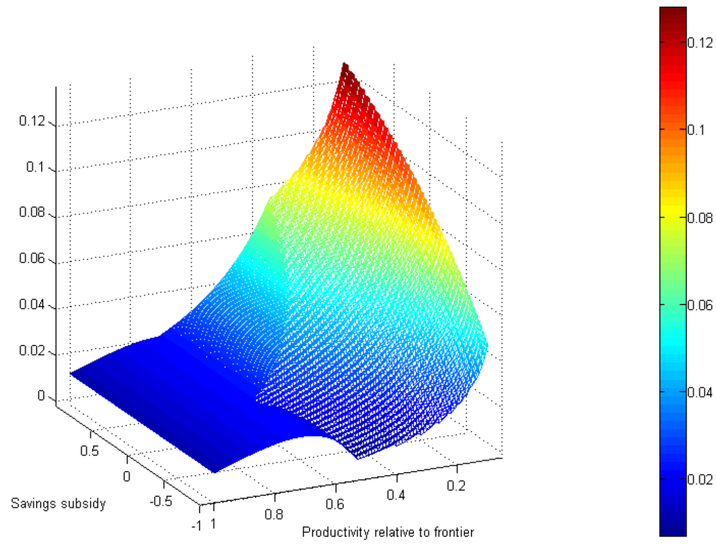

Figure 4: Annual Growth as a function of a_{t-1} and τ.

Two forces determine the growth rate of the economy. First, there is the standard convergence effect whereby a lower initial relative productivity is associated with a higher subsequent growth. Second, for $a_i < \hat{a}$, a higher saving subsidy relaxes the incentive compatibility constraint which results in a larger share of sectors adopting the frontier technology, and therefore to faster growth. Figure 5 plots the average annual growth rate for each relative productivity and saving subsidy level. There we can see both of these mechanisms at work. Consider, for example, two countries with saving subsidies equal to 0, but the first country lies at the frontier whereas the other country is at proximity $a = 0.25$. The average growth rate of the country in the frontier is 1.07% while for the country with $a_{t-1} = 0.25$ it is 5.86%. Now consider the effect of the saving subsidy on growth. The average growth rate for a country at a proximity level of 0.5 with a saving subsidy of -1 is 0.77%. By increasing the saving subsidy to 1, the growth rate rises to 4.17%. As shown in Figure 5, the effect of the subsidy on growth is even more dramatic for poorer countries. A similar change in the subsidy for a country with proximity 0.25 results in an increase in the growth rate from 1.85% to 8.38%.

4.1.2 Simulations

To assess the quantitative relevance of our mechanism we proceed to simulate 1000 panels, each of which involves 140 countries and five periods. Two necessary inputs in this Monte Carlo exercise are the process for the saving subsidies and the initial conditions for the proximity levels. Inverting the saving rate plotted in Figure 3, we can find, for each country and period in the data set, the saving subsidy that generates the observed saving rate given the initial proximity level. It turns out that for 388 of the 412 country-decade observations where initial proximity is above 0.09 (i.e. not in the bottom 25%), we can find interior saving subsidies (i.e. strictly comprised between -1 and 1). The average saving subsidy is 0.03 with a median of 0.04 and a standard deviation of 0.57. As suggested by Figure A1 in Appendix C, the uniform distribution is not a bad approximation for the distribution of saving subsidies. We therefore sample the initial subsidies from a uniform distribution with support in [-0.96,1] to approximately match the mean and variance of the observed subsidies distribution. These implied saving subsidies are quite persistent. We find that their auto-correlation is 0.77. (Keep in mind that a period corresponds to 10 years.). We use this estimate to calibrate the law of motion for subsidies in a given country. Finally, we draw initial proximities from a Normal distribution with mean 0.3 and variance 0.0676 to match the observed distribution of proximity levels prior to 1970.

Saving Table 9 reports basic statistics for the saving rates both in the actual (first row) and simulated (second row) panels. The model does a fair job in reproducing the distribution of saving across countries. It misses some of the very negative saving rates for which the implied saving subsidies are binding and some of the very high saving rates observed in the data. But the mean, median and standard deviation are very similar in the simulated and actual data.

Saving-growth relationship Next, we reestimate the relationship between saving and growth (12) in our Monte Carlo simulations, in a further attempt to evaluate the importance of the mechanism described in the model. In this context, we use the Table 1 estimates from the actual data as a benchmark.

Columns 1-3 in Table 10 reproduce the estimates from the actual data, while columns 4-6 report the average coefficients (together with the 95% confidence intervals) from the simulated data. The main observation from Table 10 is that the model generates patterns of saving and growth that are comparable to those observed in data. In particular, the estimates of lagged saving on growth are significantly larger for the poor than for the rich countries. Further, the effect of lagged saving on growth induced by our model is quantitatively important. The average coefficient for the sample of poor countries in our simulated panels is 12% with a 95% confidence interval of 11 to 14%. This coefficient is larger than the coefficient found in the data (4.3%). As discussed in section 3, measurement error in the saving rates and the correlation between lagged saving and current income are likely to generate a downward bias in the estimates of the estimated effect of saving on growth in the actual data. This could in principle account for part of the discrepancy between the estimates in actual vs. simulated data.

