

Foreign direct investment and spillovers: gradualism may be better

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Abstract. The standard argument says that in the presence of positive spillovers foreign direct investment should be promoted and subsidized. In contrast, this paper claims that the very existence of spillovers may require temporarily restricting FDI. Our argument is based on two features of spillovers: they are limited by the economy's absorptive capacity and they take time to materialize. By letting in capital more gradually, initial investment has the time to create spillovers – and upgrade the economy's absorptive capacity – before further investment occurs. The economy converges to a steady state with a superior technology and a greater capital stock. JEL classification: F2, O3

Investissement direct de l'étranger et effets de retombée : le gradualisme peut être préférable. L'argument conventionnel suggère que l'investissement direct de l'étranger (IDE) devrait être promu et subventionné si des effets de retombée positifs existent. A contrario, ce mémoire suggère que l'existence même de ces retombées peut nécessiter qu'on restreigne temporairement les IDE. Cette argumentation se fonde sur deux caractéristiques des retombées: ces retombées sont limitées par la capacité de l'économie réceptrice à les absorber, et elles prennent du temps à se matérialiser. En laissant entrer ce capital graduellement, l'investissement initial a le temps de créer des retombées – et d'améliorer la capacité d'absorption de l'économie nationale – avant que d'autres investissements se produisent. L'économie nationale converge alors vers un régime permanent doté d'une technologie supérieure et d'un stock de capital plus important.

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1. Introduction

The standard argument says that in the presence of positive spillovers foreign direct investment should be encouraged and subsidized. According to this view, transition economies should implement a ‘big bang’ liberalization of foreign investment, and additional fiscal measures should be adopted to ensure high enough levels of foreign investment. This belief in spillovers has prompted countries across the globe to apply a variety of incentive schemes to attract foreign investment (Hanson 2001).

Yet some emerging economies have followed a much more gradual approach in liberalizing the inflow of foreign capital. China, for instance, started opening up some of its coastal areas at the end of the 1970s, following Deng Xiaoping’s ‘Open Door Policy,’ and has since then continued to liberalize inward FDI in a piecemeal fashion (Chunlai 1997). This slow dismantling of restrictions has been justified as a way of limiting internal opposition to the reform process (Laffont and Qian 1999). It may also reflect a trial-and-error approach to liberalization (Jia 1994). Other reasons may also warrant a cautious liberalization of capital inflows. For instance, FDI may compete local industry out of the market, reducing the host country’s welfare (Glass and Saggi 1999). In addition, the empirical quest for spillovers has become increasingly elusive in recent years, further weakening the case for subsidizing and promoting FDI (Aitken and Harrison 1999).¹

The contribution of our paper is to provide a novel rationale for the gradual liberalization of inward FDI. We claim that the very presence of positive spillovers may require temporarily restricting foreign investment.² This contrasts with the result that spillovers should imply encouraging and subsidizing foreign investment. We deviate from the standard literature by showing that in the presence of spillovers gradualism can be welfare superior compared with a ‘big bang’ approach. This implies that the optimal policy may require foreign investment to be taxed in the early stages of liberalization.

These results obtain once we take into account two features of spillovers: first, technology transfers – and subsequent spillovers – are limited by the economy’s absorptive capacity; and second, spillovers take time to materialize. By letting capital in more gradually, initial investment has the time to create spillovers – and to upgrade the economy’s absorptive capacity – before further investment occurs. This allows subsequent capital inflows to benefit from greater technology transfers. As a result, the economy converges to a steady state with a superior technology and a greater capital stock. It may therefore pay off to restrict foreign investment in the initial stages of liberalization.

1 The debate on the existence of spillovers is still largely unsettled though. For instance, a recent paper by Keller and Yeaple (2003) finds significant international technology spillovers to U.S. manufacturing firms. For surveys of this empirical literature, see Blomström and Kokko (1998) and Görg and Strobl (2001).

2 This does not mean that we are taking a stance on whether spillovers are prevalent or not; rather, we are saying that, if spillovers exist, they do not necessarily justify a ‘big bang’ liberalization of foreign investment.

Again, the Chinese experience can serve as motivation. Though the reasons behind Chinese gradualism are diverse and complex, some features of how China opened up to foreign investment lend support to our description. As pointed out by Jia (1994), China started by allowing FDI into some of its coastal cities, because it was believed those areas were best prepared to benefit from technology transfers. It was hoped that those new technologies would then diffuse from the coastline into the hinterland and the interior provinces. As this process took place, more areas were opened up to FDI. In other words, China followed a stepwise strategy. It first channelled FDI to those areas with presumably the highest potential to attract new technologies. It then let the hinterland upgrade its absorptive capacity through a process of technology diffusion. In the meantime larger and larger areas were liberalized, starting at the coast and gradually moving inland (see Jia 1994, chap. 4).

Our simple theoretical model has the following features. We consider a one-sector small open economy. There is no domestic capital accumulation and no population growth. Time is discrete. Foreign investment brings technology transfers, which lead to an economy-wide externality with a one-period lag. The size of the externality is limited by the economy's level of development at the time the investment comes in. Technological progress is viewed as a pure externality. We compare the decentralized solution to the planner's solution, and show that gradual liberalization may be welfare improving.

The argument for restricting capital inflows can be split into three different steps. The first step is to show that a given amount of foreign capital leads to a bigger improvement in technology if it comes in more gradually. For example, consider an economy that receives 10 units of foreign investment. If all 10 units enter in the first period, the technology transfers will be limited by the host country's absorptive capacity at the beginning of the first period. If, instead, the 10 units enter over two periods, the first 5 units upgrade the economy's absorptive capacity by the beginning of the second period, so that the last 5 units are able to benefit from greater technology transfers. As a result, the economy's technology improves more if the 10 units come in over two periods.

The second step is to show that gradual liberalization leads to a steady state with a more advanced technology and a greater capital stock. This is easy to see: if the gradual inflow of a given amount of foreign capital brings greater technological progress, the returns to capital will also be greater. If the same capital stock can sustain higher returns, then the same returns can sustain a bigger capital stock. As a result, when the economy's returns to capital converge to the world interest rate and a steady state is reached, both the technology level and the capital stock will be greater.

The third step is to show that temporary restrictions on foreign investment may be necessary to ensure the optimal outcome. The trade-off between faster short-run growth (with lower steady-state technology and capital) and slower short-run growth (with higher steady-state technology and capital) would be of no policy concern if it were not for the existence of externalities. But given that technology

transfers lead to economy-wide learning externalities, private agents may not have the right incentives to time their investments in a socially optimal way. In that case the social planner may need to intervene by temporarily restricting capital inflows.

After analytically proving that gradual liberalization may be welfare improving compared with the 'big bang' approach, we quantitatively show that the payoffs from gradualism in emerging economies are potentially large. To reach this conclusion, we first calibrate the parameters in the model using data on FDI inflows and total factor productivity (TFP) for a sample of 90 countries between 1970 and 2000. We then solve the model numerically and compare the predicted effects on TFP under 'big bang' and gradualism for a subsample of Latin American and Southeast Asian economies. For the period 1970–2000 we find that cumulative TFP growth, relative to the technology frontier, was 8% under gradualism, compared with 2.2% under 'big bang.' The predicted TFP gains from gradualism are thus substantial. Additionally, we also show that our gradualism simulations are able to account for 57% of TFP growth and 70% of FDI inflows in the data.

The main result of the paper can be stated in relation to the standard learning-by-doing model à la Romer (1986): in spite of spillovers, which would suggest the need for subsidies, we find it to be optimal for governments to restrain (or tax) capital inflows in the early stages of liberalization. We choose the simplest possible model to make this point. Following Romer (1986), we stick to firms being competitive, and we model spillovers as being pure externalities, non-appropriable by firms, and affecting the whole economy. In contrast to the knowledge capital model (see, e.g., Markusen 2002), we abstract from firm structure.

