The speed of technology adoption with imperfect information in equity markets

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Abstract

Why is the speed of technology adoption different across countries? Equity markets have an important role in facilitating ownership transfers from entrepreneurs, who invest in the initial stage of technology adoption, to managers who run these firms after technology is adopted. This paper argues that technology adoption decisions of the entrepreneurs are affected by their expectations of the market value of their firms. When market participants have imperfect information, two opposite forces emerge. First, uncertain and low expected market value discourages the entrepreneur from adopting the most recent technology. Second, by investing in the newest technology, an entrepreneur can send a positive signal about the profitability of his firm, and thus increase its market value. When the number of informed investors is low, the first force dominates and technology is adopted slowly. Fast technology adoption is most likely at an intermediate number of informed investors, where the expected gains from sending a positive signal to uninformed investors are the highest. The link between the speed of technology adoption and policies that facilitate access to information is analyzed when extending the basic model to allow for an endogenous number of informed investors.

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1 Introduction

There is a growing interest in the connections between financial institutions and economic growth in the literature[1]. This paper suggests a new mechanism how the development of equity markets and related institutions can determine the speed of technology adoption.[2]

Equity markets have an important role in transferring ownership rights from entrepreneurs, who establish firms to managers running these firms. This paper analyses the technology adoption or innovation decisions that are made before the initial public offering. If equity market participants have imperfect information about the value of a firm, an entrepreneur's incentives to invest in adopting the newest and most expensive technologies are affected. High uncertainty and low expected market value of the firm can discourage investment in the most advanced technologies - the "fear of unstable markets" force. At the same time, provided that the market accepts that an entrepreneur has better information about the value of his firm than the average equity market participant, his decision to invest in the newest accessible technology issues a positive signal to the market - the "adoption to signal" force. The number of informed investors determines which of these two forces dominates.

When the number of informed investors is small, entrepreneurs become discouraged and choose to adopt technology slowly. The paper also shows how imperfect information can lead a country to persistently adopt technology slowly. Fast technology adoption is most likely with an intermediate number of informed investors. In this case, entrepreneurs have the highest expected gains from investing in the newest technology, in order to issue a positive signal to the uninformed participants in the market. In countries with very developed financial markets and a large number of informed investors, both the discouraging "fear of unstable markets" and encouraging "adopting to signal" force disappear. This implies a non-monotonic relationship between the level of equity market development and the speed of technology adoption.

There are exogenous and endogenous factors that can affect the number of informed investors. For example, some countries could rely on a higher number of informed investors because of cultural links that allow some foreign investors to be informed for a lower cost (e.g. Scandinavian investors in the Baltic States or Austrian investors in Hungary). Furthermore, the number

[1] See Levine (2004) for a comprehensive review of existing theoretical and empirical literature on this topic.

[2] Empirical studies by Beck and Levine (2004) and Rousseau and Wachtel (2000) show that more developed equity markets' have a positive impact on economic growth.

of informed investors is likely to be lower in countries with weak institutions for facilitating access to information (e.g. accounting standards and laws), and therefore less developed equity markets[3].

In order to analyze the link between policies that facilitate access to information and the speed of technology adoption, the basic model is extended to allow for any uninformed investor to become informed at a fixed cost. Within this context, the policies that affect the information cost also affect the speed of technology adoption. The paper demonstrates that the probability of fast technology adoption is maximized when this information cost is above zero. Because faster technology adoption implies faster growth in local wages and output, a local policy maker would choose zero information costs (i.e. full transparency). Setting the information cost to zero eliminates the possibility that entrepreneurs would issue a positive signal by adopting technology fast.

The paper also analyses the impact of participation of different types of foreign agents. If foreign agents (a part of foreign direct investment) have access to new technology at lower costs, their participation increases the probability of fast technology adoption. Nevertheless, the same two forces remain in action; if the number of informed equity market participants is low, these foreigners might not participate and projects that would be profitable on perfectly informed equity markets are not undertaken.

Participation of foreign portfolio equity investors increases the liquidity of the firms they trade. Higher liquidity has a positive impact on market prices of firms, and increases incentives to invest in fast technology adoption. At the same time, if portfolio investors are largely uninformed, their participation can increase uncertainty and discourage fast technology adoption. The paper shows the conditions under which forbidding foreign portfolio equity investments encourages fast technology adoption.

The setup of the model relies on two crucial assumptions. First, an entrepreneur has to sell his firm before it generates profits. The need to exit would emerge endogenously if some agents have a comparative advantage to be entrepreneurs rather than managers, as in Holmes and Schmitz (1990). Also, venture capitalists can be seen as agents who are skilled in judging whether or not a particular technology adoption is worth investing in. They are generally not constrained in credit market and prefer to exit fast (Jovanovic and Szentes, 2006). Venture capitalist involvement in running the firms is likely to limit the extent of potential agency problems between the venture capitalist and the entrepreneur. Lack of good exit opportunities is a major concern for these agents while assessing investments to developing

[3] La Porta, Lopez de Silanes and Shleifer (2006) show that laws mandating disclosure benefit stock markets.

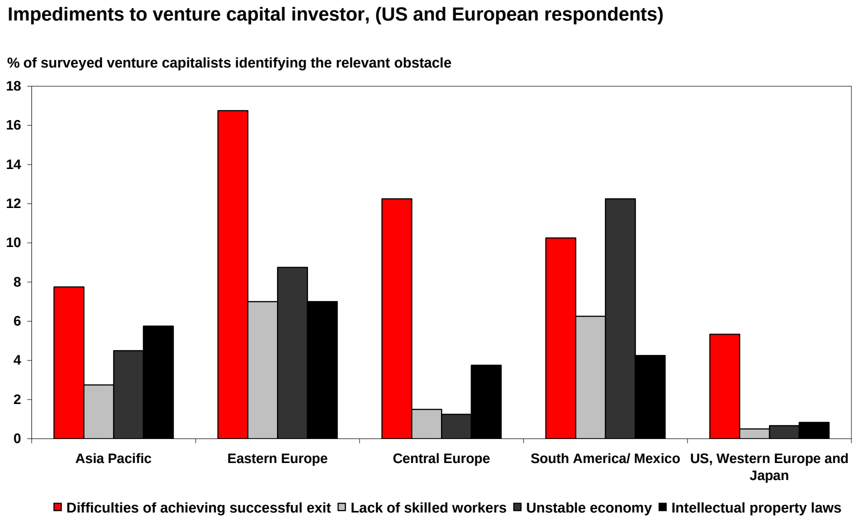

Figure 1: Survey by Deloitte Touche Tohmatsu (2006).

countries (Lerner and Pacanins,1997). Figure 1 shows that venture capitalists perceive the concerns about successful exit to be a bigger impediment than lack of skilled workers or weak intellectual property laws[4]. Among the less developed countries, Asia is often considered as one of the most attractive locations for venture capital (Aylward, 1998, and a survey by Deloitte Touche Tohmatsu, 2006). While this region does not have more skilled labor than competing regions, it has more developed equity markets. Furthermore, Asia has better legal and regulatory environment than Latin America and transition countries that have not entered European Union by 2006 (Appendix A1). Good exit opportunities facilitate long-term investments and allow for efficient use of entrepreneurial skills.

The second crucial assumption is that the rational uninformed investors' trading decisions are based on noisy information from asset prices, the technology adoption decision, and a noisy public signal. The last captures the impact of market sentiment as in Allen, Morris and Shin (2006) or Bacchetta and van Wincoop (2005). Crises in emerging markets and transition countries at the end of 1990s suggest that shifts in market sentiment is an important factor in these countries. Empirical studies show that portfolio capital flows to these countries are largely unrelated to the fundamentals in

[4]The venture capitalists surveyed are not necessarily investing in these regions. Important impediments that are excluded from the Figure 1 are "Lack of quality deals that fit investment profile" and "Lack of knowledge and expertise of business environment" that are likely to be specific to a particular venture capitalist.

these countries (e.g. Garibaldi et. al., 2002, Prasad et. al. 2004 and 2006).

Appendix A.2 looks at the relationship between GDP growth, R&D expenditures and the level of development of the equity market. Figures A1 and A2 show that in transitions countries[5] where securities markets developed faster, R&D expenditures have been higher and income per capita has grown faster from 1991 to 2004. At the same time, the relationship appears non-monotonic, which is consistent with the predictions of this paper. Figures A3 shows similar patterns for R&D expenditures in high and upper-middle income countries.

The model predicts that openness to capital flows does not guarantee fast technology adoption, unless there are institutions that encourage enough investors to be informed. This is consistent with empirical findings on the effect of openness to capital flows on growth. This effect is found to be positive only if it coincides with more developed institutions, while it is ambiguous otherwise (e.g. Klein and Olivei, 1999; Edwards, 2001; Edison et al., 2002; Prasad et al. 2006).

The paper relates to the existing theoretical literature on the determinants of the speed of technology adoption. Differences in the speed of adoption could arise from the lack of skilled labor that make the frontier technologies inappropriate for countries with lack of skilled labor (e.g. Acemoglu, 2002). While this argument is likely to be crucial in countries with the lowest shares of educated labor force, it is harder to explain the differences among countries where the share of educated labor force is similar to that of developed countries (e.g. transition countries). In this paper, the productivity of the labor force in using technology adopted is uncertain. The speed of technology adoption depends on the interaction of this productivity and number of informed investors. If the productivity of labor force is low, fast technology adoption is less likely for a given number of informed investors. However, the speed of technology adoption can differ in countries where this productivity is not significantly different.

Obstacles for technology adoption can also be commitment problems and credit constraints (e.g. Aghion et al., 2006; Aghion et al. 2003; Gertler, Rogoff, 1990). In order to emphasize the role of the equity market in providing exit opportunities, rather than access to funding, the paper abstracts from credit constraints. Credit constraints of local agents are unlikely to explain, for example, why foreign venture capitalists do not invest more in less developed countries with relatively skilled and inexpensive labor. Furthermore,

[5] This group of countries provides a good comparison group. In addition to the high and similar share of educated labor, transition countries were similar in terms of GDP per capita and institutions in 1991 after USSR dissolved.

the large private capital flows to some developed countries observed in the 1990s (see Prasad et al., 2004) could have reduced the importance of credit constraints in these countries.

Closer to the current paper are Bencivenga et al. (1995) and Levine (1991) that analyze the impact of liquidity of equity markets and the need for exit in a closed economy. Like in the current paper lack of liquidity reduces incentives to invest in technology adoption. However, information imperfections analysed in the current paper add further mechanisms. These papers also do not address the link between technology adoption and institutions facilitating the access to information.

The arguments presented in this paper are also closely related to the literature on institutions (e.g. Parente and Prescott, 1994), which assumes that weaker institutions increase the cost of technology adoption. Therefore, worse institutions should imply slower technology adoption. Marimon and Quadrini (2006) model the start-up cost in an environment with limited contract enforceability that creates incentives for new entries to innovation sector. As long as there are new entries accumulation of knowledge is decreasing in start-up costs. While new entries is assumed to be the case in the current paper to focus on the need for exit, weak institutions that increase the cost of technology adoption (e.g. property rights, taxation, or other obstacles in establishing or running a firm) could be incorporated in the model. The two main forces found in the paper would still remain in action. An innovative result in the current paper is a non-monotonic relationship between fast technology adoption and equity market development, because of technology adoption decisions potentially issuing a signal to the market.

The remainder of the paper is organized as follows. Section 2 presents the model with a fixed number of informed agents. Section 3 endogenizes the number of informed investors, and discusses the incentives for a policy maker to choose policies enhancing transparency. Section 4 provides a brief discussion on the possibility of gains from forbidding foreign portfolio equity investment in the local asset market. Section 5 concludes.

2 The model

The model is a small open economy general equilibrium model with rational expectations. It builds on the endogenous growth literature with quality improvements of technology (e.g. Aghion and Howitt, 1993; Aghion, Comin and Howitt, 2006) and rational expectations literature (e.g. Grossman and Stiglitz; 1976, Allen, Morris and Shin, 2006; Yuan, 2005).