The average estimate of the effect of saving on growth for the sample of rich countries in our Monte Carlo exercise is zero (with a very narrow confidence interval). Recall that in the data, we find that the equivalent point estimate is statistically not different from zero. Not surprisingly, given that a majority of countries belong to the poor-country sample, the average estimate of the effect of lagged saving on growth for the full sample in our simulations is also quite close to the estimate in the actual data.

These results survive a whole set of robustness tests. First, we obtain similar estimates of the relationship between saving and growth when calibrating ϕ and δ using other values in the set of values that satisfy condition (20). Second, our results are robust to including country effects (both fixed and random) in the regressions. Third, the results are also robust to relaxing the assumption that incentive compatible projects are profitable (equation 20): that is, to using other points along the curve in Figure 2 with $\phi > \bar{\phi}_0/\hat{a}$. Columns 7 through 9 in Table 10 present the estimates from our simulated data when calibrating $\phi = 0.056$ and $\delta = 0.27$. We find that the average coefficient of saving in regression (12) for the sample of poor countries is 5.9% (rather 12%) with a 95% confidence interval of [0.041 , 0.078]. For the sample of rich countries, the average point estimate is still zero. Hence, the conclusion that our model has the quantitative potential of explaining the observed patterns of saving and growth across countries is robust to alternative choices of (ϕ, δ) in our calibration scheme.

5 Conclusions

There are important barriers to adopting new technologies which explain the wide cross-country differences in productivity. What is the nature of these barriers, and why do some developing countries manage to overcome them but others don't?

This paper has developed a model where a country's ability to take advantage of international technology diffusion, is positively correlated with the level of its domestic savings. Familiarity with the frontier technology reduces its cost of adoption. Advanced countries have no problem adopting the frontier technology. However, for countries far from the technology frontier, it may be too expensive to adopt the frontier technology without outside help. Instead, entrepreneurs in these countries need to rely on foreign investors that are familiar with the frontier technology. However, there is moral hazard in the relationship between local entrepreneurs and foreign investors: namely, the domestic entrepreneur may not deliver on her input contribution, unless she has invested sufficient capital in the project.

This co-investment is in turn financed out of domestic savings. Overall, the main prediction of the model is that domestic saving is more critical for adopting new technologies in developing than in developed economies.

Confronting this predictions to available cross-country panel data, we first showed that simple reduced form regressions support this basic prediction. Then, to assess the quantitative importance of the above mechanism, we calibrated and simulated our model and indeed found that the effect of domestic saving on growth is quantitatively important. In particular, we saw that if we restrict our sample to far-from-frontier countries, an increase in the saving rate in the previous 10 years by 10 percentage points leads to an increase in the average growth rate over the next 10 years of 1.3 percentage points. Moreover this effect was found to survive a whole range of robustness checks. Finally, the quantitative importance of the effect of saving on technology diffusion *over the medium term* appeared to be significantly larger than the potential effect of future growth on current saving operating through habit.

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Table 1: Effect of Savings on Labor Productivity, TFP, and Capital Stock Growth

Dependent var:	Growth income per worker			Growth TFP			Growth capital stock		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log (initial per	-0.00998	-0.0113	-0.0216	-0.00261	-0.00404	0.00589	-0.00563	-0.00608	-0.00813
worker income)	(-4.79)	(-4.12)	(-2.20)	(-1.35)	(-1.59)	(0.47)	(-4.19)	(-3.47)	(-1.48)
Average saving rate	0.0428	0.0463	-0.0467	0.0356	0.0404	-0.0748	-0.00381	-0.00410	-0.0102
in previous ten year	(2.97)	(3.00)	(-1.07)	(2.68)	(3.11)	(-0.87)	(-0.44)	(-0.45)	(-0.32)
N	292	237	55	237	191	46	237	191	46
R^2	0.069	0.070	0.144	0.039	0.052	0.100	0.108	0.075	0.053
Sample	All	Poor	Rich	All	Poor	Rich	All	Poor	Rich
Test for equality of savings coefficient:									
p-value	0.0396			0.1708			0.8509		

Dependent variable is growth from t to t+10 in income per worker (columns 1-3), growth from t to t+10 in TFP (columns 4-6) and growth from t to t+10 in capital stock (columns 7-9). Independent variables are log income per worker at t, and average saving rate between t-9 and t. The poor sample contains observations for which income per worker is less than 70% of US income per worker. t statistics based on robust standard errors in parentheses. Non-overlapping intervals.