In a model where foreign investors are not perfectly competitive, gradualism could emerge endogenously. For example, Lin and Saggi (1999) show how in a duopoly model, in which FDI by one firm lowers the cost of FDI by the other, firms may have an incentive to delay entry. In appendix C we move away from our competitive framework and show that if one foreign firm has the monopoly over FDI, it will optimally choose gradualism. This happens for two reasons. Since the monopolist can decide the economy's capital stock, it optimally chooses a lower level of capital, with a corresponding higher marginal product of capital. In addition, the monopolist internalizes the technology spillovers. As a result, quantitatively the monopolist is found to have a similar effect on TFP as gradualism.

Compared with the theoretical work on absorptive capacity (Keller 1996; Glass and Saggi 1998), the novelty of our paper is to assume not only that technology transfers depend on absorptive capacity, but also that absorptive capacity depends on technology transfers. This circular causality is important to understand our results. Starting off with low absorptive capacity, large initial inflows of capital lead to limited technology transfers and thus to limited improvements in absorptive capacity. This, in turn, restrains the technological sophistication of future foreign investment. As a result, the host country may lose its attractiveness

to foreign investors too soon, reaching a steady state with a low capital stock and a low level of technology. It may therefore pay off to follow a more gradual approach in liberalizing foreign direct investment.

2. Empirical evidence

Our argument in favour of gradualism in the liberalization of foreign investment is a consequence of two features of the model. First, spillovers from technology transfers take time to materialize. Second, technology transfers – and spillovers deriving from them – are limited by the host country's absorptive capacity. We now provide empirical support for these characteristics.

The first feature refers to technologies not achieving their full potential at the moment of introduction (Young 1991, 1992). In the particular case of FDI, Mansfield and Romeo (1980) study technology transfers by U.S. multinationals. They estimate that it takes an average of four years for transferred technologies to become available to local firms. In an analysis of inward FDI in the United Kingdom, Haskel, Pereira, and Slaughter (2002) find a period of around two years for FDI to be fully reflected in the productivity of domestic firms. Sembenelli and Siotis (2005) report a similar figure using Spanish data. Other studies, such as Keller and Yeaple (2003) and Arnold and Javorcik (2005), find shorter lags of one year or less.

The second feature is that the host country's absorptive capacity constrains the set of technologies that can be transferred (Glass and Saggi 1998). This idea dates back to Abramovitz (1986), who argued that a country's catch-up potential depends on its technical competence. There is ample empirical support for this view. For instance, in a study of 69 countries Borenstein, De Gregorio, and Lee (1998) find that the absorptive capacity of developing economies – as measured by their stock of human capital – limits the adoption of advanced technologies. It is well known that an improvement in the host country's human capital or an increase in its R&D capacity has a positive effect on technology transfers (see Keller 2001 for a survey).

One other modelling choice requires further justification. We assume that capital flows react to differences in returns. Of course, FDI may be driven by other reasons. For instance, Markusen and Maskus (2002) find strong evidence that market access, rather than differences in factor prices, is the prime motive of multinationals. However, as they point out, one possible explanation may be that the overwhelming share of world FDI is between high-income countries. In the particular case of North-South FDI, which is the focus of this paper, factor cost differentials may very well be more important. Recent evidence suggests that this is indeed the case (Hanson, Mataloni, and Slaughter 2001; Yeaple 2003). Although it is often observed that capital does not flow from rich to poor countries, once one controls for differences in human capital and technologies, the direction and the magnitude of capital flows are consistent with differences in returns

(Lucas 1990; Bardhan 1996). In the specific case of FDI, Alfaro, Kalemli-Ozcan, and Volosovych (2003) provide empirical evidence supporting this view.

3. The model

Consider a small one-sector economy with initially a closed capital market. Time is discrete. The economy is populated by a large number of identical agents. For convenience, their number is normalized to 1. Each agent is endowed with one unit of labour and a fixed amount of capital k_0 . This implies that all aggregate variables should be interpreted in 'per worker' terms. The representative agent has the following utility function:

$$U_t = \sum_{s=0}^{\infty} \beta^s \log(c_{t+s}), \quad (1)$$

where c_t is consumption. Firms are perfectly competitive and use a Cobb-Douglas technology:

$$y_t = A_t k_t^\alpha l_t^{1-\alpha}, \quad (2)$$

where k_t and l_t are the capital and labour inputs, and A_t is the technology level. In the closed economy there is no capital accumulation and no technological progress.

Once capital markets are opened, foreign investment flows in. To be more specific, the economy attracts foreign investment if at the time of liberalization the marginal product of capital r in the host economy is greater than the world interest rate r^* . The initial inflow of foreign investment is not the end of the story. FDI brings technological progress. As a result, the marginal product of capital r rises once again above the world interest rate r^* . This leads to further capital inflows. Before describing these dynamics in detail, we need to be more precise about technological progress in our discrete-time model.

To keep things tractable, we assume that technology transfers upgrade the entire economy's technology level. As in Romer (1986), spillovers are a pure externality, non-appropriable by firms, and affecting the whole economy.³ Technology transfers happen as a simple consequence of foreign capital being technologically more sophisticated. In contrast to, for instance, Ethier and Markusen (1996), we do not explicitly model the decision of firms to transfer technologies.⁴ Moreover,

3 This differs from the vintage capital story, where subsequent generations of machines become technologically more advanced. In that case, we would expect learning to be vintage specific (Solow, 1960). Young (1991) takes an intermediate view by assuming that new capital creates limited spillovers to older vintages.

4 In the knowledge capital model of multinationals costly technology transfers, and the subsequent risk of leakage, form an integral part of a firm's decision to become a multinational or not. See Markusen (2002) for an in-depth discussion and further references.

spillovers from technology transfers are assumed to be costless. Though many types of spillovers involve substantial costs – think of reverse engineering – others do not. For instance, we would expect spillovers from labour turnover, where employees from multinationals quit to set up their own firms, to be much less costly or even free (Das 1987; Pack 1997; Fosfuri, Motta and Rønde 2001).⁵ As mentioned before, this simple way of modelling technology spillovers allows us to easily compare our results with the standard learning-by-doing models à la Romer (1986).

The optimality of piecemeal liberalization in our model has to do with the two features of spillovers from FDI discussed in the previous section. These translate into the following two properties of the technology function in our discrete-time model.

PROPERTY 1. *The set of technologies that can be transferred through foreign investment at time t is limited by the host country's absorptive capacity, measured by its technology level at the beginning of time t .*

PROPERTY 2. *Technology transfers due to foreign investment at time t cause positive spillovers at time $t + 1$.*

To clarify the first property, we can think of the rest of the world as being at the technology frontier. Technologies are ranked by their level of sophistication. As in Young (1991), an economy must first dominate simple technologies before it can move to more advanced ones. The same holds for technology transfers through foreign investment. The host country's level of technical competence – its absorptive capacity – constrains the set of technologies that can be transferred. This is reminiscent of Glass and Saggi (1998), who propose a quality ladder model, in which technology transfers from FDI can never make the host country move up the ladder by more than one rung, independently of how much FDI takes place.

Regarding the second property, the literature has generally considered the *level* of technology to be either a function of cumulative production (Young 1991) or investment (Kaldor 1957; Arrow 1962; Romer 1986). We follow the latter view by assuming TFP *growth* depends on the flow of FDI, not on its stock. This is standard in both the theoretical and the empirical literature on the effect of FDI on productivity (Rodríguez-Clare 1996; Blomström and Kokko 1998). However, we also incorporate the underlying idea of Young (1991) that learning requires experience and time by assuming that spillovers from FDI materialize with a one-period lag. It is worth clarifying that, although technology spillovers depend on the flow, not the stock, of FDI, this does not imply productivity growth is not sustained through time. Because of the one-period lag in spillovers, FDI in one period attracts further FDI the next period.