The local economy is populated with overlapping generations of agents endowed with one unit of raw labor each period. These agents work and invest in asset market, in the first period of their lives and consume only in the second period of their lives. The measure of local rational agents is μ. These agents, "investors" can be informed (type $i = I$) or uninformed (type $i = U$). There are similar overlapping generations of foreign agents endowed with exogenous wealth W_t^* in each period investing in the asset market. In the world economy, there are $\hat{\mu}_{t+1}^I = \mu_{t+1}^I + \mu_{t+1}^{*I}$ informed and $\hat{\mu}_{t+1}^U = (\mu - \mu_{t+1}^I) + \mu_{t+1}^{*U}$ uninformed investors.[6]

Some rational local agents have also special skills to be entrepreneurs, who establish local monopolistic firms engaging in technology adoption. Each local entrepreneur can adopt technology alone or in a joint venture with one foreign agent. The firm is called to be established by an "initial owner" where the exact ownership structure is not important.

All rational agents have mean-variance preferences

$$U_t = E[c_{t+1}|\Omega_t] - \frac{\tau}{2} \mathrm{Var}[c_{t+1}|\Omega_t], \tag{1}$$

where c_{t+1} is consumption, Ω_t is the available information set in t and τ is a measure of risk aversion.

None of the agents is borrowing or short-sales constrained. The assets traded are local equity (risky asset) and a foreign risk-free bond with a gross return $R \geq 1$ available with infinitely elastic supply. Equity market consists of the shares of local monopolistic firms that engage in technology adoption.

In addition to rational investors, there are noise traders who demand a stochastic stochastic quantity (s_t) of risky asset portfolio. All noise traders are assumed to be local unless specified otherwise and they do not receive wage income[7]. The existence of noise traders is necessary for risky asset prices not to be fully revealing (the Grossman and Stiglitz, 1976 paradox). The equity market clearing condition is

$$\hat{\mu}_t^I \hat{h}_t^I + \hat{\mu}_t^U \hat{h}_t^U + s_t = S_t, \tag{2}$$

where S_t is the supply of risky asset and $\hat{h}_t^I$ is the demand of risky asset by every informed investor and $\hat{h}_t^U$ is the demand by every uninformed investor.

[6] μ_{t+1}^I and μ_{t+1}^{*I} are the numbers of local and foreign informed investors and μ_{t+1}^{*U} is the number of foreign uninformed investors

[7] Their location has no impact on conclusions apart from those in Section 4, where the possibility of them being foreign will be specifically analyzed. With the mean-variance utility, the split of wage income between noise traders and local rational agents does not affect aggregate conditions and conclusions in the model.

The production side of the economy consists of a competitive final good production sector and a monopolistic intermediate goods sector.

The price of the final good is normalized to one. The final good producers use raw local labor, L, and j distinct intermediate goods that are produced by local monopolists. Each of these intermediate goods, $x_t(j)$, has quality $A_t(j)$ ($j \in [0,1]$). For example, the intermediate good could be a computer designed to perform a particular task in the production line ($x_t(j)$) and the vintage of the computer ($A_t(j)$) would determine how fast it will perform the task. The production function is

$$Y_t = (\gamma_t L)^{1-\alpha} \int_0^1 A_t^{1-\alpha}(j) x_t^{\alpha}(j) dj, \tag{3}$$

where γ_t measures the productivity of local labor force in using the technology.

This productivity is uncertain before the period when actual production takes place (i.e. uncertainty about γ_t resolves in period t) and can be decomposed into two parts

$$\gamma_t = \theta_t + u_t, \tag{4}$$

where θ_t is the explainable part of productivity that is uncorrelated across the time and with any other shocks, and u_t is a residual; $u_t \sim \mathcal{N}(0, 1/\beta_u)$ that is also uncorrelated across time with any other shocks.[8] The explainable component measures factors like education, training, working culture, management practices, etc. The unexplainable component could be affected by factors like the health of the workers, natural disasters, etc.

Final good producer buys each intermediate good, $x_t(j)$, from a local monopolists in sector j for a price $p_{x,t}(j)$. Intermediate good producers in each sector j use one unit of final good to produce one unit of intermediate good. All intermediate goods depreciate fully in one period.

Section 2.1 shows how the uncertainty about the productivity of labor force in using technology (γ_t) translates in uncertainty about the future demand for intermediate goods and the profits of local monopolists.

Initial owners establish firms two periods before these firms produce. They can adopt the frontier technology (A_t^*)[9] that grows at an exogenous

[8] The normality assumption, while being unrealistic by allowing negative output, greatly simplifies the solution. It is also widely used assumption in the finance literature about the liquidation value of assets. By reasonable assumptions about the parameters the probability of negative output or asset prices is negligible. The main mechanism would remain valid with different distributional assumptions.

[9] The frontier can also be interpreted as the newest technology that can be accessible and useful for a particular country, instead of the newest available technology worldwide.

rate,

$$g^* \equiv \frac{A^*_{t+1} - A^*_t}{A^*_t} \text{ for any } t. \quad (5)$$

For each intermediate good j there is only one initial owner, whose effort is needed for technology adoption in each period. In addition to this effort, technology adoption requires an investment in final goods.

Initial owner in sector j born in t, decides whether to invest in fast $(A_{t+2}(j) = A^*_{t+2})$ or slow $(A_{t+2}(j) = A^*_{t+1})$ technology adoption. Growth of the world frontier technology (5) allows for new firms to produce with higher quality of technology each period $(A_{t+2}(j) \geq A_{t+1}(j))$. New monopolies drive old monopolies out of the market and monopolistic profits can be sustained only for one period.[10]

Adopting the newest technology is more expensive than adopting an older one. The fixed cost of establishing a fast adopting firm is

$$I_t = \left(A^*_{t+2} - A^*_{t+1}\right) \hat{\zeta}(\cdot). \quad (6)$$

The cost of fast technology adoption is assumed to be proportional to the gain in technology from fast adoption in the period the firm will be active. The cost of adoption per technology gain for an initial owner is

$$\hat{\zeta}(\cdot) = \min[\zeta(\cdot), \zeta^*],$$

where $\zeta(\cdot) > 0$ is the cost for each local entrepreneur alone and $\zeta^* > 0$ for each potential foreign agent participating. The cost $\zeta(\cdot)$ can be constant or an increasing function of the distance from the frontier. The latter would capture the assumption that fast technology adoption may be harder for local agents, who are less familiar with the frontier technology.

Without loss of generality, the required investment to establish a firm that adopts technology slowly is zero. The technology adoption decision is denoted with

$$\tilde{1}_{I_t}(j) = \begin{cases} 1, \text{ if fast adoption is chosen in } t \text{ in sector } j \\ 0, \text{ if slow adoption is chosen in } t \text{ in sector } j \end{cases} \quad (7)$$

[10] The strict inequality, $A_{t+2}(j) > A_{t+1}(j)$, holds if technology is adopted fast in period t, because $A_{t+2}(j) = A^*_{t+2}$ and $A_{t+1}(j) \in \{A^*_{t+1}, A^*_t\}$. The same is true if slow adoption is chosen in consecutive periods, i.e. $A_{t+2}(j) = A^*_{t+1}$ and $A_{t+1}(j) = A^*_t$. $A_{t+2}(j) = A_{t+1}(j)$ only if in t initial owner chooses slow technology adoption $A_{t+2}(j) = A^*_{t+1}$, while initial owner born in $t-1$ adopted fast $A_{t+1}(j) = A^*_{t+1}$. It is assumed that in this case In new monopoly will still drive the old incumbent out of the market. Implicit assumption behind this is that an intermediate good firm cannot sustain exactly the same quality for more than one period.

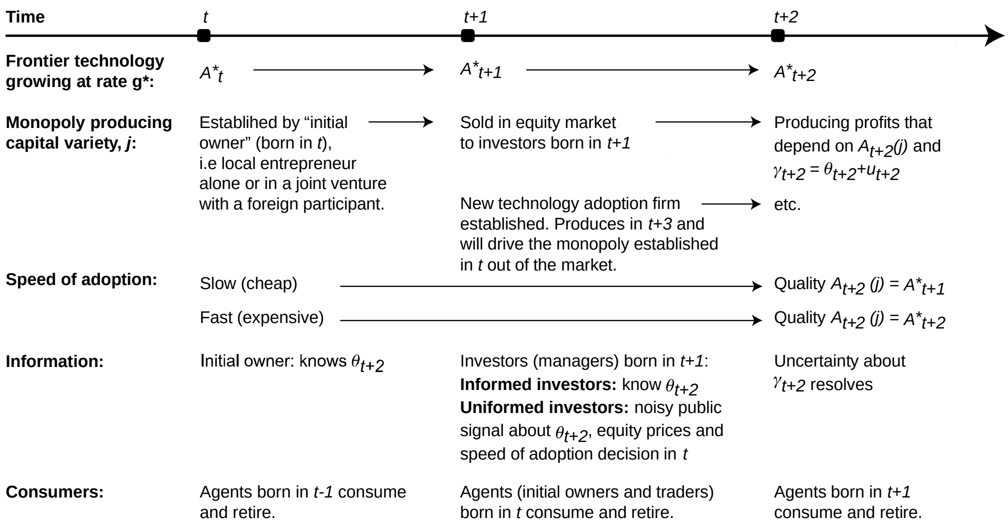

Figure 2: Timeline

Initial owner born in t knows the explainable component of the productivity (θ_{t+2}). Given that the initial owner has to retire before his firm produces profits, he sells his firm in the equity market. This assumption about the timing captures the need for exit and ownership transfers.

The firm established in t is bought by investors (local and foreign) trading in period $t+1$ equity market. Informed investors have the same information as the initial owner; the information set that is relevant for their trading decision is $\Omega^I_{t+1} = \{\theta_{t+2}\}$. Rational uninformed investors obtain information from prices of firms traded, $P_{t+1}(j)$, and the technology adoption decision made one period earlier, $\tilde{1}_{I_t}(j)$. They also receive a noisy public signal at the beginning of period $t+1$,

$$\tilde{\theta}_{t+2} = \theta_{t+2} + \epsilon_{\tilde{\theta},t+2}, \text{ where } \epsilon_{\tilde{\theta},t+2} \sim \mathcal{N}(0, 1/\beta_{\tilde{\theta}}). \tag{8}$$

The public signal would capture the "market sentiment". Information set of uninformed investors is $\Omega^U_{t+1} = \{\tilde{\theta}_{t+2}, P_{t+1}(0), .., P_{t+1}(1), \tilde{1}_{I_t}(0), ..., \tilde{1}_{I_t}(1)\}$.

An initial owner in sector j, who is an investor of type $i \in \{U, I\}$ born in $t+1$ has information set $\Omega^{i,e(j)}_t = \{\theta_{t+2}, \Omega^i_t\}$. Figure 2 summarizes the main mechanism and timing.

The final goods are used in the local market for aggregate consumption (C_{t+1}), capital ($\int_0^1 x_t(j)dj$) and investments to technology adoption ($\int_0^1 \tilde{1}_{I_{t+1}}(j) I_{t+1}(j)dj$). These expenditures have to equal to aggregate production Y_{t+1} and net inflow of goods from abroad (F_{t+1}). The local goods market clearing condition is

$$C_{t+1} + \int_0^1 x_t(j)dj + \int_0^1 \tilde{1}_{I_{t+1}}(j) I_{t+1}(j)dj = F_{t+1} + Y_{t+1}. \tag{9}$$

Final good production sector employs all local labor force. Hence, the labor market clearing condition is

$$L = \mu. \tag{10}$$

Solving this model for period t involves first deriving the profits of local monopolies in period $t+2$ in Section 2.1. Using this, the equilibrium in period $t+1$ equity market and the market value of the monopolistic firms in period $t+1$ eill be derived in Section 2.3. After that, the technology adoption decision will be derived for period t in Section 2.4 and local goods market clearing decision will be proven to hold in any period in Section 2.5.

2.1 Production decisions

In period $t+2$, a final good producer takes prices of the intermediate goods $(p_{x,t+1}(j))$ and wages (w_{t+2}) as given and solves

$$\max_{L, x_{t+2}(j)} Y_{t+2} - w_{t+2}L - \int_0^1 p_{x,t+2}(j) x_{t+2}(j)dj,$$

where Y_{t+2} is given by (3) and L is the raw labor and $x_{t+2}(j)$ is an intermediate good j.