Table 2: Time Controls and Country Fixed Effects

Dependent var:				Growth income per worker					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log (initial per	-0.00523	-0.00543	-0.0156	-0.00459	-0.00475	-0.00318	-0.0432	-0.0455	-0.0377
worker income)	(-2.34)	(-1.91)	(-0.84)	(-1.84)	(-1.48)	(-0.15)	(-11.21)	(-9.46)	(-6.50)
Average saving rate	0.0217	0.0253	-0.0475	0.0210	0.0249	-0.0357	0.0224	0.0298	-0.0961
in previous ten year	(1.43)	(1.59)	(-1.07)	(1.36)	(1.52)	(-1.06)	(0.82)	(1.01)	(-1.15)
Year	-0.000758	-0.000877	-0.000144						
	(-5.90)	(-5.78)	(-0.51)						
Year fixed effects				Yes	Yes	Yes			
Country fixed effects							Yes	Yes	Yes
N	292	237	55	292	237	55	292	237	55
R^2	0.157	0.171	0.149	0.251	0.278	0.400	0.404	0.392	0.369
Sample	All	Poor	Rich	All	Poor	Rich	All	Poor	Rich
Test for equality of savings coefficient:									
p-value		0.1100			0.0769			0.0734	

Dependent variable is growth from t to t+10 in income per worker. Independent variables are log income per worker at t, average saving rate between t-9 and t, year (columns 1-3), year fixed effects (columns 4-6) and country fixed effects (columns 7-9). The poor sample contains observations for which income per worker is less than 70% of US income per worker. t statistics based on robust standard errors in parentheses. Non-overlapping intervals.

Table 3: Different Splits of the Sample into Rich and Poor

Dependent var:	Growth income per worker								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Log (initial per	-0.00998	-0.0132	-0.0200	-0.0119	-0.0177	-0.0109	-0.0213	-0.0107	-0.0163
worker income)	(-4.79)	(-4.34)	(-2.78)	(-3.96)	(-2.36)	(-4.38)	(-1.88)	(-4.54)	(-1.18)
Average saving rate	0.0428	0.0454	-0.0237	0.0455	-0.0180	0.0466	-0.0523	0.0473	-0.0513
in previous ten year	(2.97)	(2.79)	(-0.78)	(2.86)	(-0.55)	(3.07)	(-1.07)	(3.13)	(-0.99)
N	292	217	75	226	66	248	44	258	34
R^2	0.069	0.079	0.127	0.070	0.124	0.070	0.136	0.071	0.083
Sample	All	$< 60\%$	$> 60\%$	$< 65\%$	$> 65\%$	$< 75\%$	$> 75\%$	$< 80\%$	$> 80\%$
Test for equality of savings coefficient:									
p-value		0.0412		0.0762		0.0457		0.0577	

Dependent variable is growth from t to t+10 in income per worker. Independent variables are log income per worker at t and average saving rate between t-9 and t. The samples are split with respect to income per worker relative to the US. For example, the sample used in column 2 consists of all countries with per worker income lower than 60% of the US per worker income that year. t statistics based on robust standard errors in parentheses. Non-overlapping intervals.

Table 4: Financial Development

Dependent var:	Growth income per worker					
	(1)	(2)	(3)	(4)	(5)	(6)
Log (initial per	-0.00998	-0.00527	-0.00640	-0.0432	-0.0712	-0.0401
worker income)	(-4.79)	(-1.57)	(-0.82)	(-11.21)	(-3.17)	(-8.95)
Average saving rate	0.0428	0.0332	0.0463	0.0224	0.00275	0.0173
in previous ten year	(2.97)	(1.29)	(1.60)	(0.82)	(0.03)	(0.50)
Country fixed effects				Yes	Yes	Yes
N	292	254	38	292	61	231
R^2	0.069	0.020	0.097	0.404	0.400	0.375
Sample	All	LFD	HFD	All	LFD	HFD
Test for equality of savings coefficient						
p-value		0.7261			0.8167	

Dependent variable is growth from t to t+10 in income per worker. Independent variables are log income per worker at t, average saving rate between t-9 and t and country fixed effects (columns 4-6). In columns 2 and 3, the sample is split according to whether the private credit - GDP ratio is below (LFD) or above (HFD) the 87th percentile in the sample that year. In columns 5 and 6, the sample is split according to whether the private credit - GDP ratio is below (LFD) or above (HFD) the 37th percentile in the sample that year. The 37th percentile cut-off is suggested by the regression tree step if country fixed effects are included in the regressions, the 87th percentile is suggested if they are left out. t statistics based on robust standard errors in parentheses. Non-overlapping intervals.

Table 5: Connecting Our Results to CW, full sample

Dependent var:	Growth in income per worker						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Average savings rate	0.0428	0.0299					
in previous ten years	(2.97)	(2.10)					
Average savings rate			0.0318	0.073	0.0645	0.0699	0.0061
in previous five years			(2.76)	(3.90)	(2.13)	(2.12)	(0.12)
Log (initial per	-0.01	-0.0008	-0.001	-0.0081	-0.0515	-0.0529	
worker income)	(-4.79)	(-0.45)	(-0.71)	(-3.64)	(-12.53)	(-12.28)	
Average growth rate						-0.0149	0.1169
in previous five years						(-0.29)	(1.50)
Country fixed effects					Yes	Yes	Yes
N	292	288	589	344	344	342	342
R^2	0.069	0.023	0.020	0.074	0.365	0.377	0.014

1 = 10-year intervals 1950-2000, 2 = 10-year intervals 1953-1992, 3 = 5-year intervals 1958-1987, 4 = CW countries 5 = add country fixed effects, 6 = add lagged growth, 7 = remove initial income. t statistics based on robust standard errors in parentheses.