5 For an excellent survey on different kinds of spillovers and further references, see Saggi (2002).

Properties 1 and 2 allow us to postulate the following economy-wide technology function:

$$A_{t+1} = A_{t+1}^* - (A_{t+1}^* - A_t)e^{-\lambda(K_t - K_{t-1})}$$

where

$$A_{t+1}^* = \begin{cases} A_t + \gamma & \text{if } A_t + \gamma \leq A^* \\ A^* & \text{else} \end{cases}, \quad (3)$$

where λ and γ are exogenously given parameters and K_t is the economy's aggregate capital stock at time t . An example will help to highlight the features of this function. In period t the host economy's technology level is A_t . Foreign investment in period t , $K_t - K_{t-1}$, brings in technology transfers, that improve the economy's technology A_{t+1} in period $t + 1$. Because absorptive capacity limits the technologies that can be transferred, A_{t+1} has an upper bound A_{t+1}^* . As can be seen, this upper bound A_{t+1}^* means that the technology can never improve by more than γ between any two periods t and $t + 1$, without of course ever surpassing the world technology frontier A^* . It is important to realize that because spillovers are modelled as a pure externality, all firms share the same technology level.

3.1. The decentralized solution: 'big bang' liberalization

We start by describing the dynamics of the 'big bang' approach. This refers to the complete and immediate liberalization of inward FDI. Since there is no government intervention, this can be thought of as the decentralized solution. Given that technological progress is a pure externality, non-appropriable by firms and affecting the entire economy, in each period capital flows in until the host country's marginal returns to capital are equal to the world interest rate. We assume that all restrictions on capital inflows are lifted at time $t = 1$. If r_1 is greater than r^* , foreign investment comes in until returns equalize. By the beginning of period $t = 2$ the economy has learned how to use the technologies transferred by foreign investment in period $t = 1$. This technological progress raises the host country's returns once again above r^* , thus attracting a fresh inflow of foreign investment. This process continues until the economy converges to a steady state.

For a given initial level of technology A_1 and an initial aggregate stock of capital K_0 , we can easily solve for the path of capital stocks and technology levels. In each period t foreign investment enters until the marginal return to capital equalizes the world interest rate:

$$\alpha A_t K_t^{\alpha-1} = r^*.$$

This, combined with the technology function (3) and the initial conditions A_1 and K_0 , is enough to compute $\{K_t, A_t\}_{t=1}^{\infty}$. Assuming a competitive labour market, the wage rate w_t is

$$w_t = (1 - \alpha)A_t K_t^{\alpha-1}.$$

Given $\{K_t, A_t, w_t\}_{t=1}^{\infty}$, the representative agent then solves the following optimization problem:

$$\begin{aligned} \max_{\{c_t\}_{t=1}^{\infty}} \quad & \sum_{t=1}^{\infty} \beta^{t-1} \log(c_t) \\ \text{s.t.} \quad & \sum_{t=1}^{\infty} \frac{w_t + r^* k_0}{(1+r^*)^t} = \sum_{t=1}^{\infty} \frac{c_t}{(1+r^*)^t} \\ & k_0 \text{ given.} \end{aligned} \tag{4}$$

Note that agents can borrow and lend in the international capital market at interest rate r^* . If $\beta = 1/(1+r^*)$, this implies that consumption will be constant in each period. We call this value permanent consumption.

3.2. The planner's solution: gradual liberalization

We start by showing that imposing (temporary) capital controls increases steady-state income. This is stated in proposition 1.

PROPOSITION 1. *Gradualism in the form of imposing (temporary) controls on the inflow of foreign capital raises the host country's steady-state capital and technology, compared with the 'big bang' approach.*

Proof. See appendix A.1

To understand this result, go back to our two stylized facts: technology transfers are limited by the host economy's absorptive capacity, and learning how to use those transfers takes time. By restricting foreign investment, the economy has the time to learn about the technology transfers from the previous period, thus upgrading its absorptive capacity before more capital comes in. This allows future foreign investment to transfer more sophisticated technologies. It follows that, for a given stock of foreign capital, the economy reaches a higher level of technology – and returns are higher – if that capital came in more gradually. If the same capital stock can sustain higher returns, then the same returns can sustain a greater capital stock. Therefore, compared with the steady state under the 'big bang' approach, when returns eventually converge to the world interest rate, the capital stock will be greater and the technology more advanced.

What drives the results in our model are the two properties of the technology accumulation function: absorptive capacity and delay. In contrast to the standard learning-by-doing model à la Romer (1986), this leads to path dependence: the effect on technology of an inflow of foreign capital is greater if the capital comes in more gradually. To see the difference between both approaches, note that in Romer (1986) A depends on K , not on how K was accumulated. As a result, there would never be an incentive to postpone capital inflows: reaching

the same steady state, but later, could hardly be welfare improving. In fact, with a Romer-like technology function, optimal policy would call for encouraging, rather than slowing down, capital inflows. In contrast, in our model A depends on the entire path of past investments. There is no longer a one-to-one relation between K and A . This path dependence leads to a more complex spillovers structure. It implies that giving up some spillovers today may lead to greater spillovers tomorrow. This is the intuition of why slowing down capital inflows may be welfare improving. To highlight the importance of properties 1 and 2, proposition 2 in appendix A.2 shows that, if either one of them fails, there is no longer path dependence. In that case, proposition 1 would cease to hold, and the motive for slowing down FDI would vanish.

Although we have shown that temporarily restricting the inflow of foreign investment increases steady-state capital and technology, this comes at the cost of lower short-run growth. The economy therefore faces a trade-off. On the one hand, limiting capital inflows increases long-run capital and technology. On the other hand, slowing down capital accumulation dampens the economy's short-run growth.

In the remainder of this section we distinguish between two cases, depending on the policy instruments available to the social planner. We start by looking at the possibility of introducing quotas on foreign investment. Though this is enough to show that temporary restrictions may be welfare improving, we would expect taxes to lead to a Pareto-superior outcome by providing additional government income. In a second exercise we therefore consider taxes as a way of controlling capital inflows, and confirm our prior.

3.2.1. Optimal path of foreign investment using quotas

In this exercise the social planner determines the optimal path of foreign capital inflows using quotas. In other words, for each period a maximum amount of foreign investment is announced. As soon as the quota for a given period is reached, no further capital is allowed to enter.⁶ To determine these quotas, the planner solves the following maximization problem:

$$\begin{aligned}
 & \max_{\{C_t, A_t, K_t\}_{t=1}^{\infty}} \sum_{t=1}^{\infty} \beta^{t-1} \log(C_t) & (5) \\
 \text{s.t.} & \sum_{t=1}^{\infty} \frac{(1 - \alpha) A_t K_t^{\alpha-1} + \alpha A_t K_t^{\alpha-1} K_0}{(1 + r^*)^t} = \sum_{t=1}^{\infty} \frac{C_t}{(1 + r^*)^t} \\
 & A_{t+1} - A_t = \gamma(1 - e^{-\lambda(K_t - K_{t-1})}) \\
 & \alpha A_t K_t^{\alpha-1} \geq r^* \\
 & K_0, A_1 \text{ given,}
 \end{aligned}$$

6 Alternatively, the government could auction off the rights to invest. In that case quotas would act in the same way as taxes.

where upper-case C_t refers to aggregate consumption. According to (5), the planner chooses the sequence of consumption, capital stock, and technology that maximizes the discounted sum of period utility. However, by substituting the first and the second constraint into the objective function, it should be obvious that the social planner's problem reduces to choosing the sequence of capital stocks. Note, furthermore, from the third constraint that the domestic return to capital cannot fall below the world interest rate. If technological progress takes the form of an externality non-appropriable by firms, then under complete capital market liberalization foreign investment comes in until returns equalize. Consequently, quotas can never cause returns to drop below those in the rest of the world.