Intermediate good firm in sector j solves

$$\max_{p_{x,t+2}(j), x_{t+2}(j)} \pi_{t+2}(j) = p_{x,t+2}(j) x_{t+2}(j) - x_{t+2}(j) \text{ st. } p_{x,t+2}(j) = \frac{\partial Y_{t+2}}{\partial x_{t+2}(j)}.$$

Optimal solution implies a demand function for an intermediate good that is linear in the labor productivity and the quality of technology,

$$x_{t+2}(j) = \left(\alpha^2\right)^{\frac{1}{1-\alpha}} \gamma_{t+2} L A_{t+2}(j). \tag{11}$$

The equilibrium profit in sector j is

$$\pi_{t+2}(j) = \Gamma A_{t+2}(j) \gamma_{t+2}, \tag{12}$$

where

$$\Gamma \equiv \frac{1-\alpha}{\alpha} \left(\alpha^2\right)^{\frac{1}{1-\alpha}}.$$

Replacing the labor market clearing condition (10) and demand for intermediate capital goods, (11), in the production function (3) the aggregate final good production also becomes linear in the level of technology and productivity of labor force

$$Y_{t+2} = \left(\alpha^2\right)^{\frac{\alpha}{1-\alpha}} \mu A_{t+2} \gamma_{t+2}, \tag{13}$$

where $A_{t+2} = \int_0^1 A_{t+2}(j)dj$ is the average quality of technology. The equilibrium wages are proportional to the aggregate final good production:

$$w_{t+2} = (1-\alpha)\frac{Y_{t+2}}{\mu}. \tag{14}$$

2.2 Identical technology adoption decisions

Initial owners are not borrowing constrained and can always finance their investment in technology adoption. From (12) the only difference between the firms in different sectors is $A_{t+2}(j)$. The productivity of labor force and information about this productivity (θ_{t+2}), the cost of technology adoption and the frontier technology is the same in each sector j. This implies that all initial owners make identical choices and all intermediate capital goods are produced with the same quality of technology, i.e. for any j

$$\begin{aligned} \tilde{1}_{I_t}(j) &= \tilde{1}_{I_t} \\ A_{t+2}(j) &= A_{t+2}. \end{aligned} \tag{15}$$

As a result, there is a continuum of monopolistic firms whose profits are perfectly correlated. Modelling all these firms and their owners is equivalent to modelling one risky asset and one initial owner for all monopolists in the country. The price of all firms will be the same

$$P_{t+1}(j) = P_{t+1}. \tag{16}$$

2.3 Equity market

Using results from Section 2.2, (4) and (12), the profits of local monopolists can be expressed as

$$\pi_{t+2} = \Gamma(\theta_{t+2} + u_{t+2})A_{t+2}. \tag{17}$$

The supply of risky asset in period t is given by the number of monopolistic firms

$$S_t = \int_0^1 j dj = 1. \tag{18}$$

The demand of noise traders is

$$s_{t+1} \sim \mathcal{N}(0, 1/\Gamma^2 A_{t+2}^2 \beta_s), \tag{19}$$

and s_{t+1} is uncorrelated across time and with any other shocks. The assumption that the variance of noise trading is proportional to the inverse of $\Gamma^2 A_{t+2}^2$ guarantees that the variance of the price signals of uninformed investors does not increase over time. As it will be pointed out later in the paper, relaxing this assumption would strenghten the results. While noise traders do not receive wage income, they still invest in asset market and their consumption is

$$c_{t+2}^N = (\pi_{t+2} - RP_{t+1})s_{t+1},$$

where P_{t+1} is the equilibrium price of the risky asset.

From (1) the trading decision for type $i \in \{I, U\}$ can be expressed as

$$\max U_{t+1}^i = E(\hat{c}_{t+2}^i|\Omega_{t+1}^i) - \frac{\tau}{2}\operatorname{Var}(\hat{c}_{t+2}^i|\Omega_{t+1}^i) \tag{20}$$
$$\text{st. } \hat{c}_{t+2}^i = (\Gamma(\theta_{t+2} + u_{t+2})A_{t+2} - RP_{t+1})\hat{h}_{t+1}^i + R\hat{W}_{t+1},$$

where $\hat{c}_{t+2}^i$ is the consumption of investor of type i in period $t+2$ and τ is a measure of risk aversion. $\hat{W}_{t+1}$ is the wealth or wage income that can be invested on asset markets for agent i. If the agent is local $\hat{W}_{t+1} = W_{t+1} = w_{t+1}$ is wage income given by (14), if he is foreign $\hat{W}_{t+1} = W_{t+1}^*$ is exogenous wealth. It should be pointed out that initial owners of monopolists established in $t+1$ trade in the asset market as well. However, under CARA type utility, with no borrowing or short-sales constraints and information structure assumed, the trading and adoption decisions are independent and can be solved for separately[11].

As is well known, type i investor's, who can be local or foreign, demand for risky asset is

$$\hat{h}_{t+1}^i = \frac{E(\pi_{t+2}|\Omega_{t+1}^i) - RP_{t+1}}{\tau \operatorname{Var}(\pi_{t+2}|\Omega_{t+1}^i)}. \tag{21}$$

As described at the beginning of Section 2 informed investors' information set is $\Omega_{t+1}^I = \{\theta_{t+2}\}$. Therefore, if investor is informed

$$E(\pi_{t+2}|\Omega_{t+1}^I) = \Gamma\theta_{t+2}A_{t+2}, \tag{22}$$
$$\operatorname{Var}(\pi_{t+2}|\Omega_{t+1}^I) = \Gamma^2 A_{t+2}^2 \frac{1}{\beta_u}.$$

Uninformed investors obtain information from asset prices, public signal (8) and technology adoption decision (7) and (15). All firms traded in $t+1$ have

[11] Independence is first assumed to be the case. Later, Appendix D will prove it formally.

the same price (16). Replacing the optimal demand of informed investors ((21) and (22)) and supply of risky asset (18) in the asset market clearing condition (2) the information uninformed investors obtain from asset prices: the price signal is[12]

$$\tilde{P}_{t+1} = \theta_{t+2} + \frac{\tau \Gamma A_{t+2}}{\hat{\mu}^I_{t+1}\beta_u} s_{t+1}. \tag{23}$$

The information set to uninformed investors can be expressed as $\Omega^U_{t+1} = \{\tilde{\theta}_{t+2}, \tilde{P}_{t+1}, \tilde{1}_{I_t}\}$. Given that initial owners have superior information (know θ_{t+2}), we can conjecture that their decision to invest in fast; $\tilde{1}_{I_t} = 1$ (slow; $\tilde{1}_{I_t} = 0$) adoption implies that $\theta_{t+2} \geq \bar{\theta}_{t+2}$ ($\theta_{t+2} < \bar{\theta}_{t+2}$). This conjecture is verified in Section 2.4. Section 2.4 also shows that the threshold ($\bar{\theta}_{t+2}$) is known to uninformed investors trading in $t+1$.

Expected profits and variance for an uninformed investor are

$$E(\pi_{t+2}|\Omega^U_{t+1}) = \Gamma A_{t+2}\left(z_{t+1}\tilde{\theta}_{t+2} + (1-z_{t+1})\tilde{P}_{t+1} + \sqrt{z_{v,t+1}}\lambda_{\tilde{1}_{I_t}}(b_{t+1})\right), \tag{24}$$

$$\text{Var}(\pi_{t+2}|\Omega^U_{t+1}) = \Gamma^2 A^2_{t+2} z_{v,t+1}\left(1 - \lambda_{\tilde{1}_{I_t}}^2(b_{t+1}) + b_{t+1}\lambda_{\tilde{1}_{I_t}}(b_{t+1})\right) + \Gamma^2 A^2_{t+2}\frac{1}{\beta_u},$$

where

$$b_{t+1} \equiv \frac{1}{\sqrt{z_{v,t+1}}}\left(\bar{\theta}_{t+2} - z_{t+1}\tilde{\theta}_{t+2} - (1-z_{t+1})\tilde{P}_{t+1}\right), \tag{25}$$

$$z_{v,t+1} \equiv \frac{1}{\beta_{\tilde{\theta}} + \left(\frac{\hat{\mu}^I_{t+1}\beta_u}{\tau}\right)^2 \beta_s}, \qquad z_{t+1} \equiv \beta_{\tilde{\theta}} z_{v,t+1}$$

and $\lambda_{\tilde{1}_{I_t}}(b_{t+1})$ is the inverse Mills ratio[13]. The derivation of these these expressions is presented in Appendix B.

For the intuition behind the conditional expected value for an uninformed investor, assume for a moment that all investors are uninformed. In such case, they get information only from the public signal $\tilde{\theta}_{t+1}$ (8) and the technology adoption decision (7) and (15), because asset prices do not reveal any extra information. Fast (slow) technology adoption implies $\theta_{t+2} \geq \bar{\theta}_{t+2}$ ($\theta_{t+2} < \bar{\theta}_{t+2}$) and the conditional distribution of θ_{t+2} becomes a truncated normal. This implies $E(\pi_{t+2}|\tilde{\theta}_{t+2}, \tilde{1}_{I_t}) = \Gamma A_{t+2}\left(\tilde{\theta}_{t+2} + \sqrt{1/\beta_{\tilde{\theta}}}\lambda_{\tilde{1}_{I_t}}(\sqrt{\beta_{\tilde{\theta}}}(\bar{\theta}_{t+2} - \tilde{\theta}_{t+2})\right)$. The expectations differ from the perfect information (22) in two respect. First,

[12] See Appendix B for further details.

[13] If $\tilde{1}_{I_t} = 1$, $\lambda_{\tilde{1}_{I_t}=1}(b_{t+1}) = \frac{\phi(b_{t+1})}{1-\Phi(b_{t+1})}$. If $\tilde{1}_{I_t} = 0$, $\lambda_{\tilde{1}_{I_t}=0}(b_{t+1}) = -\frac{\phi(b_{t+1})}{\Phi(b_{t+1})}$,. where $\phi(.)$ and $\Phi(.)$ are standard normal p.d.f. and c.d.f respectively.

there is noise in the public signal, $\tilde{\theta}_{t+2}$, that can increase or reduce expected value of the firm. This could reflect the "market sentiment". Second, fast (slow) technology adoption implies a positive (negative) Mills ratio and expectations about the fundamental are higher (lower) even if the public signal is correct.

Including informed investors in the model $\theta_{t+2}|\tilde{\theta}_{t+2}\tilde{P}_{t+1} \sim \mathcal{N}(z_{t+1}\tilde{\theta}_{t+2} + (1-z_{t+1})\tilde{P}_{t+1}, z_{v,t+1})$. Incorporating the information revealed by technology adoption decision again results the labor productivity having a truncated normal distribution from the percpective of an uninformed investor. Expected value is closer to the fundamental and technology adoption decision has less effect on the expected value if $z_{v,t+1}$ is smaller. This is the case when other signals have lower variance (e.g. $\beta_{\tilde{\theta}}$, β_s, $\hat{\mu}^I_{t+1}$ are higher).

The equilibrium price can be derived by replacing (18), (21), (22) and (24) into the market clearing condition (2). The equilibrium risky asset price is a function of the expectations of informed investors, the expectations of uninformed investors, the liquidity premium and the risk premium. As the expression is lenghty, and only the relevant limiting cases are analyzed, full details are left to Appendix B.

If the number of informed investors approaches infinity (or the variance of public information is zero), then the equilibrium asset prices equal the discounted expected profits by informed investors:

$$P^{PI}_{t+1} = \frac{\Gamma A_{t+2}}{R}\theta_{t+2}. \tag{26}$$

In such case, the equilibrium asset prices will be fully revealing, investors' asset holdings approach zero, and the risk premium and liquidity premium are pushed to zero. The implications of imperfect information in financial markets can be compared with this benchmark.