Table 6: CW specification, split into rich and poor

Dependent Var:	Growth in income per worker		
	(1)	(2)	(3)
Average savings rate	0.0168	-0.004	0.0311
in previous five years	(1.05)	(-0.11)	(1.57)
Average growth rate	0.329	0.1661	0.3175
in previous five years	(5.90)	(1.74)	(4.91)
N	342	71	271
R^2	0.119	0.034	0.130
Sample	Full	Rich	Poor

t statistics based on robust standard errors in parentheses, no fixed effects.

Table 7: Savings and growth, with and without growth miracles

Dependent var:	Growth in income per worker		
	(1)	(2)	(3)
Average savings rate	0.0463	-0.0197	0.0408
in previous ten years	(3.00)	(-1.33)	(2.98)
Log (initial per	-0.0113	-0.0025	-0.0035
worker income)	(-4.12)	(-0.87)	(-1.43)
N	237	33	204
R^2	0.070	0.091	0.042
Sample	All	Miracles	Non-miracles

The sample is the sample of poor countries only, since no "growth miracles" occur for rich countries. Column 1 uses all periods, Column 2 uses high growth periods (growth$>$ 5%), column 3 omits high growth periods (growth$<$ 5%). t statistics based on robust standard errors in parentheses, no fixed effects.

Table 8: Calibration of New Parameters

Parameter	Interpretation of parameter	Value in baseline calibration	Moments used for calibration
ϕ	Cost of adoption with foreign investor	0.045	$\hat{a} = .7$ (from regression tree analysis)
δ	% Increase in probability of success from exerting effort	0.23	All IC projects are worthwhile, Inequality (5)
$\bar{\phi}_0$	Cost of adoption solo	0.032	Relationship between R&D/GDP and productivity relative to frontier for rich sample
$\bar{\mu}$	Probability of success with effort	0.85	Average profit rate in US over post-war period
$\bar{c}$	Maximum cost of exerting effort	0.055	Convergence regression for rich countries
$1-\alpha$	Labor Share	2/3	Cooley and Prescott (1995)
r	World interest rate	$1.07^{10}-1$	Cooley and Prescott (1995)
ρ	Rate of time preference	$1.05^{10}-1$	Cooley and Prescott (1995)
$\bar{g}$	Growth rate of the world technology frontier	$1.02^{10}-1$	Balanced growth for the U.S.

Table 9: Distribution of Savings Rates in the Data and in the Model

	Mean	Median	Standard Deviation	Minimum	Maximum
Data	0.18	0.185	0.11	-0.12	0.54
Model	0.17	0.184	0.1	-0.19	0.33
	[0.157,0.184]	[0.16,0.2]	[.09, .11]	[-.26,-.07]	[.33, .33]

Note: statistics computed across the panel for economies with proximity level above 9 percent where the savings subsidies are not binding. 95 percent confidence interval in square brackets.

Table 10: Estimates of Savings-Growth Relationship for Split Samples in Actual and Simulated Data

	Actual Data		
Dependent var:	Productivity growth over the next ten years		
	(1)	(2)	(3)
Log (initial per	-0.00998	-0.0113	-0.0216
worker income)	[-0.014,-0.006]	[-0.017,-0.006]	[-0.041,-0.002]
Average saving rate	0.0428	0.0463	-0.0467
in previous ten year	[0.014,0.071]	[0.016,0.077]	[-0.134,0.041]
N	292	237	55
R^2	0.069	0.070	0.144
Sample	All	Poor	Rich

	Simulated Data					
Dependent var:	Productivity growth over the next ten years					
	Baseline: $\phi = 0.045$, $\delta = 0.23$			$\phi = 0.056$, $\delta = 0.27$		
	(4)	(5)	(6)	(7)	(8)	(9)
Log (initial per	-0.04	-0.042	-0.02	-0.028	-0.033	-0.019
worker income)	[-0.043, -0.036]	[-0.045, -0.04]	[-0.025,-0.014]	[-0.033, -0.022]	[-0.038, -0.028]	[-0.026, -0.01]
Average saving rate	0.108	0.125	0	0.046	0.059	0
in previous ten year	[0.085,0.128]	[0.108,0.14]	[-0.001, 0.002]	[0.029, 0.066]	[0.041, 0.078]	[-0.002, 0.002]
N	682	636	47	676	635	42
R^2	0.96	0.97	0.99	0.9	0.92	0.99
Sample	All	Poor	Rich	All	Poor	Rich

95 % confidence intervals in square brackets.