3.2.2. Optimal path of foreign investment using taxes

We now solve for the optimal path of foreign investment, assuming the planner can use taxes. Compared with the previous exercise, we should expect taxes to be welfare improving over quotas, as they lead to additional government income.

We must be precise about what is being taxed. If only new foreign investment were to be taxed, not the entire capital stock, investors might be willing to put up with returns below r^* at the time of entry, in order to reap returns above r^* in future periods. To keep things simple, we therefore assume that taxes apply to the entire capital stock, not just to new investment.

The social planner's maximization problem can therefore be written as

$$\begin{aligned} \max_{\{C_t, A_{t+1}, K_t, \tau_t\}_{t=1}^{\infty}} & \sum_{t=1}^{\infty} \beta^{t-1} \log(C_t) & (6) \\ \text{s.t.} & \sum_{t=1}^{\infty} \frac{(1-\alpha)A_t K_t^{\alpha-1} + \alpha A_t K_t^{\alpha-1} K_0 + \tau(K_t - K_0)}{(1+r^*)^t} = \sum_{t=1}^{\infty} \frac{C_t}{(1+r^*)^t} \\ & A_{t+1} - A_t = \gamma(1 - e^{-\lambda(K_t - K_{t-1})}) \\ & \tau_t = \alpha A_t K_t^{\alpha-1} - r^* \\ & \tau \geq 0 \\ & K_0, A_1 \text{ given.} \end{aligned}$$

Since taxing domestic capital does not affect domestic income, the first constraint includes only tax proceeds coming from the foreign-owned capital stock. The second constraint is obvious. The third constraint says that the net return to capital should equal the world interest rate. Since taxes apply to the entire capital stock, foreigners invest until returns equalize. The fourth constraint says that taxes should be positive. As in the exercise with quotas, the first and the second constraint imply that the planner's problem amounts to choosing how much capital to let in by setting the tax rates in each period.⁷

⁷ It can be shown that the tax considered here is equivalent to a tax on the return to foreign capital, in the sense that it leads to the same necessary conditions for maximization.

4. Calibration

Before numerically solving our model, we need to assign values to the parameters λ and γ . To do so, we use data for a large sample of countries, and the technology equation (3).⁸ We construct data counterparts of the theoretical variables A_t and $(K_t - K_{t-1})$ and find the values of γ and λ that minimize the sum of squared residuals,

$$\min_{\lambda, \gamma} \sum_{j=1}^N (A_{j+1} - [A_j + \gamma(1 - e^{-\lambda(K_j - K_{j-1})})])^2, \quad (7)$$

where each observation j corresponds to a country and a year. Using time periods of one year means we are assuming that spillovers materialize with a one-year lag.

4.1. Data

Data on FDI inflows come from UNCTAD.⁹ All other data come from Klenow and Rodriguez-Clare (2005). By merging both datasets, we get a panel of 90 countries and 30 years (1970–2000). We now discuss the construction of variables consistent with our model.

In the data TFP tends to display a positive trend in most countries. In contrast, in our model TFP converges to a steady state with zero growth. This is because the theoretical model focuses on a country's catch-up to a fixed technological frontier. To capture the catch-up component, we therefore detrend each country's TFP growth by the growth of the technological frontier, assumed to be the United States. This detrended TFP gives us the catch-up component of TFP, which the models views as being the result of positive spillovers from inward FDI.

In our model all aggregate variables, such as FDI, are written in per worker terms. To be consistent with the data in Klenow and Rodriguez-Clare (2005), who compute TFP in a model with physical and human capital (rather than labour), we express FDI inflows in per human capital terms.

4.2. Parameter values

We determine γ and λ by numerically minimizing the sum of squared residuals (7). We use an unconstrained minimization routine.¹⁰ We consider a number of different specifications. The simplest specification involves pooling all countries and all years. The richest specification includes variables for seven different regions (Eastern Europe and Central Asia; East Asia and Pacific; Middle East and

⁸ We assume that the world technology frontier is not reached. In the numerical exercises the world technology frontier, A^* , is never binding.

⁹ The UNCTAD dataset is available at <http://stats.unctad.org/FDI/>.

¹⁰ The algorithm is available at <ftp://ftp.mpls.frb.fed.us/pub/research/mcgrattan/mfiles/uncmin.m>, and is due to Ellen R. McGrattan.

North Africa; Latin America and Caribbean; South Asia; Sub-Saharan Africa; Western Europe, the U.S., and Canada) and three different decades (1970s, 1980s, 1990s). Including dummies amounts to allowing for different values of γ across these different country groupings and time periods. There are D dummy variables indexed by i . Dummy variables corresponding to observation j are denoted by d_{ij} . This allows us to rewrite the minimization problem (7) as

$$\min_{\lambda, \gamma_i} \sum_{j=1}^N \left(A_{j+1} - \sum_{i=1}^D [A_j + \gamma_i d_{ij} (1 - e^{-\lambda(K_j - K_{j-1})})] \right)^2.$$

Depending on the number of dummies included, we get different values of λ and γ . In the simplest specification, with no dummies, we find $\lambda = 0.002$ and $\gamma = 2.88$. In the richest specification, with 10 dummies, we find a λ of 0.0045 and an average γ of 3.35. We have also tried specifications in which we eliminate, for example, the 1970s or Sub-Saharan Africa. Using alternative specifications, we find that the value of λ falls between 0.002 and 0.005, whereas the value of γ lies between 2.42 and 3.61.¹¹ Averaging over these different specifications gives $\lambda = 0.0035$ and $\gamma = 3.00$. These are the values we will use in our benchmark numerical experiment.

5. Model predictions

In this section we use the calibrated model to analyze how the planner's solution improves over the decentralized solution. In particular, we are interested in understanding the importance of gradualism for TFP growth. To support our findings, we contrast the predicted values of TFP growth and FDI inflows with those in the data. The simulations focus on nine Latin American and nine East Asian countries.¹² We have chosen this subsample for two reasons. First, it includes a varied group of countries, some with high and others with low TFP growth rates and FDI inflows. We wanted to focus exclusively neither on stories of relative success (East Asia), nor on stories of relative failure (Latin America). Second, the subsample is smaller and has different characteristics than the one we used to calibrate γ and λ .

Before running our numerical experiments, we need to define the empirical counterparts of some variables in our theoretical model. We start by defining the world interest rate, r^* . In our benchmark experiment, we set r^* equal to the U.S. marginal product of capital in 2000, because we consider it to be a reasonable approximation of the long-run world interest rate. In the Klenow and

11 The details of these different specifications are available upon request.

12 The list of countries is Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Mexico, Peru, Venezuela, Hong Kong, Indonesia, Japan, Korea, Malaysia, Philippines, Singapore, Taiwan, Thailand.

Rodriguez-Clare (2005) database this corresponds to a high number: 18%.¹³ However, what drives most of the results is the differences in returns across countries, not the absolute levels of those returns. Given that we view r^* as the long-run world interest rate, we accordingly set the discount rate $\beta = 1/(1 + r^*)$. We now turn to choosing the initial values of TFP, A , and the capital stock, K . Using the dataset of Klenow and Rodriguez-Clare (2005), we set the initial A equal to the average TFP level in our subsample of eighteen countries in 1970. Computing the initial value of the capital stock is more elaborate. We start by computing the difference in the average marginal product of capital in our subsample and the marginal product of capital in the U.S. in 1970. This difference is 3.3%.¹⁴ We then set the initial capital stock in such a way that the implicit marginal product of capital is 3.3% higher than the world interest rate r^* . In other words,

$$K = \left(\frac{\alpha A}{r^* + 0.033} \right)^{\frac{1}{1-\alpha}},$$

where A is the initial value of TFP, and $\alpha = 1/3$, as in Klenow and Rodriguez-Clare (2005). In the theoretical model the initial values of TFP and the capital stock are denoted by A_0 and K_1 .