In a more realistic environment, the number of informed investors is limited. Given that this paper analyses a small open economy, it is reasonable to assume that the number of uninformed foreign investors who can invest in the local risky assets is infinite compared to the size of the local market. If the number of uninformed investors approaches infinity, the excess returns of uninformed investors approach to zero. Using (23) and (24), equilibrium asset prices can be expressed as

$$\begin{aligned} P_{t+1} =& \frac{\Gamma A_{t+2}}{R}\left(z_{t+1}\tilde{\theta}_{t+2} + (1-z_{t+1})\theta_{t+2} + \sqrt{z_{v,t+1}}\lambda_{\tilde{1}_{I_t}}(b_{t+1})\right) \\ &+ \frac{z_{s,t+1}\Gamma^2 A^2_{t+2}}{R}s_{t+1}, \end{aligned} \tag{27}$$

where

$$z_{s,t+1} \equiv (1-z_{t+1})\tfrac{\tau}{\hat{\mu}^I_{t+1}\beta_u}. \tag{28}$$

In this case, asset prices are affected by the public signal, noise trading, and an extra term that captures the impact of the signal from the adoption decision. Looking at the expressions for z_{t+1}, $z_{s,t+1}$ and $z_{v,t+1}$ ((25) and (28)), it is clear that the larger the number of informed investors $(\hat{\mu}^I_{t+1})$, the closer the asset price will be to the perfect financial markets benchmark $(\hat{\mu}^I_{t+1} \longrightarrow \infty \Longrightarrow z_{t+1}, z_{v,t+1} \longrightarrow 0)$. Both the public signal $\tilde{\theta}_{t+2}$ and noise trading s_{t+1} create uncertainty in asset prices. The latter affects asset prices through the information revealed to uninformed investors by price signals. Normality assumptions do not exclude the possibility of negative price, however with reasonable assumptions about parameters the probability of this is negligible (see footnote 8).

Without infinitely many investors (whether uninformed or informed), asset prices would be lower *ceteris paribus,* because the local asset market would not be liquid enough. Noise trader demand would have a direct impact on asset prices, in addition to its impact on the uninformed investors' price signals. This question will be revisited in Section 4, when analyzing the impact of forbidding foreigners to invest in local asset market. Until then, the number of foreign uninformed investors is assumed to be infinite.

2.4 Adoption decision

Initial owners' technology adoption decision in period t is based on their knowledge of the explainable part of productivity, θ_{t+2}. There is uncertainty about the asset price in period $t+1$, because these agents do not know the next period market perception (signal $\tilde{\theta}_{t+2}$) and noise trading (s_{t+1}).

From (1) and the independence of trading and technology adoption decision, investment in fast technology adoption is optimal if $U_t(\tilde{1}_{I_t} = 1) \geq U_t(\tilde{1}_{I_t} = 0) + RI_t$, where the utility from fast adoption

$$U_t(\tilde{1}_{I_t} = 1) = E(P_{t+1}|\theta_{t+2}, \tilde{1}_{I_t} = 1) - \frac{\tau}{2}\operatorname{Var}(P_{t+1}|\theta_{t+2}, \tilde{1}_{I_t} = 1), \qquad (29)$$

while the utility from slow adoption

$$U_t(\tilde{1}_{I_t} = 0) = E(P_{t+1}|\theta_{t+2}, \tilde{1}_{I_t} = 0) - \frac{\tau}{2}\operatorname{Var}(P_{t+1}|\theta_{t+2}, \tilde{1}_{I_t} = 0). \qquad (30)$$

It can be seen from (27) that the selling price of firms that adopt technology fast is always higher. This is because asset prices are proportional to A_{t+2} and from (5) $A^*_{t+2} > A^*_{t+1}$.

Explicit derivation of $E(P_{t+2}|\theta_{t+2}, \tilde{1}_{I_t})$ and $\operatorname{Var}(P_{t+2}|\theta_{t+2}, \tilde{1}_{I_t})$ is complicated by the fact that asset prices (27) include the inverse Mills ratio $(\lambda_{\tilde{1}_{I_t}}(b_{t+1}))$. While b_{t+1} is an observable constant for investors trading in $t+1$, it depends on $\tilde{\theta}_{t+2}$ and $\tilde{P}_{t+1}$, which are unknown in period t. As a result, b_{t+1} has a normal distribution from the point of view of initial owner who is deciding on speed of technology adoption. The moments of Mills ratio with normally distributed b_{t+1} are, to the best of my knowledge, impossible to derive in closed form. However, the Mills ratio can be approximated with a linear or polynomial function. The results presented in this paper employ the linear approximation for simplicity. This is sufficient because the most interesting cases for analysis occur in the neighborhood of $\lambda_{\tilde{1}_{I_t}}(0)$, where initial owners are close to being indifferent between fast and slow technology adoption.[14] Approximation with a second order polynomial does not invalidate the results[15].

2.4.1 Two forces affecting the technology adoption decision

Proposition 1 *Initial owners choose to adopt the technology fast ($A_{t+2} = A^*_{t+2}$) if the observable component of productivity satisfies $\theta_{t+2} \geq \bar{\theta}_{t+2}$, where*

$$\begin{aligned} \bar{\theta}_{t+2} &= \frac{R^2}{\Gamma}\hat{\zeta}(\cdot) - \frac{2+g^*}{g^*}\sqrt{z_{v,t+1}}\eta_1 \\ &\quad + \frac{\tau}{2}\frac{\Gamma\,(2+g^*)}{R}A^*_{t+1}\,(1-\eta_2)^2\, z_{v,t+1}, \end{aligned} \tag{31}$$

and η_1 and η_2 are constants from the linear approximation of the inverse Mills ratio satisfying η_1,$\eta_2 > 0$ and $\eta_2 < 1$.

Proof. Presented in Appendix C. ■

It can be seen from (31) that the threshold depends on the variables and constants that are observable by all agents. Therefore, uninformed investors trading in period $t+1$ know the value of $\bar{\theta}_{t+2}$.

Corollary 2 *In perfect financial markets (i.e. if all investors are informed), the threshold simplifies to*

$$\bar{\theta}^{PI}_{t+2} = \frac{R^2}{\Gamma}\hat{\zeta}(\cdot). \tag{32}$$

Replacing $\lim_{\hat{\mu}^I_{t+1}\to\infty} z_{v,t+1} = \lim_{\mu_I\to\infty} [\beta_{\tilde{\theta}} + \left(\hat{\mu}^I_{t+1}\beta_u/\tau\right)^2 \beta_s]^{-1} = 0$ in (31) yields (32).

[14] From (24) $E[b_{t+1}|\theta_{t+2}] = \frac{1}{\sqrt{z_{v,t+1}}}(\bar{\theta}_{t+2} - \theta_{t+2})$, $\bar{\theta}_{t+2}$ is the threshold above which fast technology adoption will be undertaken.

[15] Details about the results with second order polynomial are available upon request.

As long as some investors are uninformed, there are two opposite forces that affect the adoption decision: **"fear of unstable markets"** and **"adoption to signal"**.

The "fear of unstable markets" force is captured by the term $\frac{\tau}{2}\frac{\Gamma(2+g^*)}{R}A^*_{t+1}(1-\eta_2)^2 z_{v,t+1}$ in (31). Uncertainty about the price on exit can discourage risk averse agents from adopting the frontier technology, which they would find profitable in perfect asset markets (32).

The "adoption to signal" term is captured by $\frac{2+g^*}{g^*}\sqrt{z_{v,t+1}}\eta_1$ in (31). Investors who establish local monopolies have superior information compared to the average investor who determines the market value of their firm. They know that these investors will take fast adoption as an indication of higher profitability. As a result, initial owners might invest in fast adoption to gain from uninformed investors, even if they would not do so in perfect financial markets (32). The possibility of these gains remains despite of the fact that uninformed investors are rational and aware of the force.

Both of these forces decrease with the number of informed investors: $\frac{\partial z_{v,t+1}}{\partial \hat{\mu}^I_{t+1}} < 0$.

Corollary 3 *If productivity of labor is such that initial owners are indifferent between fast or slow adoption in perfect financial markets ($\theta_{t+2} = \bar{\theta}^{PI}_{t+2}$), they will be discouraged from adopting due to the "fear of unstable markets" in imperfectly informed financial markets if*

$$2R < \tau\Gamma g^* A^*_{t+1}\frac{(1-\eta_2)^2}{\eta_1\sqrt{\beta_{\tilde{\theta}} + \left(\frac{\hat{\mu}^I_{t+1}\beta_u}{\tau}\right)^2 \beta_s}}. \quad (33)$$

Indifference between fast or slow adoption in perfect markets implies that $\theta_{t+2} = \frac{R^2}{\Gamma}\hat{\zeta}(\cdot)$ from (32). Applying this fact to (31), and using constants from (24) and (27) shows (33). Corollary 3 has some interesting implications.

A lower number of informed investors ($\hat{\mu}^I_{t+1}$) magnifies the "fear of unstable markets". We can think of the number of informed investors as a measure of the size or development of local financial markets. Therefore, the model suggests that countries with underdeveloped financial markets are more likely to adopt frontier technology slowly, even if the productivity is high enough to justify fast technology adoption in perfect financial markets.

An increase of the number of informed investors encourages "adopting to signal", but causes the resulting gains to decrease. This implies that this force is likely to be most important at an intermediate number of informed investors. If the number of informed investors is very high, potential gains are negligible. Figure 3 illustrates how the threshold for fast technology adoption (31) depends on the number of informed investors.

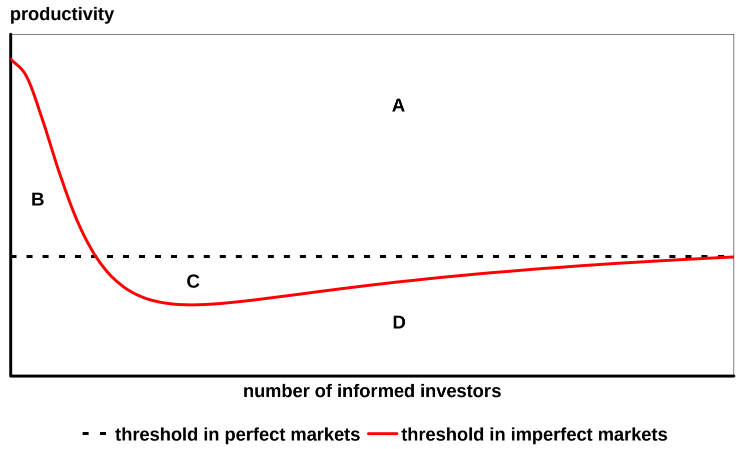

Figure 3: Relationship between productivity (θ_{t+2}), number of informed investors ($\hat{\mu}^I_{t+1}$) and speed of technology adoption. Perfect financial markets: fast (slow) adoption in areas A&B (C&D); Imperfect markets: fast (slow) adoption areas A&C (B&D). In B slow technology adoption is due the "fear of unstable markets" force and in C fast technology adoption is due to the "adoption to signal" force.

Higher risk aversion (τ) pushes initial owners towards the "fear of unstable markets". One reason for this is the direct impact of higher risk aversion, making initial owners care more about uncertainty in the following period. There is also a secondary effect, since higher risk aversion reduces the quality of price information through lower demand for the risky asset from informed investors. A higher variance for the unexplainable component of productivity ($1/\beta_u$) has similar effect on the quality of price signal. With an infinite number of traders, the unexplainable component of productivity affects initial owners only through its' impact on price signals.

Similarly, higher variance of the public signal ($1/\beta_{\tilde{\theta}}$) and noise trading ($1/\beta_s$) increase the uncertainty investors are facing, increasing the "fear of unstable markets". In these cases, there is another secondary effect at play, as these move the equilibrium equity price closer to fundamentals (see (27)). However, this force is not strong enough to eliminate the negative direct impact from higher uncertainty.

An increase of the risk-free rate has a dual effect on incentives to invest in fast technology adoption. First, there is a direct effect, by which the threshold productivity has to be higher to make investment in fast adoption worthwhile (31). This effect is present also in perfect financial markets. Second, (33) implies that a higher risk-free rate reduces the impact of "fear of unstable markets force", because it implies a lower variance of equity prices. This suggests that an increase of risk-free rate (R) reduces the probability of fast technology adoption less in imperfect equity markets.

2.4.2 The impact of evolution of the frontier - tendency towards persistently slow technology adoption

Claim 4 *Improvements in the frontier technology have a negative impact on a country's ability to adopt the world frontier technology (A^*_{t+2}), due to information imperfections.*

Assume that the cost of adoption for a given change in technology is constant, $\hat{\zeta}(\cdot) = \hat{\zeta}$. In this case, it is clear from (32) that if productivity would stay constant at some level $\bar{\theta} \geq \frac{R^2}{\Gamma}\hat{\zeta}$, a country can always keep up with adopting the newest technology under perfect financial markets.