Appendix A (Not for publication)

This appendix demonstrates that there exists a contract (x, y) satisfying conditions 1~4 in section 2.4 of the text if and only if condition (4) holds. Suppose (4) holds. Then every contract satisfies condition 1. Choose $x = \phi - sa$ and $y = x/\overline{\mu}$. By construction conditions 2 and 4 are satisfied. Also by construction we have

$$\begin{aligned} & \left(\overline{\mu} - \underline{\mu}\right)(\pi - y) \\ = \; & \delta\left(\overline{\mu}\pi - \overline{\mu}y\right) \\ = \; & \delta\left(\overline{\mu}\pi - x\right) \\ = \; & \delta\left(v + sa\right) \end{aligned}$$

so (4) implies condition 3. This establishes the if part. Now suppose that there exists a contract (x, y) satisfying conditions 1 through 4. Conditions 2 and 3 imply

$$c \leq \left(\overline{\mu} - \underline{\mu}\right)\left(\pi - x/\overline{\mu}\right)$$

which together with condition 4 and the definition $v = \overline{\mu}\pi - \phi$ implies

$$c \leq \delta\left(v + sa\right)$$

This and condition 1 imply (4). This establishes the only if part.$\|$

Appendix B (Not for publication)

This appendix derive the consumption function (11). Define X_2 as the individual's consumption when old, net of the cost of entrepreneurial effort:

$$X_2 = C_2 - ce\overline{A}_t$$

The utility function can be written as

$$u = \ln\left(C_1\right) + \frac{1}{1+\rho}\ln\left(EX_2\right)$$

and the lifetime budget constraint is

$$(1+\tau)C_1 + \frac{1}{1+r}(EX_2 + T) = (1+\tau)w_{t-1} + \frac{1}{1+r}E\left(R - ce\overline{A}_t\right)$$

Define

$$z \equiv E\left(R - ce\overline{A}_t\right)/\overline{A}_t$$

Consider first the case where an individual who is given an opportunity to undertake an investment project prefers to undertake it alone:

$$v \leq v_0\left(a_{t-1}\right)$$

She will realize that opportunity provided that $c \leq v_0\left(a_{t-1}\right)$, so

$$z = \int_0^{v_0(a_{t-1})} \left(v_0\left(a_{t-1}\right) - c\right)\left(1/\overline{c}\right) dc.$$

Consider next the case where an entrepreneur would prefer to partner with a foreign investor:

$$v > v_0\left(a_{t-1}\right)$$

She can attract a partner if and only if she has enough saving to satisfy condition (4), which can be written using (5) as

$$c \leq \delta\left(v + s_t^{'}\right)$$

where we use the shorthand notation

$$s_t' = s_{t-1}a_{t-1}$$

There are two subcases to consider:

1. if $a_{t-1} > \widehat{a}$, then by the definition of $\widehat{a}$ we have $\delta\left(v + s_t'\right) < v_0\left(a_{t-1}\right)$ and

$$z = \int_0^{\delta(v+s_t')} \left(v - c\right)\left(1/\overline{c}\right) dc + \int_{\delta(v+s_t')}^{v_0(a_{t-1})} \left(v_0\left(a_{t-1}\right) - c\right)\left(1/\overline{c}\right) dc$$

   that is, if the entrepreneur's normalized effort cost c is less than $\delta\left(v + s_t'\right)$ then the incentive compatibility constraint will be satisfied and she will partner with a foreign investor, earning an expected net rent of $v - c$, whereas if c is between $\delta\left(v + s_t'\right)$ and $v_0\left(a_{t-1}\right)$ then although she cannot attract a foreign investor she will undertake a project on her own, earning an expected net rent of $v_0\left(a_{t-1}\right) - c$. (Assumption A3 ensures that $v_0\left(a_{t-1}\right) > \overline{c}$.)

2. if $a_{t-1} \leq \widehat{a}$ then $v_0(a_{t-1}) \leq \delta(v + s'_t)$ and

$$z = \int_0^{\delta(v+s'_t)} (v - c)(1/\overline{c})\, dc$$

that is, all incentive-compatible projects with a foreigner will be undertaken but no project will be undertaken alone.

Putting these results together we see that z can be expressed as the function

$$z = \widehat{z}(s'_t, a_{t-1})$$

with

$$\frac{\partial \widehat{z}}{\partial s'_t} = \left\{ \begin{array}{ll} 0 & \text{if } v \leq v_0 \\ \delta(v - v_0)(1/\overline{c}) > 0 & \text{if } \delta\left(v + s'_t\right) < v_0 < v \\ \delta\left(v - \delta\left(v + s'_t\right)\right)(1/\overline{c}) > 0 & \text{if } v_0 \leq \delta\left(v + s'_t\right) \end{array} \right\}$$

and

$$\frac{\partial \widehat{z}}{\partial a_{t-1}} = \left\{ \begin{array}{ll} v'_0 v_0 (1/\overline{c}) > 0 & \text{if } v \leq v_0 \\ v'_0(v_0 - \delta(v + s'_t))(1/\overline{c}) > 0 & \text{if } \delta(v + s'_t) < v_0 < v \\ 0 & \text{if } v_0 \leq \delta(v + s'_t) \end{array} \right\}$$

where we have suppressed the argument a_{t-1} of the v_0 function.