5.1. Benchmark experiment

With values for A_0 , K_1 , λ , γ , α , r^* , and β , we are ready to solve the model numerically, for both the decentralized problem and the planner's problem. The main goal is to measure the gains from gradualism. In the benchmark experiment we take $\lambda = 0.0035$ and $\gamma = 3.00$.

Before we report the results, it is worth remembering that the underlying idea of our model is that TFP growth in emerging economies is made up of two parts: an exogenous component, equal to the growth of the technology frontier, and an endogenous catch-up component due to technology transfers and spillovers from FDI. Therefore, whenever we refer to either predicted or actual TFP growth, it is always relative to the technology frontier, which in the data we take to be the United States. Between 1970 and 2000 in our subsample of 18 countries, cumulative TFP growth, relative to the U.S., was 11.5%.

13 In principle, the real interest rate should exclude the depreciation rate. Klenow and Rodriguez-Clare (2005) use an annual depreciation rate of 8% when constructing physical capital stocks. This would give a real interest rate of 10% for the U.S. in 2000. However, we choose to work with the implicit marginal product of capital, because in our model the depreciation rate is zero.

14 To be precise, 3.3% measures the difference in the marginal products of capital between our subsample and the U.S. in excess of the long-run difference. This excess difference is the relevant one if for a variety of reasons, such as risk premia, there continues to be a positive difference in steady state. The difference in the year 2000 was 2%; the difference in the year 1970 was 5.3%. If we take the year 2000 to be the long run, the excess initial difference is 5.3% minus 2%, which gives us 3.3%.

TABLE 1
Benchmark experiment

	Data	Model	% accounted
Big bang liberalization			
Growth TFP	11.5	2.2	19.2
Growth capital due to FDI	77.9	33.0	42.3
Planner: quotas			
Growth TFP	11.5	8.0	69.5
Growth capital due to FDI	77.9	44.3	56.9
Planner: taxes			
Growth TFP	11.5	9.0	78.6
Growth capital due to FDI	77.9	46.4	59.6

Starting off with initial values for A_0 and K_1 , we numerically compute the paths of TFP growth and capital accumulation through FDI for both the decentralized economy ('big bang') and the planner ('gradualism'). Computing those paths in the decentralized case is trivial. In each period FDI flows in until the marginal product of capital is equal to r^* . Thanks to spillovers from technology transfers, one period later the economy's TFP improves, following the technology function (3). This raises the marginal product of capital above r^* , attracting further FDI. In the case of the planner, we distinguish between two policy instruments to manage capital inflows: quotas and taxes. Those problems are described in (5) and (6). Details about the numerical algorithm can be found in appendix B.

Table 1 reports the results of our benchmark experiment. Our findings suggest that gradualism improves substantially over the decentralized solution. Whereas in the decentralized solution cumulative TFP growth is 2.2%, this figure increases to 8.0% when the planner is allowed to use quotas to restrain capital inflows. This amounts to an improvement by a factor of 3.6. When taxes are used, cumulative TFP growth rises even further, to 9.0%, an increase by a factor of 4.1, compared with the decentralized economy. According to our theoretical model, this is due to the planner slowing down inflows in the early stages of liberalization. Figure 1 shows this graphically for the case of quotas. In the early years capital inflows are slower than they are under complete liberalization. This allows the economy's absorptive capacity to upgrade before further capital comes in. As a result, a given amount of capital inflow has a greater effect on TFP, and the economy converges to a higher steady-state level of capital and TFP. Figure 2 shows the same information for the case of taxes. As can be seen, the planner chooses an initial tax rate on capital inflows of 3%.¹⁵ This optimal tax schedule declines over time, and FDI is completely liberalized after 14 years.

15 Although there are no fully satisfactory tariff (or tax) equivalent measures of FDI restrictions, this figure is not large. For a discussion of such measures, see Hardin and Holmes (1997), Hoekman (2001), and Brown and Stern (2001).

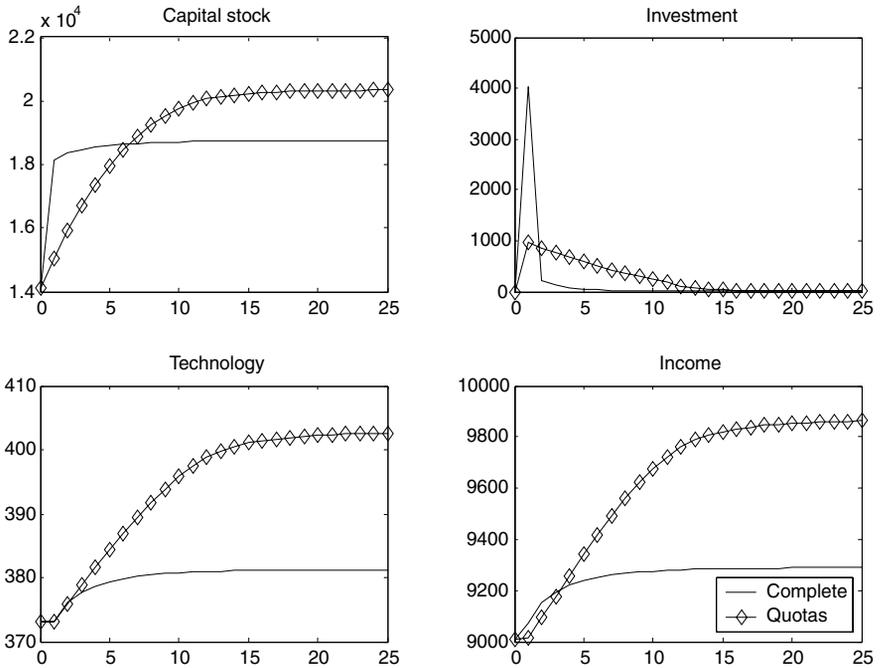


FIGURE 1 Quotas vs. complete liberalization

To see whether our simulation results are sensible, we compare the predicted growth rates of TFP and the predicted FDI inflows to the data. Compared with the actual figures, the planner's solution with quotas can account for 69.5% of TFP growth and 56.9% of capital inflows. In the case of the planner's solution with tariffs, the part of TFP growth and capital inflows we can account for increases to, respectively, 78.6% and 59.6%. These findings suggest that the parameter values we are using are reasonable, lending support to the simulated TFP gains from gradualism.¹⁶

In terms of welfare, our simulations find that using quotas raises permanent consumption by 1.5%, compared with the decentralized solution. Using taxes increases this number to 1.7%. These improvements in permanent consumption may not seem substantial. However, small differences in welfare in comparisons of different capital market configurations are not unusual. Gourinchas and Jeanne

16 Note that gradualism accounts for a much greater proportion of TFP growth and FDI inflows in the data than the 'big bang' approach. With 'big bang' liberalization, the model accounts for 19.2% of TFP growth (compared with 78.6% in the case of taxes) and 42.3% of FDI inflows (compared with 59.5% in the case of taxes). Given that gradualism does a better job of accounting for the data, this could be viewed as indirect evidence that emerging economies have indeed been liberalizing gradually. However, to make this point more quantitative information would be needed about the actual liberalization policies of those developing countries.