In imperfect financial markets, the impact of "fear of unstable markets" will increase with the level of technology. Keeping up with the adoption of newest technology with imperfectly informed investors, has to imply an increase in the number of informed investors (or other variables that would lower the threshold or an increase of productivity). Furthermore, a higher growth rate of frontier technology reduces the gains from "adopting to signal" while increasing the negative impact of "fear of unstable markets". If, for example, pure "fear of unstable markets" discourages initial owners from adopting fast in period t, the next generations will also not adopt fast, *ceteris paribus.*

The intuition for this is the following. By (17), monopolistic profits increase with the evolution of frontier technology. Uninformed investors do not know how well local labor is able to use any technology, and therefore uncertainty about profits is higher at higher technology levels. This result is driven by the assumption that uncertainty regarding the productivity of using any level of technology is the same.[16]

If in addition we assume that the cost of adoption is an increasing function of the distance to the frontier (for example, $\hat{\zeta}(\frac{A^*_{t+2}}{A_t}) = \hat{\zeta}(\frac{1+g}{(A_t/A^*_{t+1})}$), $\hat{\zeta}'(\cdot) > 0$) and similarly to Aghion, Comin and Howitt (2006), the improvements in the frontier would be even more discouraging. Failing to adopt fast in some period would in such case make it also more costly to adopt fast in the following period and the threshold (31) increases[17].

Assuming that the variance of price signal has constant quality over time (19) eliminated another mechanism that would imply further impact of "fear

[16] If, this uncertainty is higher for the more advanced technology adopted, evolution of the frontier technology makes it even harder to sustain fast technology adoption.

[17] This argument is more relevant if firms are established by local entrepreneurs alone.

of unstable markets" with the growth of technology. If the variance of noise trading would not fall with $\Gamma^2 A_{t+2}^2$, the price signals would become worse over time, because a limited number of informed investors holds a relatively smaller proportion of firms. In such case the tendency towards persistently slow technology adoption would also be stronger.

Countries that have big and well developed financial markets (the number of either local or foreign informed investors is large) are less affected by both forces analyzed. This is consistent with developed countries having less volatile capital markets, and high technology level. The model suggests that this outcome does not require developed countries to have either more skilled labor force (higher θ_t) or lower technology adoption costs.

2.4.3 Impact of the participation of a foreign investor

It can be seen from Proposition 1 that, even with foreign initial owners capable of cheaper adoption technology ($\hat{\zeta} = \zeta^* < \zeta(\cdot)$), the impact of the two forces analyzed would be also present and the dominating force does not depend on the adoption cost (Corollary 3). Nevertheless, the threshold $\bar{\theta}_{t+2}$ is lower than the threshold if the local entrepreneurs operates alone:

$$\begin{aligned}\bar{\theta}_{t+2}^{loc} \equiv & \frac{R^2}{\Gamma}\zeta(\cdot) - \frac{2+g^*}{g^*}\sqrt{z_{v,t+1}}\eta_1 \\ & + \frac{\tau}{2}\frac{\Gamma(2+g^*)}{R}A_{t+1}^*(1-\eta_2)^2 z_{v,t+1}\end{aligned}$$

It is clear that if the fast technology adoption is more costly for a foreigner ($\zeta^* > \zeta(\cdot)$), he would never participate. This is due to the assumption that the adoption of any technology requires effort by a local entrepreneur, who is the only agent with the relevant skills to adopt in local intermediate goods' sector j. With a similar argument, there is no foreign participation, if slow technology adoption would be optimal for the possible joint venture with the local entrepreneur and foreign investor that can adopt technology fast for a cost $\hat{\zeta} = \zeta^* < \zeta(\cdot)$. Therefore, the relevant cases to analyze are when $\theta_{t+2} \geq \bar{\theta}_{t+2}$, $\bar{\theta}_{t+2} < \bar{\theta}_{t+2}^{loc}$ and $\zeta^* < \zeta(\cdot)$. It is assumed that in a joint venture, foreigner has all the bargaining power.

First, the local alone might choose slow technology adoption, while fast adoption would be undertaken in a joint venture ($\bar{\theta}_{t+2} \leq \theta_{t+2} < \bar{\theta}_{t+2}^{loc}$). If the local entrepreneur's reward in the joint venture (received in period $t+1$) is $q_{sl,t+1}$, his participation constraint is $q_{sl,t+1} \leq U_t(\tilde{1}_{I_t} = 0)$. With the foreigner having the bargaining power, this holds with equality. The foreigner will bear all costs of fast adoption $\zeta^*(A_{t+2}^* - A_{t+1}^*)$ and receives the gains from higher firm value $q_{sl,t+1}^* = U_t(\tilde{1}_{I_t} = 1) - U_t(\tilde{1}_{I_t} = 0)$ in $t+1$. The foreign agent can be seen acting as a venture capitalist, investing in a costly project and receiving a risky return.

Second, the local might be able to adopt fast technology alone, but it is cheaper in the joint venture ($\theta_{t+2} \geq \bar{\theta}^{loc}_{t+2}$). In such case the local's utility from the joint venture equals to his opportunity cost $q_{fa,t+1} = U_t(\tilde{1}_{I_t} = 0) - R\zeta(\cdot)(A^*_{t+2} - A^*_{t+1})$ and foreigner pays for adoption cost $\zeta^*(A^*_{t+2} - A^*_{t+1})$ and extracts $q^*_{fa,t+1} = R\zeta(\cdot)(A^*_{t+2} - A^*_{t+1})$ from local entrepreneur. This essentially means that the local entrepreneur will hire the services of the foreigner to reduce his costs. It requires highly productive labor, little negative impact from uncertainty related to imperfect information and low cost of fast technology adoption for locals. This case is less realistic in developing countries.

2.5 Local goods market clearing

The local goods market condition is given by (9). Appendix E proves that it holds. The net inflow of goods from abroad (F_{t+1}) is determined as follows. In period $t+1$, there is an inflow of returns from risk-free asset (the investment local investors/consumers made in period t) and of foreigners investment to the local risky asset (monopolistic firms established at t). There is an outflow of period $t+1$ investment in the risk-free asset by locals, and period $t+1$ profits claimed by foreign investors. If in addition to local entrepreneur, foreign investors participate in technology adoption, there are additional capital inflows and outflows from their investment to the technology and exit.

The predictions from goods market clearing are standard. If domestic investment is higher, because fast technology adoption in undertaken, net foreign asset position will be lower. In such case agents need to borrow more or invest less in the risk-free asset.

Given that the foreign partner always compensates the opportunity cost to the local entrepreneur (Section 2.4.3), foreign participation in technology adoption projects does not affect aggregate consumption of the generation that forms a joint venture with foreign agents (see Appendix E)[18]. If foreign investors are capable of adopting fast technology that locals are not, consumption of future generation is higher because of higher wages ((14) and (13)).

[18]Relaxing the assumption that technology adoption requires the unique skills of a local entrepreneur could allow for welfare losses from foreign investors' participation in technology adoption. Especially if optimal speed of adoption is slow.

3 Endogenous number of informed investors and incentives for transparency

3.1 Equilibrium number of informed investors

Section 2.4 highlighted the fact that the number of informed investors ($\hat{\mu}^I_{t+1}$) is one of the crucial determinants for the speed of adoption in a small open economy. So far, this number is taken as exogenous. This section assumes that uninformed investors can become informed for a fixed cost (D_{t+1}) during the trading period. When an uninformed investor decides whether to become informed, he does not know what value of θ_{t+2} he will observe after paying the information cost. He will compare his expected utility as an informed investor with his expected utility from staying uninformed, conditional on his available information set, Ω^U_{t+1}. He will decide to become informed if

$$E\left[U^I_{t+1}|\Omega^U_{t+1}\right] - RD_{t+1} \geq E\left[U^U_{t+1}|\Omega^U_{t+1}\right].$$

The information cost function is assumed to be given by a known time specific constant in $t+1$, $D_{t+1} = \delta_{t+1}\vartheta_{t+1}$, where δ_{t+1} is a constant that measures how expensive becoming informed is at any level of technology, and ϑ_{t+1} is a constant that allows uninformed investors to discover more easily if technology adoption decision issues a false signal.[19]

The number of informed investors cannot be negative, $\hat{\mu}^I_{t+1} \geq 0$ and $\mu^I_{t+1} \geq 0$. Assuming the existence of some local investors who become informed at zero cost, i.e. $\mu^I_{t+1} > 0$, could be justified since at least some local investors are likely to be able to understand local information better. They could also have more direct contact with managers of firms, superior knowledge of the local labor force and business environment and better access to "inside information".

Proposition 5 *An investor will choose to become informed if $\delta_{t+1} \leq \bar{\delta}_{t+1}$. In equilibrium, the cost of information will equal to the gains from becoming informed and the equilibrium number of informed investors*

$$\hat{\mu}^I_{t+1} = \begin{cases} \mu^I_{t+1}, \textit{ if } \delta_{t+1} > \bar{\delta}_{t+1} = \frac{\beta_u}{R2\tau}\frac{1}{\beta_{\tilde{\theta}} + \frac{\mu^2\beta_u^2}{\tau^2}\beta_s} \\ \sqrt{\frac{\tau}{\beta_u\beta_s}\left(\frac{1}{R2\delta_{t+1}} - \frac{\beta_{\tilde{\theta}}\tau}{\beta_u}\right)}, \textit{ otherwise.} \end{cases} \tag{34}$$

[19] The cost being proportional to $\vartheta_{t+1} \equiv 1 - \lambda^{\cdot 2}_{\tilde{1}_{I_t}}(b_{t+1}) - b_{t+1}\lambda_{\tilde{1}_{I_t}}(b_{t+1})$ affects the $\mathrm{Var}[\theta_{t+2}|\Omega^U_{t+1}]$. It assumes that information cost is lower if according to other signals, uninformed investors would expect the productivity to be low (high), and the country nevertheless adopted fast (slow). Therefore, this assumption works against the distortions analyzed by limiting the initial owner's potential gains from "adopting to signal". It simplifies the analysis, because ϑ_{t+1} is unknown in period t.

Proof. See Appendix 5. ■

Intuitively, becoming informed is profitable as long as the cost is not too high compared to the freely available information. As investors do not know what signal they get, the gain from information is the opportunity to reduce the variance of their returns. The more investors become informed, the more informative asset prices will be. More informative prices limit the gains from better private information. If any uninformed investor finds it profitable to become informed, the equilibrium number of informed investors equalizes the gains of better information with its costs. If information cost is high and no uninformed investor finds it profitable to become informed, the equilibrium number of informed investors is given by the number of investors, who are informed for zero cost.

As can be seen from (34), the number of informed investors is higher if either the risk-free return (R) or information costs (δ_{t+1}) are low. If the public signal is more informative (high $\beta_{\tilde{\theta}}$), less investors decide to become informed. Similarly, lower variance of noise trading ($1/\beta_s$) reduces the number of uninformed investors who find it profitable to become informed, because price signals are more informative. Higher risk aversion (τ) and ($1/\beta_u$) affect the incentives to acquire costly information in two opposite ways. First, they reduce the willingness of the investors to invest in the risky asset and pay the information costs. Second, they increase the incentives to bear information costs, because lower participation of informed investors reduces the informativeness of price signals. The second effect dominates as long as it is optimal for any investor to pay the information cost ($\delta_{t+1} \leq \bar{\delta}_{t+1}$). These results are similar to Tinn (2005).

It can be seen from (34) that the equilibrium number of informed investors does not depend on the level or growth rate of the technology. Even though technology improvements imply higher profits, the adoption decision is made before the trading period and is known to all participants of financial markets. The risky asset price adjusts to take this improvement into account for any number of informed investors.[20]

[20] This result relies on the assumption that variance on noise trading decreases over time (19). If this is not the case, less informative asset prices at higher technology level would give more incentives to paying the information costs. However, this would only offset the extra negative impact from "fear of unstable markets" that is eliminated in the current setup.