Equivalently we can use the definition of s'_t to write

$$z = \widetilde{z}(s_{t-1}, a_{t-1})$$

where $\widetilde{z}$ is defined as

$$\widetilde{z}(s_{t-1}, a_{t-1}) = \widehat{z}(s_{t-1}a_{t-1}, a_{t-1})$$

which the above results show is increasing in both arguments.

The young individual's problem is therefore

$$\begin{array}{l} \max\limits_{\{C_1, EX_2\}} \ln(C_1) + \frac{1}{1+\rho}\ln(EX_2) \\ \text{subj to } (1+\tau)C_1 + \frac{1}{1+r}EX_2 = W + \frac{1}{1+r}\overline{A}_t \widetilde{z}\left(\frac{(1+r)(w_{t-1} - C_1)}{a_{t-1}\overline{A}_t}, a_{t-1}\right) \end{array}$$

where $W = (1+\tau)w_{t-1} - \frac{1}{1+r}T$. The first-order conditions for this problem together with the government budget constraint (9) yield (11).‖

Appendix C (Not for publication)

Regression Tree Analysis

The threshold $\hat{a}$ has been defined as the relative productivity level at which a country undertakes marginal R&D projects on its own. It therefore depends on the costs of adopting the technology with and without a foreign investor. Information about the threshold would help us calibrate the costs of adopting frontier technology. One approach to get such information is to investigate the origin of technology and engineers in specific projects. In reality, even for relatively rich countries, foreign consultants familiar with the frontier technology are often involved in the adoption of frontier technology.[26]

We can obtain a more formal estimate of $\hat{a}$ by performing a regression tree analysis. The idea of this exercise is to split the sample so as to maximize the combined R^2 for the regressions run on the two subsamples. More specifically, for each year, we compute the gap in log GDP per worker between country i and the US. For each integer n between 1 and 98, we then perform the following steps:

1. Split the sample into two subsamples, one with log GDP per worker gap above the n^{th} percentile (the "rich"sample) and one with the log GDP per worker gap at or below the n^{th} percentile (the "poor"sample).

2. Regress growth in TFP between year t and year $t + 10$ on log GDP per worker in year t and average saving over the years $t - 9$ to t on the poor sample and the rich sample separately. In our baseline specification we conduct this exercise without any country effect, but we test the robustness of the results to including country fixed effect and random effects.

3. For each of the two regressions, compute the sum of squared residuals (SSR) and add them together.

We then select n^* as the n for which the SSR is lowest. Splitting the sample along the n^{*th} percentile of the log GDP per worker gap therefore results in two samples for which both regressions together have the highest explanatory power.

We have conducted the regression tree analysis on the sample without the poorest 25% of all countries and, as above, use a sample with non-overlapping intervals.. We have used three different specifications: the baseline specification in (12), adding country fixed effects or adding country random effects. In all three exercises, the cut off at which countries start using the help of foreign investors to adopt frontier technologies is when output per worker is approximately below 70% of the US. (This, for example, corresponds to Greece in 1980.) Hence, our estimate of $\hat{a}$ is 0.7.

[26] That was, for example, the case when Siemens helped build the high speed train (AVE) in Spain in the early 1990s.

This estimate of $\hat{a}$ is an important piece of information for our calibration for two reasons. First, it defines the sample of rich countries which we use below to pin down the values of $\bar{\mu}$, $\bar{\phi}_0$ and $\bar{c}$. Second, we shall use it below together with the optimal adoption decision (i.e. eq. 6) to infer information about the adoption costs with the help of a foreign investor, ϕ.

R&D intensity and proximity

The fraction of sectors that try to adopt the state of the art technology in countries close to the frontier (i.e. $a > \hat{a}$) is given by

$$\lambda(a) = v_0 \left(1/\bar{c}\right) = \left(\bar{\mu}\pi - \bar{\phi}_0/a\right)\left(1/\bar{c}\right).$$

And the share of adoption expenses in GDP is[27]

$$\frac{Adoption\ Expenses}{GDP} = \frac{\overbrace{\bar{\phi}_0/a}^{\text{cost per project}} \quad * \quad \overbrace{\lambda(a)}^{\text{\# of projects undertaken}}}{\underbrace{a\kappa^{\alpha}}_{GDP}} = \frac{\bar{\phi}_0/a}{a\kappa^{\alpha}}\frac{\left(\bar{\mu}\pi - \bar{\phi}_0/a\right)}{\bar{c}}$$

One reasonably good proxy for the adoption expenses for rich countries are R&D expenses. Of course, there are significant investments other than R&D that improve the country's productivity. However, it may not be unreasonable to assume that these are approximately proportional to R&D expenditures for rich countries. Under this assumption, we can write the following non-linear relationship between R&D expenditures and proximity:

$$\left(\frac{R\&D}{Y}\right)_i = \beta_0\left(\frac{1}{a_i}\right)^2 - \beta_1\left(\frac{1}{a_i}\right)^3 + \epsilon_i \tag{14}$$

where $\beta_0 \equiv \Phi\frac{\bar{\phi}_0\bar{\mu}\pi}{\bar{c}\kappa^{\alpha}}$, $\beta_1 = \beta_0 * \bar{\phi}_0/\bar{\mu}\pi$ and Φ captures the gap between R&D and total adoption expenditures.