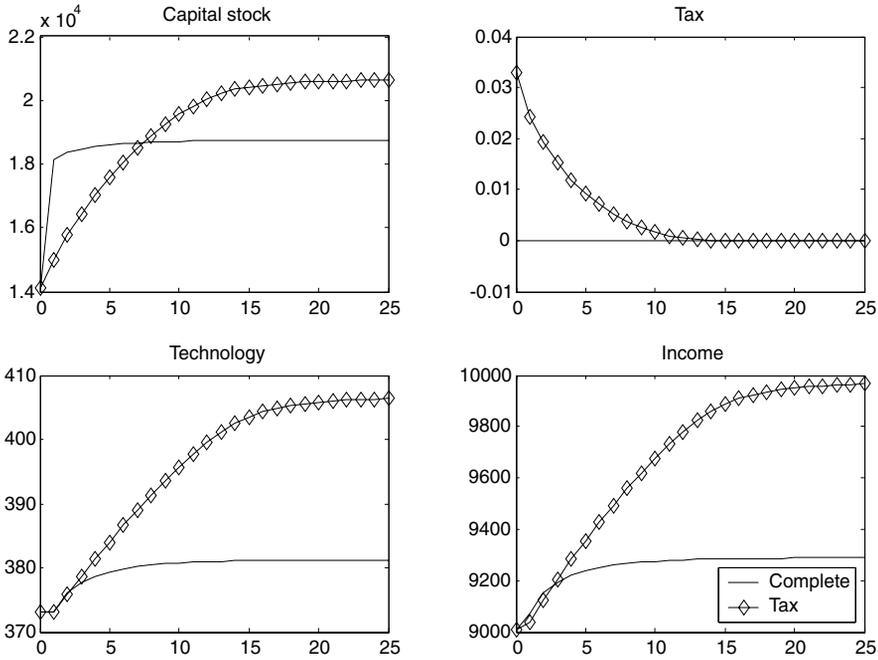


FIGURE 2 Taxes vs. complete liberalization

(2003), for example, find that moving from financial autarky to open capital markets leads to a permanent increase in consumption of 1%.

In our model the need for slowing down capital inflows is related to competitive investors not internalizing the dynamics of spillovers. In appendix C we move away from the competitive framework and assume that one foreign firm has the monopoly over FDI. We show that the foreign monopolist will optimally choose a more gradual sequence of FDI, compared with the one obtained in a competitive framework when liberalization occurs in a ‘big bang’ fashion.

5.2. Sensitivity

In this section we analyze how sensitive our results are to some of the choices we made in the benchmark experiment. In particular, we perform two types of sensitivity analysis: on the values of λ and γ , and on the sample of countries. The results are reported in table 2. For comparison purposes, panel 0 in table 2 reproduces the main results for the benchmark case.

The first experiment concerns changing the values of γ and λ . A higher γ implies increasing the economy’s catch-up potential in each period. This leads to higher TFP growth and capital inflows. A higher λ corresponds to a more concave learning function in each period, implying a greater marginal benefit

TABLE 2
Sensitivity analysis

	Data	Big bang		Quotas	
		Model	Accounted (in %)	Model	Accounted (in %)
0. Benchmark					
Growth TFP	11.5	2.2	19.2	8.0	69.5
Growth capital due to FDI	77.9	33.0	42.3	44.3	56.9
1. High γ and λ $\gamma = 3.1, \lambda = 0.0037$					
Growth TFP	11.5	2.7	23.9	9.0	78.2
Growth capital due to FDI	77.9	34.0	43.6	46.4	59.5
2. Low γ and λ $\gamma = 2.9, \lambda = 0.0033$					
Growth TFP	11.5	1.9	16.1	7.1	61.6
Growth capital due to FDI	77.9	32.3	41.4	42.5	54.6
3. Smaller sample of 14					
Growth TFP	15.9	2.2	13.9	2.8	17.9
Growth capital due to FDI	81	20.0	24.7	27.9	34.4
4. Larger sample of 21					
Growth TFP	7.6	2.2	28.9	7.7	101.4
Growth capital due to FDI	76.7	32.0	41.7	42.8	55.8

from postponing FDI inflows. Panel 1 in table 2 shows that, compared with the benchmark experiment, a higher γ and λ leads to higher TFP growth, both under 'big bang' liberalization and under quotas. Lowering γ and λ has the opposite effects. This can be seen in panel 2. However, in both cases the benefit from gradualism, relative to 'big bang,' continues to be large.

The second experiment changes the sample of countries. In panel 3 we leave out two Asian and two Latin American countries, in particular, Bolivia, Ecuador, Indonesia, and the Philippines.¹⁷ This gives us a sample of 14 emerging economies: seven Latin American and seven East Asian countries. An important difference from the benchmark case is that the initial differential with the world interest rate drops from 3.3% to 1.9%. Not surprisingly, this implies the model generates less capital inflow, and there is thus less room for TFP growth. The gains from gradualism on TFP, though still positive, are now smaller. Quotas generate a 2.8% growth in TFP, compared with 2.2% under the 'big bang' approach. In this sample of countries, the predicted values of TFP growth and FDI inflows explain a smaller part of the actual data, compared with the benchmark case.

17 Bolivia and Ecuador were left out, since they were the two smallest Latin American countries in our sample of 18. Indonesia and the Philippines were removed because they were 'outliers' compared with other East Asian economies for the period 1970–2000; they displayed a significantly higher marginal product of capital and lower TFP growth, respectively.

In panel 4 we increase the sample to 21 countries by adding Costa Rica, Panama, and Uruguay.¹⁸ Once again, gradualism has an important impact on TFP growth. When we use quotas, TFP growth, relative to the technology frontier, is 7.7%, compared with 2.2% in the decentralized solution. In this sample, the predicted values of TFP growth and FDI inflows explain a larger fraction of the actual data, compared with the benchmark case. In particular, in the case of quotas our simulations account for 101.4% of TFP growth and 55.8% of FDI inflows.

6. Conclusion

This paper has presented a novel rationale for the gradual liberalization of inward FDI by showing that the presence of spillovers may require temporarily restricting the inflow of foreign capital. This stands in contrast to the standard argument, which claims that spillovers should call for the promotion, rather than the restriction, of foreign investment. Our result is a consequence of incorporating two features of spillovers into a simple model. First, the extent of technology transfers – and subsequent spillovers – is limited by the host country's absorptive capacity. Second, spillovers take time to materialize. As a result, if foreign investment enters gradually, it has the time to create spillovers, and upgrade the country's absorptive capacity, before more capital comes in. Subsequent capital inflows will then benefit from greater spillovers. This means that a given amount of foreign investment leads to more technological progress if it enters more gradually. Compared with complete capital market liberalization, restricting foreign investment leads to a steady state with a bigger capital stock and a superior technology.

Quantitatively, we show the gains from gradualism on TFP to be large in a sample of East Asian and Latin American economies. Under complete liberalization, we find that cumulative TFP growth, relative to the technology frontier, is 2.2% for the period 1970–2000. When quotas are introduced in the early phases of liberalization, the cumulative TFP growth increases to 8.0%. Using tariffs, rather than quotas, gives an even higher number of 9.0%. We view these results as evidence that gradualism matters.

This paper suggests a number of areas for future research. First, we have considered markets to be perfectly competitive, in spite of FDI often being dominated by large firms. Moreover, the micro-foundations of spillovers have not been explicitly modelled. Incorporating these elements into a calibrated model to further explore the relation between foreign investment and productivity should be useful. Second, our numerical simulations provide evidence of the positive effect of gradualism on TFP. However, they do not constitute a test of the theoretical model. Such a test would require quantitative information on the speed of

18 No further East Asian economies are added, owing to lack of data.

liberalization of FDI in different countries. Although some evidence exists for a limited number of OECD countries (Golub 2003), no comprehensive time series data are available for a broad set of emerging economies.

Appendix A: Proofs

A.1. Proof of proposition 1

We start by proving the following lemma:

LEMMA 1. *Under a 'big bang liberalization' the steady-state level of technology is strictly below A^* .*

Proof. The proof of this lemma proceeds in two steps:

- a) Compare the technology function given by (3), henceforth referred to as technology function 1, with technology function $A = A^* - (A^* - A_0)e^{-\lambda(K-K_0)}$ (where $K - K_0$ is the accumulated inflow of foreign investment), henceforth referred to as technology function 2. We show that for any amount of capital inflows, the technology level under technology function 2 is greater than or equal to the technology level under technology function 1.
- b) We then show that under technology function 2 the economy's technology level in stationary state is strictly below A^* .