3.2 Adoption with endogenous number of informed investors and incentives for transparency

This section assumes that $\delta_{t+1} \leq \bar{\delta}_{t+1}$, which implies that at least some uninformed investors will decide to become informed. Replacing (34) in (31) and simplifying the threshold gives

$$\bar{\theta}_{t+2} = \frac{R^2}{\Gamma}\zeta(\cdot) - \frac{2+g^*}{g^*}\sqrt{\frac{R2\tau}{\beta_u}}\sqrt{\delta_{t+1}}\eta_1 + +\tau^2\Gamma\left(2+g^*\right)A^*_{t+1}\left(1-\eta_2\right)^2\frac{1}{\beta_u}\delta_{t+1} \quad (35)$$

The forces of "fear of unstable markets" and "adopting to signal," and the factors influencing these, are still present with an endogenous number of informed investors. The technology adoption decision becomes a function of the cost of information δ_{t+1}. Policies towards transparency by local policy makers could affect this cost. This creates a link between technology adoption and institutions that affect financial markets' development.

In order to investigate the policy maker's incentives for transparency, consider an extreme case where it has full control over δ_{t+1}. Suppose the policy maker's objective is to maximize the chances for the country to adopt fast. This objective can be justified, because it allows for output and wages ((13) and (14)) to increase earlier and therefore increases the consumption of agents benefiting from this. Maximizing the probability of fast technology adoption is equivalent to minimizing the threshold, i.e.

$$\delta^{opt}_{t+1} = \arg\min_{\delta_{t+1}}\left(\bar{\theta}_{t+2}\right),$$

where $\bar{\theta}_{t+2}$ is given by (35).[21]

Proposition 6 *If a policy maker has a full control over the cost of information, he will set the cost to be*

$$\delta^{opt}_{t+1} = \left(\frac{\eta_1\sqrt{R\beta_u}}{g^*\Gamma A^*_{t+1}\left(1-\eta_2\right)^2\sqrt{2\tau^3}}\right)^2 > 0.$$

Proof. See Appendix G. ■

This Proposition suggests that the local policy maker does not choose full transparency ($\delta^{opt}_{t+1} = 0$). The reason comes from the "adopting to signal" force. As long as some investors are uninformed, initial owners would

[21] Appendix H shows that the results are similar, if the local policy maker chooses the precision of the public signal, for the same policy objective.

find it optimal to adopt fast at a lower level of productivity than would be possible in perfectly informed equity markets. It is important to point out that the counter-intuitive policy encouraging "too fast" technology adoption is justified because the policy maker is local. The extra opportunities of fast technology come at the expense of losses of foreign uninformed investors. Given that the local market is limited in size, asset holdings of local uninformed investors are marginal. In equilibrium $RP_{t+1} = E(\pi_{t+2}|\Omega^U_{t+1})$, and from (21) each of the local uninformed investors holds in equilibrium $h^U_{t+1} = \hat{h}^U_{t+1} = 0$. At the same time, local informed investors are expected to get excess gains from asset market as long as there are not infinitely many informed investors.[22]

Both the higher level and growth rate of frontier technology imply more incentives towards transparency. As discussed in the Sections 2.4.1 and 2.4.2, evolution of frontier technology implies higher uncertainty. Therefore, countries that try to keep up with improvements in the frontier technology are expected to aim to become more transparent over time,

$$\frac{\delta^{opt}_{t+2}}{\delta^{opt}_{t+1}} = \left(\frac{A^*_{t+1}}{A^*_{t+2}}\right)^2 = \left(\frac{1}{1+g^*}\right)^2$$

Other variables that increase the optimal transparency are higher risk aversion (τ), variance of unexplainable component of productivity ($1/\beta_u$) and lower risk-free interest rate (R). As it can be seen from (35), these changes tilt towards the dominance of "fear of unstable markets" force. Section 3.1 showed that for a given information cost, the same variables give incentives to more uninformed investors to become informed. However, this is not sufficient and policy maker would give further incentives to acquire costly information through higher transparency.

[22] Policy makers' objective could also be maximizing the utility of local agents. This is more cumbersome mainly because it is hard to identify what is the reasonable information set the local policy maker has. However, it would not alter the optimal information cost being above zero in this setup. Agents affected by the choise of δ_{t+1} are 1) local entrepreneurs born in t, 2) local investors born in $t+1$ and 3) workers born in $t+2$. Higher probability of fast technology adoption is beneficial for agents 1) and 3). Lower transparency is beneficial for an average local investor. Therefore, the local policy with such objective function is likely to set information cost higher and not lower compared to the one analyzed.

4 Closing the local asset market to foreign portfolio investors

One of the reasons why countries restrict the foreign portfolio investments is the potential instability of these flows. This section analyses if preventing foreigners to trade in the local equity market can make fast technology adoption more likely. Since the justification for capital restrictions implies that foreign capital is less informed than local, assume that all potential foreign investors are uninformed and all local investors are informed but limited in number ($\mu = \mu^I_{t+1}$ is finite). Assume that the restrictions of foreign investors imply that none of the foreign investors can invest in the country ($\mu^{*U}_{t+1} = \mu^{*I}_{t+1} = 0$). This section analyzes two cases in this framework, where the location of noise traders is different.

In the first case, assume that all noise traders are local. Using (18), the optimal demand (21), (22), and the equity market clearing condition (2), the equilibrium price can be expressed as

$$P^R_{t+1} = \frac{\Gamma A_{t+2}\theta_{t+2}}{R} - \frac{\tau\Gamma^2 A^2_{t+2}}{\mu\beta_u R} + \frac{\tau\Gamma^2 A^2_{t+2}}{\mu\beta_u R} s_{t+1}. \tag{36}$$

Because the size of local market is limited, equity prices contain a liquidity premium and a risk premium. Both premiums are decreasing in the number of local informed investors (μ). A liquidity premium is introduced because the limited number of local investors cause excess supply of risky asset. As a result, asset prices will be lower and excess gains of local rational investors higher. This has a new discouraging impact on the incentives to adopt fast. There is still uncertainty in the local market from noise traders and the "fear of unstable markets" has an impact. Absence of uninformed investors, who take fast adoption as a signal of high productivity, eliminates any potential gains from "adopting to signal". If all noise traders are local, there is more uncertainty regarding the asset price despite less uncertainty from the impact of sentiment in international markets. In such case it is never optimal for a country to forbid uninformed, but rational foreigners from investing in the country, if the goal of the local policy maker is to encourage fast technology adoption. Appendix I proves it formally.

In the second case, it is assumed that all noise traders are foreign. Then

$$P^R_{t+1} = \frac{\Gamma A_{t+2}\theta_{t+2}}{R} - \frac{\tau\Gamma^2 A^2_{t+2}}{\mu\beta_u R}.$$

On one hand, initial owners deciding the speed of technology adoption, face no uncertainty and the "fear of unstable markets" force disappears. On the other hand, absence of "adoption to signal" force and liquidity premium reduce the incentives to invest in fast adoption. In this case there exists a possibility that restricting foreign portfolio investments can encourage faster technology adoption (see Appendix I). However this possibility exists only under specific conditions. First, the number of local informed investors has to be low enough such the "fear on unstable markets" force would dominate if the country was open to foreign portfolio investments (Section 2.4). Otherwise, participation of uninformed foreign investors would eliminate the liquidity premium and allow "adopting to signal". Second, the variance of foreign noise trading or unexplainable component of labor productivity has to be high. This implies that price signals are not sufficiently informative. Third, the number of local informed investors cannot be very low, i.e. the local market is very small. In such case, the need for liquidity is pressing.

Hence, the model suggests that countries that could benefit from fast technology adoption by restricting foreign uninformed capital are those with small, but not the smallest local equity markets. In this case, potential benefits would arise only if the uncertainty in the purely domestic market is very low compared to uncertainty associated with the behavior of foreign investors.

5 Concluding remarks

This paper presented an alternative answer to the question, why is the speed of technology adoption different across countries?. It argues that if ownership transfers of firms that engage in technology adoption have to be made in imperfectly informed equity markets, two opposite forces arise: a negative "fear of unstable markets" force and a positive "adopting to signal" force. These forces affect the incentives for developers to adopt the accessible frontier technology.

The relative importance of these forces depends on the size of financial markets. "Adopting to signal" is likely to be most influential in countries where equity markets are at an intermediate level of development, while "fear of unstable markets" should dominate in underdeveloped markets. The less precise are the signals uninformed traders base their decisions on, the stronger these forces are. The importance of both forces falls with the number of informed investors; it follows that countries with well informed (developed and large) financial markets are less affected. Nevertheless, if the recent developments in the United States' and other developed countries' technology sector assets were a bubble, it suggests that there would be room for "adoption to signal" (in this case it should be seen as "innovation to signal") even in developed countries.

Fast technology adoption tends to be more difficult to sustain because of the participation of uninformed traders. Provided that the number of informed investors and cost of technology adoption does not change, the evolution of the frontier technology implies an increasing importance of the "fear of unstable markets". This is because uncertainty about the ability of labor in using any technology creates higher uncertainty about profits if the technology is more advanced and profits are higher.

The mechanisms analyzed in this paper affect both local agents and foreign investors (such as venture capitalists) intending to invest in establishing new firms. Lack of informed investors in the equity market, can discourage foreign investors from participating in projects where they could reduce the costs associated with adopting the frontier technology. The limited presence of venture capitalists in most developing countries is likely to be affected by the weakness and instability of local asset markets.

When the number of informed investors is made endogenous, by letting the local policy maker to determine the magnitude of information costs, it is shown that countries would not choose to be completely transparent. This situation arises from the "adopting to signal" force. Nevertheless, a policy maker has incentives to enhancinge more transparency over time to keep up with adopting the frontier technology.

The model considered two extremes cases generating information asymmetries: the number of informed investors being exogenous, and the local policy maker having full control over information costs. In the more realistic case, where the local policy maker has some, but not full, control over the information costs, both policies and exogenous factors will determine the number of informed investors.

The better performance of transition countries that joined the EU in 2004, when compared with those that did not, could be explained by their ability to attract informed investors from neighboring developed countries more easily. Estonia is a stark example of a country that has been very active in adopting Internet and Communication Technologies in 1990s, and attracted venture capital funded Skype, arguably due to the impact of the "adopting to signal" force. At the same time, Romania or Ukraine, which have similar shares of educated labor, have lower rates of technology adoption, and may have been more affected by the "fear of unstable markets" force.

The model assumed that openness to international portfolio capital flows guarantees sufficient liquidity in the local equity market. In reality, less developed equity markets can also lack liquidity, even if they are open, because the number of foreign investors who are interested in investing in these countries is low. The liquidity premium has a further negative impact on the incentives to adopt costly frontier technology in less developed equity markets, and forbidding foreign portfolio equity flows would increase it. In countries where the local equity markets are smallest, the need for attracting foreign portfolio equity flows to generate liquidity is pressing, and entry of foreign traders is likely to encourage investments in fast technology adoption. Gains from preventing foreign portfolio equity flows are only possible under very specific conditions in this setup. First, local equity markets have to be small, such that the "fear of unstable markets" would dominate in open equity capital markets. Second, policies should enable only local investors to be well informed, while the foreign investors are largely uninformed and their behaviour is highly uncertain. Only in such case, the benefits from lower uncertainty could potentially offset the losses due to a higher liquidity premium. In countries with intermediate and big equity markets, the "fear of unstable markets" has little negative effect and even a small additional liquidity provided by the participation of foreign traders would justify openness to foreign portfolio equity investments.

The model does not specify whether firms are listed in the local or foreign stock market. Listing in a well established stock exchange (e.g. NASDAQ) can allow a firm to access a larger number of informed potential buyers. Also, the regulations of well developed stock exchange should reduce information costs. However, for most of the firms from developing countries, fixed costs associated with an initial public offering in NASDAQ are likely too high and they have to rely on the local equity market. Therefore, this possibility is available only for the most successful and innovative firms. Moreover, the most successful and innovative local firms can be more easily sold to a strategic foreign owner. As long as the price the strategic owner pays for a firm reflects its market value, the mechanism suggested in this paper remains valid. If the local equity market is very underdeveloped and most firms are transferred directly between local agents, both potentially the low number of informed buyers and lack of liquidity are likely to discourage fast technology adoption.

Finally, the mechanisms suggested in this paper need further empirical quantification, which is left for future research.