Estimating (14) for the sample of countries with $a_i > \hat{a}$ in 1993 (the year for which we have the most comprehensive $R\&D$ data), we find that

$$\hat{\beta}_0 = \underset{(0.14,\ 0.3)}{0.22}$$
$$\hat{\beta}_1 = \underset{(0.059,\ 0.167)}{0.11}$$

[27] This expression is in general an overestimate of the share of adoption expenditures. This is because for countries that are above $\hat{a}$ but below $\bar{a}$ (in Figure 1), many projects are still undertaken with a foreign investor because this is cheaper than going solo. However, the percentage overestimation goes to zero as ϕ increases to its upper limit (the red dashed line in Figure 2). At this limit, $\hat{a}$ and $\bar{a}$ coincide, so all projects are solo for countries above $\hat{a}$. This limit actually corresponds with our baseline calibration.

where the numbers in parenthesis are the 95 percent confidence interval. Dividing $\hat{\beta}_0$ by $\hat{\beta}_1$, we obtain the following restriction[28]

$$\frac{\bar{\mu}\pi}{\bar{\phi}_0} = \frac{\hat{\beta}_0}{\hat{\beta}_1} = 2 \tag{15}$$

Convergence regression

A natural relationship to use in the calibration is the convergence equation implied by equations (G) and (6) for the sample of high productivity countries. Using (15), this relationship can be expressed as

$$\ln(\frac{y_{it+10}}{y_{it}}) = \left(\frac{1+\bar{g}}{a_{it-1}} - 1\right)\beta_2\left(1 - \frac{.5}{a_{it-1}}\right) + \epsilon_{it},$$

where $\beta_2 = 2 * \bar{\mu}\bar{\phi}_0\,(1/\bar{c})$.

Using a non-overlapping panel over the post-war period for those countries with labor productivity higher than 70% of US level, yields the following estimate for β_2,[29]

$$\hat{\beta}_2 = \begin{matrix} 0.96 \\ (0.76,\ 1.15) \end{matrix}$$

This estimate implies that

$$\bar{c} \simeq 2 * \bar{\mu}\bar{\phi}_0 \tag{16}$$

Profit rate

We can obtain a third restriction by using information on the US profit rate over the post-war period. In particular, the profit rate in the model is given by

$$\theta = \frac{\bar{\mu}\pi - \bar{\phi}_0}{\kappa^{\alpha}} \tag{17}$$

The average profit rate in the US over the post-war period has been approximately equal to 9.5% of GDP.[30] Based on this, we set θ at 0.095. Plugging in the values of π and κ, the values of $\bar{\phi}_0$, $\bar{c}$, $\bar{\mu}$ that satisfy (15), (16) and (17) are:

$$\begin{aligned} \bar{\phi}_0 &= 0.032 \\ \bar{c} &= 0.055 \\ \bar{\mu} &= 0.85 \end{aligned}$$

[28] Note that, the assumption on the proportionality between R&D and adoption expenditures precludes us from using the levels of either $\hat{\beta}_0$ or $\hat{\beta}_1$ for the calibration.

[29] 95 percent confidence intervals in parenthesis.

[30] These are computed using the BEA series on corporate profits with inventory valuation and capital consumption adjustments.

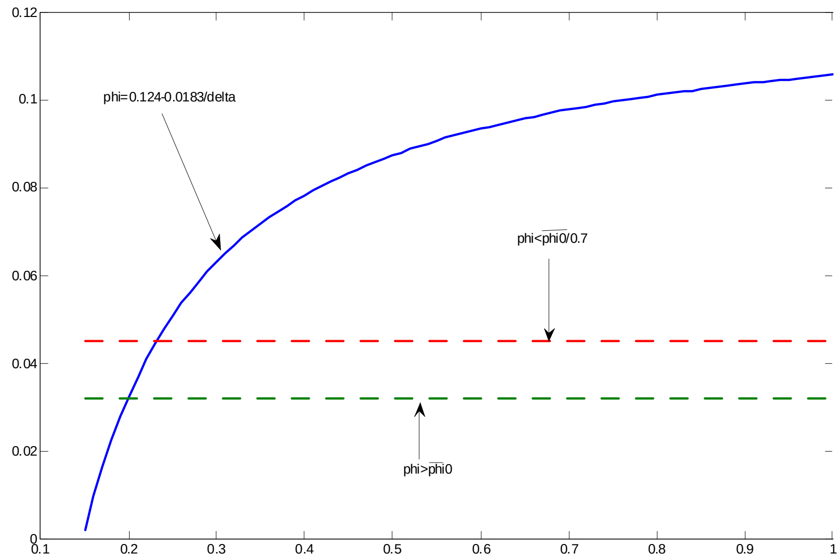

Figure 5: Possible values of ϕ for a given value of δ.