Step (a) and step (b) then allow us to complete the proof.

Let us first prove step (a). We start by showing that the marginal effect of capital inflows on the technology level is greater under technology function 2 than under technology function 1. Take some level of technology A' . For technology function 1, we bias the results against us by taking the marginal effect on technology when $I = 0$ (since timing does not matter, we are dropping time subscripts):

$$\frac{\partial A}{\partial I} \Big|_{\{I=0, A=A'\}} = \lambda\alpha, \quad (8)$$

where $\alpha \leq A^* - A'$. Compare this with the marginal effect on technology of capital inflows under technology function 2: $\partial A / \partial I \Big|_{A=A'} = \lambda(A^* - A_0)e^{-\lambda K}$, where K can be derived from the fact that $A' = A^* - (A^* - A_0)e^{-\lambda K}$, so that

$$\frac{\partial A}{\partial I} \Big|_{A=A'} = \lambda(A^* - A'). \quad (9)$$

Since $\alpha \leq A^* - A'$, the marginal effect of capital inflows is weakly superior under technology function 2 than under technology function 1. When we start off with identical initial conditions, this implies that for a same amount of capital inflows, the technology level under technology function 2 will be greater than or equal

to the technology level under technology function 1. This concludes the proof of step (a).

Let us now prove step (b). Under technology function 2 we know that A^* is reached only if K goes to infinity. But as K goes to infinity, the return to capital goes to 0. Since the world interest r^* is assumed to be strictly positive, in steady state K must be finite, so that the technology level must be strictly below A^* . This concludes the proof of step (b).

From (a) and (b) it follows that the steady-state level of technology is weakly inferior under technology 1 than under technology 2 and therefore is strictly lower than A^* . ■

Proof of proposition 1. Using lemma 1, we now proceed to prove proposition 1. Take the sequence of accumulated capital inflows under complete capital market liberalization, $\{K_1^1, K_2^1, \dots, K_t^1, K_{t+1}^1, \dots\}$, and call this sequence 1. Following proposition 1, this sequence reaches a steady-state technology level $A^{*1} < A^*$. Now take a different sequence of accumulated capital inflows, $\{K_1^2, K_2^2, \dots, K_t^2, K_{t+1}^2, \dots\}$ and call this sequence 2. Assume that $\{K_1^2, K_2^2, \dots, K_t^2, K_{t+1}^2, \dots\} = \{K_1^1/2, K_1^1, K_2^1, \dots, K_t^1, K_{t+1}^1, \dots\}$. In other words, the capital inflows during period 1 in sequence 1 are spread equally over two periods in sequence 2; from then onwards period t capital inflows in sequence 2 are identical to period $t - 1$ capital inflows in sequence 1.

The rest of the proof will go through the following steps: (a) It will be shown that for any given level of accumulated capital inflows the technology level is higher in sequence 2 than in sequence 1. (b) This implies that in sequence 2 the technology level A^{*1} is reached for a lower level of capital inflows than in sequence 1. (c) We then design a new sequence of accumulated capital inflows, sequence 3, which coincides with sequence 2 until A^{*1} is reached, after which we let foreign capital come in freely. It is easy to show that sequence 3 (which involves capital controls until A^{*1} is reached) leads to a higher steady-state level of technology and welfare, compared with sequence 1 (full capital market liberalization).

We start by proving steps (a) and (b). Initial productivity for both sequences is identical: A_1 . In sequence 1 capital inflows K_1^1 give the following technology level:

$$A_2^1(K_1^1) = A_1 + \gamma - \gamma e^{-\lambda(K_1^1 - K_0)}. \tag{10}$$

As said before, in sequence 2 this same amount of foreign investment K_1^1 enters equally spread over two periods; that is, $K_2^2 = K_1^1$. The technology level, once learning has occurred, will be

$$A_3^2(K_2^2) = A_1 + 2\gamma - 2\gamma e^{-\lambda \frac{(K_2^2 - K_0)}{2}}. \tag{11}$$

Since $K_2^2 = K_1^1$, we can simplify notation by writing $K_2^2 = K_1^1 = K_1$. This allows us to write $A_2^1(K_1^1) = A^1(K_1)$ and $A_3^2(K_2^2) = A^2(K_1)$. The derivative of

$A^2(K_1) - A^1(K_1)$ with respect to K_1 is strictly positive if $K_1 > 0$. Given that $A^2(K_1) - A^1(K_1) = 0$ when $K_1 = 0$, this implies that $A^2(K_1) > A^1(K_1)$ as soon as $K_1 > 0$. Equivalently, $A^2(K_2^2) > A^1(K_1^1)$.

To complete the proof of (a) and (b) we now show that if $A^2(K_{t+1}^2) > A^1(K_t^1)$, then $A^2(K_{t+2}^2) > A^1(K_{t+1}^1)$. Following the above notation, $K_{t+1}^2 = K_t^1 = K_t$ and $K_{t+2}^2 = K_{t+1}^1 = K_{t+1}$. Using this notation, we need to show that if $A^2(K_t) > A^1(K_t)$, then $A^2(K_{t+1}) > A^1(K_{t+1})$. In sequence 1 the technology level after an accumulated inflow of $K_{t+1} = K_{t+1}^1$ is

$$\begin{aligned}
 A^1(K_{t+1}^1) &= A^1(K_{t+1}) \\
 &= \begin{cases} A^1(K_t) + \gamma - \gamma e^{-\lambda(K_{t+1}-K_t)} & \text{if } \gamma < A^* - A^1(K_t) \\ A^* - (A^* - A^1(K_t))e^{-\lambda(K_{t+1}-K_t)} & \text{else.} \end{cases} \quad (12)
 \end{aligned}$$

Likewise, under sequence 2 the technology level after an accumulated inflow of $K_{t+1} = K_{t+2}^2$ is

$$\begin{aligned}
 A^2(K_{t+2}^2) &= A^2(K_{t+1}) \\
 &= \begin{cases} A^2(K_t) + \gamma - \gamma e^{-\lambda(K_{t+1}-K_t)} & \text{if } \gamma < A^* - A^2(K_t) \\ A^* - (A^* - A^2(K_t))e^{-\lambda(K_{t+1}-K_t)} & \text{else,} \end{cases} \quad (13)
 \end{aligned}$$

where $K_t = K_{t+1}^2$ and $K_{t+1} = K_{t+2}^2$. Given that $A^2(K_t) > A^1(K_t)$, there are three possibilities: (i) $\gamma < A^* - A^2(K_t)$ and $\gamma < A^* - A^1(K_t)$; (ii) $\gamma \geq A^* - A^2(K_t)$ and $\gamma < A^* - A^1(K_t)$; (iii) $\gamma \geq A^* - A^2(K_t)$ and $\gamma \geq A^* - A^1(K_t)$. In each of the three possibilities, subtracting (12) from (13) gives us the result that $A^2(K_{t+1}) > A^1(K_{t+1})$. Equivalently, $A^2(K_{t+2}^2) > A^1(K_{t+1}^1)$. Therefore, if sequence 1 reaches A^{*1} in steady state, it must be that sequence 2 reaches A^{*1} for a lower level of capital inflows. This completes the proof (a) and (b).