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A Tables and figures

A.1 Labor force, stock markets and institutions

Table. Data for 1996-2004, medians

	Labor with sec. educ.*	Stock mrk. cap.	Turnover ratio	Rule of law	Regul. qual.
Asia	28.2	44.5	80.3	0.30	0.35
Latin America	33.3	24.5	15.3	-0.29	0.26
Transition (EU)	62.9	13.4	38.4	0.60	0.74
Other transition	56.6	10.4	8.9	-0.07	0.28
EU (excl. new)	45.0	66.8	72.8	1.74	1.39
United States	na	133.9	141.4	1.73	1.46

* no data available after 2001

Indicators:
Labor with sec. educ. - Percentage of labor force with at least secondary education out of total labor force. Source: World Bank Development Indicators
Stock mrk. cap. - Ratio of stock market capitalization to GDP. Source: Financial Sector Development Indicators. World Bank
Turnover ratio - Stock market turnover ratio equals to stocks traded divided by stock market capitalization. Source: Financial Sector Development Indicators. World Bank
Rule of law. - Original index in scale -2.5 to 2.5, rescaled to 0-5 scale. Measures the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, the police, and the courts, as well as the likelihood of crime and violence. Source: D. Kaufmann, A. Kraay, and M. Mastruzzi (2006), Governance Matters V: Governance Indicators for 1996-2005. World Bank
Regul. qual. - Regulatory quality index. Original index in scale -2.5 to 2.5 is rescaled to 0-5 scale. Measures the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development. Source: D. Kaufmann, A. Kraay, and M. Mastruzzi (2006), Governance Matters V: Governance Indicators for 1996-2005. World Bank

Country groups:
Asia - China, Hong Kong, India, Indonesia, Korea, Malaysia, Philippines, Singapore, Thailand
Latin America - Argentina, Brazil, Chile, Colombia, Mexico, Peru, Venezuela

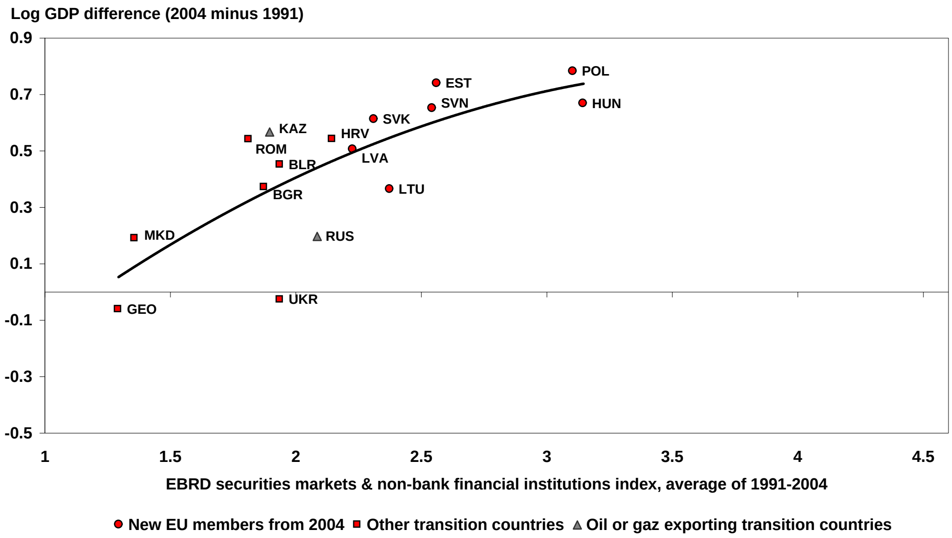
Transition (EU) - transition countries that joined European Union in 2004, i.e. Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovak Republic, Slovenia
Other transition - other transition countries that have initial PPP adjusted GDP per capita above 3.0 thousand USD in 1991, i.e. Belarus, Bulgaria, Croatia, Georgia, Kazakhstan, FYR Macedonia, Romania, Russian Federation, Ukraine.
European Union (excl. new) - European Union members excluding "Transition (EU)" and Luxembourg, i.e. Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Portugal, Spain, Sweden, United Kingdom

A.2 Income per capita and R&D expenditures

Figures A1 and A2 present data on transition countries that are comparable in various characteristics. These countries are similar in high share of educated labour force, institutions and lack of securities markets at the time when Soviet Union dissolved and initial level of GDP. The figures exclude five transition countries that had substantially lower initial PPP adjusted GDP per capita (below 3.0 thousand USD) in 1991. The remaining countries have mean 6.6 thousand USD and standard deviation 2.0 thousand USD.

Figure A1 shows the relationship between development of equity markets and PPP adjusted GDP per capita in US dollars (World Bank Development Indicators). Figure A2 shows similar relationship with R&D expenditures per capita in PPP adjusted US dollars (World Bank Development Indicators). The measure of equity markets' development is "Securities market & non-bank financial institutions index" (European Bank for Reconstruction and Development). The index evaluates countries on a scale 1-4.5, where 1: little progress; 2: Formation of security exchanges, market-makers and brokers, some trading in government paper and/or securities; rudimentary legal and regulatory framework for the issuance and trading securities; 3: substantial issuance of securities by private enterprises, secure clearance and settlement procedures, and some protection of minority shareholders, emergence of non-bank financial institutions and associated regulatory environment; 4: securities laws and regulation approaching the IOSCO standards, substantial market liquidity and capitalization, well functioning non-bank financial institutions and effective regulation; 4.5 standards and performance norms of advanced industrial economies, full coverage or securities laws and regulations with the IOSCO standards, fully developed non-bank intermediation. In 1989 all transition countries had index "1". The value of index for the EU average and the United States is taken to be equal to 4.5 (the maximum

Figure A1: Securities market and PPP adjusted GDP per capita (in US$) growth, 1991-2004



index value), which is consistent with the definition.

Figure A3 shows similar patterns for R&D expenditures in high and upper-middle income countries as classified by World Bank. The measure of equity markets development used is the "Equity Size Index" (Financial Sector Development Indicators, World Bank). The index is an average of scaled market capitalization to GDP, value traded to GDP and turnover ratio: value traded to market capitalization. Scaling is done according to the median and standard deviation of the variables such that most scaled values are in the interval [2.5, 7.5].

Figures show a concave and possibly non-monotonic relationship that would be consistent with the predictions of the model. The patterns are similar if using other available measures of equity market development (e.g. number of IOSCO principles implemented, realized equity return volatility) or technology adoption (e.g. number of personal computers or internet users per 1000 people and GDP growth).

Figure A2: Securities market and log R&D expenditures per capita (in PPP adjusted US$), 1996-2003

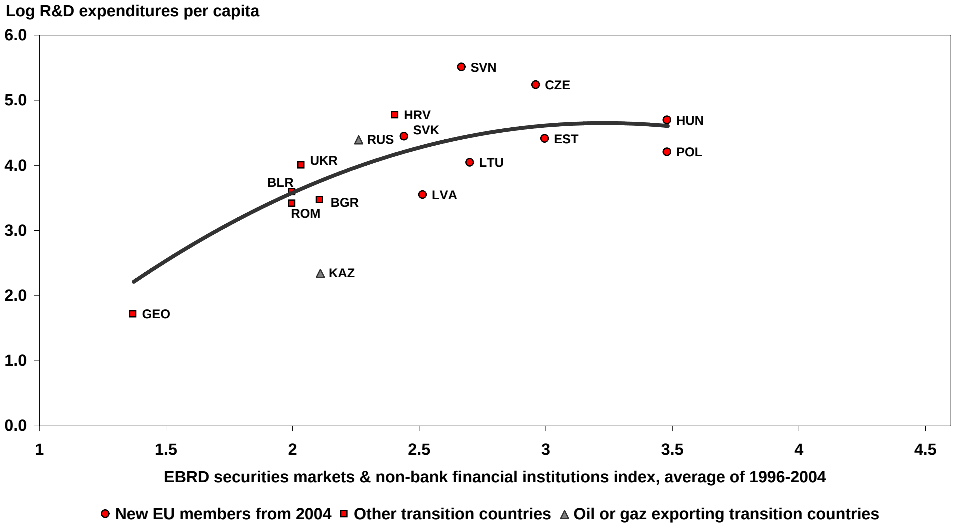
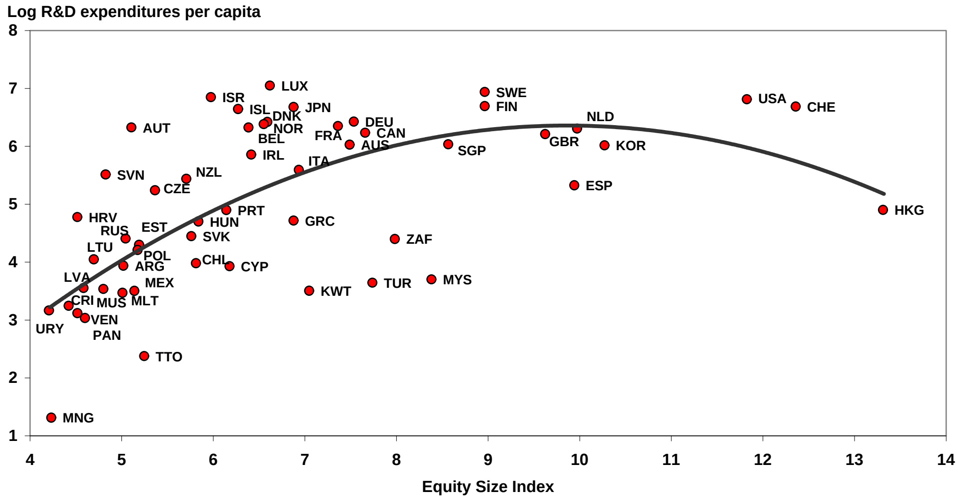


Figure A2: Securities market and log R&D expenditures per capita (PPP adjusted 2000 US$), 1996-2003, high and upper middle income countries.



B Equilibrium in the asset market

The optimal demand of informed traders is specified in (21) and (22). Uninformed investors obtain information from their public signal (8), adoption decision made by the initial owners in period t and the price. Replacing the optimal demand of informed agents into the asset market clearing condition (2). This implies,

$$\hat{\mu}^I_{t+1}\frac{\Gamma\theta_{t+2}A_{t+2}-RP_{t+1}}{\tau\Gamma^2A^2_{t+2}\frac{1}{\beta_u}}+\hat{\mu}^U_{t+1}\hat{h}^U_{t+1}+s_{t+1}=1. \tag{37}$$

Uniformed investors are all identical and they know their optimal demand ($\hat{h}^U_{t+1}$). This means that they also know the optimal demand of all other uninformed investors. Therefore, the price signal can be found from rearranging the equation into observable (the price signal, $\tilde{P}_{t+1}$) and unobservable part from the point of view of any uninformed investor. As a result

$$\begin{aligned}\tilde{P}_{t+1} &\equiv \frac{RP_{t+1}}{\Gamma A_{t+2}}-\frac{\tau\Gamma A_{t+2}\frac{1}{\beta_u}}{\mu_I}(1-\hat{\mu}^U_{t+1}\hat{h}^U_{t+1})=\\ &= \theta_{t+2}+\frac{\tau\Gamma A_{t+2}}{\hat{\mu}^I_{t+1}\beta_u}s_{t+1},\end{aligned}$$

which is the same as (23). Given that $s_{t+1}\sim\mathcal{N}(0,1/\Gamma^2A^2_{t+2})$, the conditional distribution $\tilde{P}_{t+1}|\theta_{t+2}\sim\mathcal{N}\left(\theta_{t+2},\frac{1}{\beta_s\left(\frac{\hat{\mu}^I_{t+1}\beta_u}{\tau}\right)^2}\right)$. This means that

$$\theta_{t+2}|\tilde{\theta}_{t+2},\tilde{P}_{t+1},\sim\mathcal{N}\left(\frac{\beta_{\tilde{\theta}}\tilde{\theta}_{t+2}+\beta_s\left(\frac{\hat{\mu}^I_{t+1}\beta_u}{\tau}\right)^2\tilde{P}_{t+1}}{\beta_{\tilde{\theta}}+\beta_s\left(\frac{\hat{\mu}^I_{t+1}\beta_u}{\tau}\right)^2},\frac{1}{\beta_{\tilde{\theta}}+\beta_s\left(\frac{\hat{\mu}^I_{t+1}\beta_u}{\tau}\right)^2}\right).$$