Optimal adoption

Adopters in a country with proximity equal to $\hat{a}$ are indifferent between using the help of a foreign investor and adopting frontier technology solo.[31] Formally,

$$v_0(\hat{a}) = \delta(v + s_{t-1}\hat{a}) \tag{18}$$

Setting $\hat{a}$ at 0.7, s_{t-1} at the average (adjusted) saving rate, and $\overline{\phi}_0$, $\overline{c}$, $\overline{\mu}$ at their calibrated values above, yields the following relationship between δ and ϕ which is represented by the blue curve in Figure 2:

$$\phi = 0.124 - \frac{0.0183}{\delta} \tag{19}$$

This leaves just one degree of freedom in the calibration. We further restrict the set of values for δ and ϕ by invoking two further assumptions in the model. First, $\phi \geq \bar{\phi}_0$. This is represented by the bottom dashed line in Figure 2. Second, assumption (5) implies that[32]

$$\delta(v + \overline{sa}) \leq v. \tag{20}$$

Combining (18) and (20), we get that $\phi \leq \bar{\phi}_0/\hat{a} = 0.045$. This is represented by the top

[31] In theory, the threshold $\hat{a}$ is a function of s_{t-1} and therefore of τ. However, as we shall see below, the steepness of v_0 is such that $\hat{a}$ varies very little with τ.

[32] Recall that this assumption implied that for countries far from the frontier, all incentive compatible projects are worthwhile.

dashed line in Figure 2. As a result, the possible values of δ and ϕ are those on the solid curve between the two dashed lines. For example, at the upper limit where $\phi = 0.045$ we have $\delta = 0.23$. At the lower limit, where $\phi = 0.032$, we have $\delta = 0.20$. Note that this feasible region is fairly narrow. Since presumably ϕ is significantly larger than $\bar{\phi}_0$, we set the baseline values of ϕ and δ to 0.045 and 0.23 which are on the upper range of the region of possible values. Our results are robust to other feasible values on the interval. Below, we also explore the robustness of the results to relaxing the assumption that incentive compatible projects are profitable (i.e. eq. 20) in the calibration. Table 8 summarizes our calibrated values and the moments used to set these values.

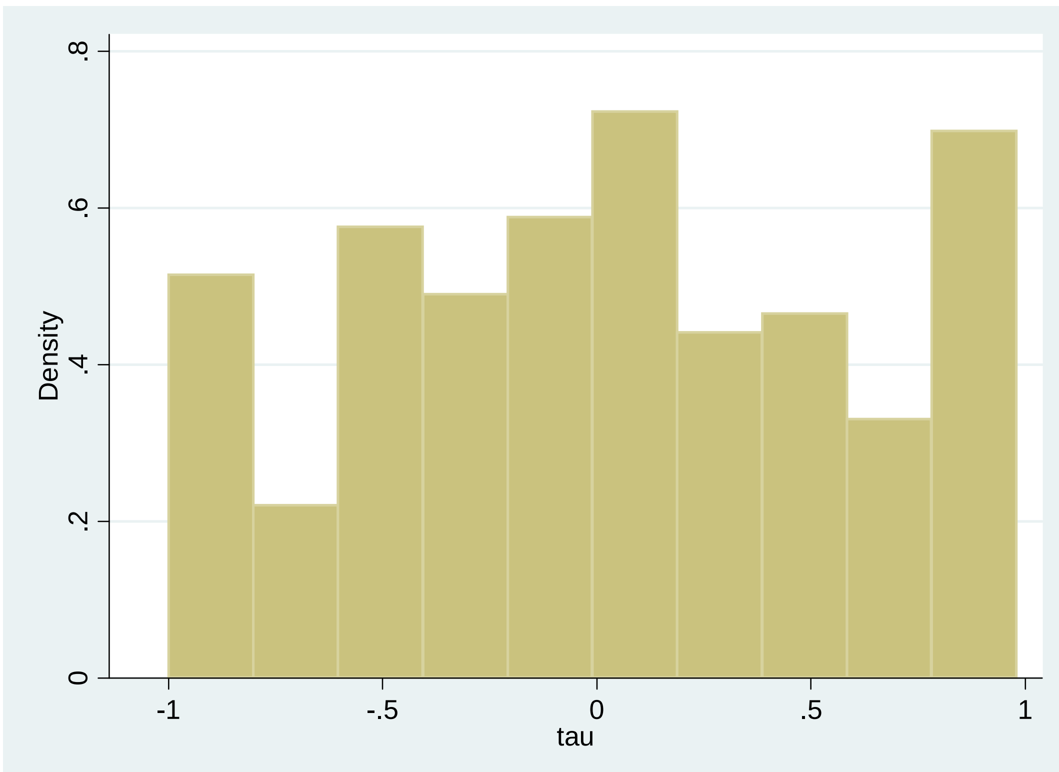

Figure A1: Distribution of savings subsidies (τ).