We now prove part (c). The capital inflows in sequence 3 are identical to those in sequence 2 until A^{*1} is reached; after that the capital market is fully liberalized, so that capital inflows are determined by the condition that returns to capital should equal the world interest rate. From (b) we know that sequence 2, and thus sequence 3, reach A^{*1} for an accumulated stock of foreign capital inferior to that in sequence 1. This implies that returns to capital are strictly above r^* . At this point capital markets are fully liberalized, so that capital comes in until returns equalize. Since the technology level in sequence 3 is equal to the steady-state level in sequence 1, it is obvious that after the inflow of foreign investment the capital stock in sequence 3 will likewise equal the steady-state capital stock in sequence 1. The difference, however, is that sequence 3 has not reached steady state. Since there has been a strictly positive inflow of foreign capital, the technology level in the next period increases, thus pushing returns to capital back above r^* . This leads to further capital inflows, so that in the steady state corresponding to

sequence 3 both the capital stock and the technology level are greater than in sequence 1. ■

A.2. Proof of proposition 2

PROPOSITION 2. *Property 1 (absorptive capacity) and Property 2 (delay) are necessary for path dependence.*

Proof. First assume that Property 1 does not hold. If absorptive capacity does not limit the adoption of new technologies, the host economy's only constraint is the world technology frontier A^* . In that case, the technology function (3) can be rewritten as

$$A_{t+1} = A^* - (A^* - A_t)e^{-\lambda(K_t - K_{t-1})}.$$

Iterating, this simplifies to

$$A_{t+1} = A^* - (A^* - A_0)e^{-\lambda(K_t - K_0)}. \quad (14)$$

This technology function now depends only on $K_t - K_0$; it no longer depends on how $K_t - K_0$ was accumulated. This implies there is no more path dependence. Therefore, postponing foreign investment would not have any effect on steady-state income. In fact, it is straightforward to compute the steady-state capital stock and technology level. In steady-state, the marginal return to capital, $\alpha \hat{A} \hat{K}^{\alpha-1}$, equals the world interest rate, r^* . Plugging (14) into the marginal returns expression gives us the following steady-state condition:

$$r^* = \alpha(A^* - (A^* - A_0)e^{-\lambda(\hat{K} - K_0)})\hat{K}^{\alpha-1}.$$

This corresponds to a unique \hat{K} and a unique \hat{A} , so that steady-state income is independent of the path of capital accumulation.

Now assume that Property 2 does not hold; then, any investment inflow upgrades the country's absorptive capacity instantaneously. As long as $A < A^* - \gamma$, we can write $\partial A / \partial I = \gamma \lambda e^{-\lambda I}$. Instantaneous upgrading implies that the technological improvement of each unit of foreign investment is equal to the value of this derivative evaluated at $I = 0$. In other words, each unit of investment upgrades the technology by $\gamma \lambda$. Integrating that expression allows us to compute the technology level A corresponding to the cumulative level of foreign investment I . This gives us the expression $A = \gamma \lambda I$, up to a constant. The constant can be determined using the initial condition, so that

$$A = A_0 + \gamma \lambda (K - K_0). \quad (15)$$

Here again, the technology function (15) does not exhibit path dependence. ■

Appendix B: The computational algorithm

The computational procedure used to solve for the optimal solution of the model follows Auerbach and Kotlikoff (1987), and it is an iterative technique often referred to as Gauss-Seidel method. Notice that, since the economy undergoes a transition in which conditions change over time and the social planner is assumed to take into account the consequences of current actions on the entire path of future levels of technology, it is necessary to solve simultaneously for allocations in all transition years, so that the solution is time consistent. In order to implement this procedure we assume that the economy reaches a steady state in 500 periods, and we have checked that it was not binding (in fact in all of the experiments a steady state is reached before period 40). After working out with the first-order conditions and substituting away the path of technology, we arrive at the following optimal condition for each K_t at each t in the case of quotas:

$$\begin{aligned} & \beta^{t-1} A_t \alpha (1 - \alpha) [K_t^{\alpha-1} - K_t^{\alpha-2} K_0] \\ & + \beta^t \gamma \lambda e^{-\lambda(K_t - K_{t-1})} [(1 - \alpha) K_{t+1}^\alpha + \alpha K_{t+1}^{\alpha-1} K_0] \\ & + \sum_{i=1}^{\infty} \beta^{t+i} [\gamma \lambda e^{-\lambda(K_t - K_{t-1})} - \gamma \lambda e^{-\lambda(K_{t+1} - K_t)}] \\ & \times [(1 - \alpha) K_{t+i+1}^\alpha + \alpha K_{t+i+1}^{\alpha-1} K_0] = 0. \end{aligned} \quad (16)$$

Then, the steps of the algorithm are the following:

- Given initial conditions K_0 and the initial state of technology A_1 , provide a guess for the path of the capital stock $\{K_t\}_{t=1}^{t=500}$.
- Using $\{K_t\}_{t=1}^{t=500}$ and the current state of technology A_t , obtain the optimal capital stock chosen by the planner for each t $\{K_t^*\}_{t=1}^{t=500}$, by means of the first-order conditions, subject to the constraint that the maximum inflow of capital is restricted by the world interest rates.
- If the implied $\{K_t^*\}_{t=1}^{t=500}$ are equal to the guesses of the first step, the algorithm is stopped. If not, update the guess and go back to the first step.

A similar algorithm was used in the tax case.

Appendix C: The foreign investor as a monopolist

In this appendix we analyze what would happen if only one foreign firm were allowed to invest in the host economy. This firm has the choice between investing its capital in the international market at the exogenously given world interest rate, r^* , or in the host market at the locally determined marginal product of capital. Given the default of earning a return of r^* , the foreign firm will maximize the

TABLE C1
Monopolist

	Data	Model	% accounted
Big bang liberalization			
Growth TFP	11.5	2.2	19.2
Growth capital due to FDI	77.9	33.0	42.3
Quotas			
Growth TFP	11.5	8.0	69.5
Growth capital due to FDI	77.9	44.3	56.9
Monopolist			
Growth TFP	11.5	7.9	68.4
Growth capital due to FDI	77.9	31.2	40.0

additional income it gets from investing in the host economy relative to what it would get in the international market:

$$\begin{aligned} \max_{\{K_t\}_{t=1}^{\infty}} \quad & \sum_{t=1}^{\infty} \beta^{t-1} [\alpha A_t K_t^{\alpha-1} - r^*] (K_t - K_0) \\ \text{s.t.} \quad & A_{t+1} - A_t = \gamma (1 - e^{-\lambda(K_t - K_{t-1})}) \\ & K_0, A_1 \text{ given.} \end{aligned}$$

Compared with the competitive solution, less capital comes in for two reasons. First, the foreign firm invests in the host market until the marginal revenue from an additional unit of capital is larger than the world interest rate. Given that the marginal product of capital is decreasing, this condition is reached for a marginal product strictly larger than r^* . Second, given that the foreign firm has the monopoly to invest in the host market, it internalizes the technology spillovers. This gives it an incentive to delay FDI.

We numerically solve for the firm's problem, and compare the solution with the competitive one. We use the same parameter values that we do in our benchmark experiment in the paper. We find that the sequence of capital is always below the competitive solution, which confirms our basic intuition. However, because of the more gradual inflow of capital, TFP growth is higher than the one of the competitive solution.

Table C1 compares the monopolist with both the 'big bang' and the planner's solution in the competitive framework. In the case of the monopolist, TFP growth, relative to the technology frontier, is 7.9%. This number is nearly identical to the 8% of TFP growth under the planner's solution with quotas. However, the monopolist generates less capital inflows than both the 'big bang' and the planner's solution. As mentioned above, the reason is that the monopolist does not invest until the local marginal product of capital is equal to the world interest rate r^* .

In terms of welfare, the monopolist increases permanent consumption of the host country by 0.48%, relative to the complete liberalization case in the competitive market. In other words, having a foreign monopolist deciding how much to invest turns out to be better from the point of view of the host economy than having a fully liberalized competitive capital market. The main reason for this result is that the host economy is more productive as a result of the more gradual inflow of foreign capital. Not surprisingly, welfare remains lower than in the planner's solution. In that case permanent consumption increased by 1.5%.

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