Defining coefficients z_{t+1} and $z_{v,t+1}$ as in (25)

$$\theta_{t+2}|\tilde{\theta}_{t+2},\tilde{P}_{t+1},\sim\mathcal{N}\left(z_{t+1}\tilde{\theta}_{t+2}+(1-z_{t+1})\tilde{P}_{t+1},z_{v,t+1}\right)$$

Uninformed investors also get information from knowing the adoption decision of local informed investors. If in previous period the adoption speed was chosen to be fast ($\tilde{1}_{I_t}=1$), it implies $\theta_{t+2}\geq\bar{\theta}_{t+2}$. If it was slow ($\tilde{1}_{I_t}=0$) then $\theta_{t+2}<\bar{\theta}_{t+2}$. Following Green (2000, pp. 899) the moments of truncated normal can be expressed as

$$\begin{aligned}E(\theta_{t+2}|\Omega^U_{t+1}) &= \left(z_{t+1}\tilde{\theta}_{t+2}+(1-z_{t+1})\tilde{P}_{t+1}+\sqrt{z_{v,t+1}}\lambda_{\tilde{1}_{I_t}}(b_{t+1})\right) \quad (38)\\ \mathrm{Var}(\theta_{t+2}|\Omega^U_{t+1}) &= z_{v,t+1}\left(1-\lambda^2_{\tilde{1}_{I_t}}(b_{t+1})+b_{t+1}\lambda_{\tilde{1}_{I_t}}(b_{t+1})\right),\end{aligned}$$

where $b_{t+1} \sim \mathcal{N}(0,1)$ defined as in (25) and $\lambda_{\tilde{1}_{I_t}}$ is inverse Mills ratio; $\lambda_{\tilde{1}_{I_t=1}}(b_{t+1}) = \frac{\phi(b_{t+1})}{1-\Phi(b_{t+1})}$ and $\lambda_{\tilde{1}_{I_t=0}}(b_{t+1}) = -\frac{\phi(b_{t+1})}{\Phi(b_{t+1})}$, where $\phi(.)$ and $\Phi(.)$ are standard normal p.d.f. and c.d.f respectively. Using the (4) and the independence of u_{t+1} from the public signal and noise trading shocks, the expectation of profits is (24) for uninformed investors.

Plugging the demand of uninformed investors (21) and (24), we can express the equilibrium price from (37) as

$$P_{t+1} = \frac{\hat{\mu}^I_{t+1}\frac{\Gamma\theta_{t+2}A_{t+2}}{\tau\Gamma^2 A^2_{t+2}\frac{1}{\beta_u}} + \hat{\mu}^U_{t+1}\frac{E(\pi_{t+2}|\Omega^{*U}_{t+1})}{\tau\,\mathrm{Var}(\pi_{t+2}|\Omega^{*U}_{t+1})} - 1 + s_{t+1}}{R\left(\frac{\hat{\mu}^I_{t+1}}{\tau\Gamma^2 A^2_{t+2}\frac{1}{\beta_u}} + \frac{\hat{\mu}^U_{t+1}}{\tau\,\mathrm{Var}(\pi_{t+2}|\Omega^{*U}_{t+1})}\right)}$$

As the number of foreign uninformed investors $\mu^U_{t+1} \to \infty$, which also implies $\hat{\mu}^U_{t+1} \to \infty$, the price becomes equal to the discounted expected profits by uninformed investors.

$$P_{t+1} = \frac{E(\pi_{t+2}|\Omega^U_{t+1})}{R}$$

Using (24) and (23)

$$\begin{aligned} P_{t+1} &= \frac{\Gamma A_{t+2}}{R}\left(z_{t+1}\tilde{\theta}_{t+2} + (1-z_{t+1})\tilde{P}_{t+1} + \sqrt{z_{v,t+1}}\lambda_{\tilde{1}_{I_t}}(b_{t+1})\right) = \\ &= \frac{\Gamma A_{t+2}}{R}\left(z_{t+1}\tilde{\theta}_{t+2} + (1-z_{t+1})\theta_{t+2} + (1-z_{t+1})\frac{\tau\Gamma A_{t+2}}{\hat{\mu}^I_{t+1}\beta_u}s_{t+1} + \sqrt{z_{v,t+1}}\lambda_{\tilde{1}_{I_t}}(b_{t+1})\right). \end{aligned}$$

C Proof of Proposition 1

Let us assume that there exists a threshold level of productivity $\bar{\theta}_{t+2}$ above which fast technology adoption is optimal. Assume also that this threshold is observable for uninformed investors trading in the next period.

The approximation of Mills ratio with a linear function around 0 is $\lambda_{1_{I_t}}(b_{t+1}) \approx \eta_2 b_{t+1} + \eta_1(-1)^{1-\tilde{1}_{I_t}}$. Mills ratios for right and left truncation is a reflection from origin. Therefore, the absolute value of intercept is the same for right and left truncation. For example estimated in the range $[-1,1]$ $\eta_2 = 0.6247$ and $\eta_1 = 0.8377$ or in the range $[-3,3]$ $\eta_2 = 0.5701$, $\eta_1 = 1.1101$. For the left truncation the ratio is effectively 0 below -3 and close to linear above 3. In the linear area of Mills ratio function, the slope is below 1 and the function is convex in between. Therefore, in any symmetric range around 0 the slope must be below $\eta_2 < 1$. For left (right) truncation Mills ratio is an increasing and convex (concave) function above (below) 0, which implies $\eta_1, \eta_2 > 0$.

Using this, the asset prices can be expressed as

$$P_{t+1} \approx \frac{1}{R}\Gamma A_{t+2} \quad \Big[z_{t+1}\tilde{\theta}_{t+2} + (1 - z_{t+1})\theta_{t+2} \\ + z_{s,t+1}\Gamma A_{t+2}s_{t+1} + \sqrt{z_{v,t+1}}(\eta_2 b_{t+1} + (-1)^{1-\tilde{1}_{I_t}}\eta_1)\Big]$$

Expanding the price by replacing in b_{t+1}, $\tilde{\theta}_{t+2}$ and $\tilde{P}_{t+2}$, the price becomes

$$P_{t+1} = \frac{\Gamma A_{t+2}}{R} \quad \big[(1-\eta_2)\,\theta_{t+2} + (1-\eta_2)\,z_{t+1}\epsilon_{\tilde{\theta},t+2} \\ + (1-\eta_2)\,z_{s,t+1}\Gamma A_{t+2}s_{t+1} + \eta_2\bar{\theta}_{t+2} + \sqrt{z_{v,t+1}}(-1)^{1-\tilde{1}_{I_t}}\eta_1)\Big] \tag{39}$$

From here we can find the conditional moments as

$$E\left[P_{t+1}|\theta_{t+2}, 1_{I_t}\right] = \frac{\Gamma A_{t+2}}{R}\left[(1-\eta_2)\,\theta_{t+2} + \eta_2\bar{\theta}_{t+2} + \sqrt{z_{v,t+1}}(-1)^{1-\tilde{1}_{I_t}}c_1)\right]$$

$$\mathrm{Var}\left[P_{t+1}|\theta_{t+2}, 1_{I_t}\right] = \frac{\Gamma^2 A_{t+2}^2}{R^2}(1-\eta_2)^2\left[\frac{z_{t+1}^2}{\beta_{\tilde{\theta}}} + \frac{z_{s,t+1}^2}{\beta_s}\right] = \frac{\Gamma^2 A_{t+2}^2}{R^2}(1-\eta_2)^2 z_{v,t+1}$$

By definition, if $\tilde{1}_{I_t} = 1$, then $A_{t+2} = A_{t+2}^*$ and if $\tilde{1}_{I_t} = 0$, then $A_{t+2} = A_{t+1}^*$. Investors, will choose to adopt the technology fast if $U_t(\tilde{1}_{I_t} = 1) \geq U_t(\tilde{1}_{I_t} = 0)$. Using the moments just derived and the adoption cost function (6), the condition to adopt fast becomes

$$\frac{\Gamma\left(A_{t+2}^* - A_{t+1}^*\right)}{R}\left((1-\eta_2)\,\theta_{t+2} + \eta_2\bar{\theta}_{t+2}\right) \geq R\left(A_{t+2}^* - A_{t+1}^*\right)\hat{\zeta}(\cdot) \\ - \frac{\Gamma\left(A_{t+2}^* + A_{t+1}^*\right)}{R}\sqrt{z_{v,t+1}}\eta_1 + \frac{\tau}{2}\frac{\Gamma^2\left(A_{t+2}^{*2} - A_{t+1}^{*2}\right)}{R^2}(1-\eta_2)^2 z_{v,t+1}$$

This can be simplified by expressing it in terms of growth rate of frontier $g^* = \frac{A_{t+2}^*}{A_{t+1}^*} - 1$ as

$$(1-\eta_2)\,\theta_{t+2} + \eta_2\bar{\theta}_{t+2} \geq \frac{R^2}{\Gamma}\hat{\zeta}(\cdot) \\ - \frac{(2+g^*)}{g^*}\sqrt{z_{v,t+1}}\eta_1 + \frac{\tau}{2}\frac{\Gamma(2+g^*)A_{t+1}^*}{R}(1-\eta_2)^2 z_{v,t+1}$$

If the productivity is at the threshold $\theta_{t+2} = \bar{\theta}_{t+2}$, investor is indifferent between adopting fast or slow. This implies

$$\bar{\theta}_{t+2} = \frac{R^2}{\Gamma}\hat{\zeta}(\cdot) \\ - \frac{\Gamma(2+g^*)}{Rg^*}\sqrt{z_{v,t+1}}\eta_1 + \frac{\tau}{2}\frac{\Gamma^2(2+g^*)A_{t+1}^*}{R^2}(1-\eta_2)^2 z_{v,t+1}$$

Replacing $\bar{\theta}_{t+2}$ into the condition for adoption above and simplifying, the condition for fast adoption becomes

$$\theta_{t+2} \geq \frac{R^2}{\Gamma}\hat{\zeta}(\cdot) - \tfrac{(2+g^*)}{g^*}\sqrt{z_{v,t+1}}\eta_1$$
$$+\frac{\tau}{2}\tfrac{\Gamma(2+g^*)A^*_{t+1}}{R}\left(1-\eta_2\right)^2 z_{v,t+1} = \bar{\theta}_{t+2}.$$

$\bar{\theta}_{t+2}$ depends on R, $\hat{\zeta}(\cdot)$, Γ, g^*, $z_{v,t+1}$, $\beta_{\tilde{\theta}}$ and β_s that are all known to uninformed investors in period $t+1$.

D Independence of adoption and trading decisions

In period $t+1$ some initial owners trading in the financial markets are also initial owners of monopolistic firms that produce profits in period $t+3$ (investment $\tilde{1}_{I_{t+1}} I_{t+1}$ will produce profits $\pi_{t+3} = \Gamma A_{t+3}(\theta_{t+3} + u_{t+3})$). Assume that such agent is an investor of type $i \in \{I, U\}$ in his trading decision. The information set that is relevant for his trading decision is Ω^i_{t+1} (that is $\Omega^U_{t+1} = \{\tilde{\theta}_{t+2}, \tilde{P}_{t+1}, \tilde{1}_{I_t}\}$ or $\Omega^I_{t+1} = \{\theta_{t+2}\}$). The information that is relevant for his technology adoption decision is θ_{t+3}. He solves

$$\max_{\hat{h}^i_{t+1}, \tilde{1}_{I_{t+1}}} \; E[c^{e,i}_{t+2}|\Omega^i_{t+1}, \theta_{t+3}] - \tfrac{\tau}{2}\operatorname{Var}[c^{i,e}_{t+2}|\Omega^i_{t+1}, \theta_{t+3}],$$
$$\text{st. } c^{e,i}_{t+2} = c^i_{t+2} + c^e_{t+2}$$
$$c^i_{t+2} = (\Gamma(\theta_{t+2} + u_{t+2})A_{t+2} - RP_{t+1})\hat{h}^i_t + R\hat{W}^i_{t+1}$$
$$c^e_{t+2} = \tilde{1}_{I_{t+1}} P_{t+2}(\tilde{1}_{I_{t+1}} = 1) + (1 - \tilde{1}_{I_{t+1}})P_{t+2}(\tilde{1}_{I_{t+1}} = 0) - \tilde{1}_{I_{t+1}} R I_{t+1},$$

where $c^{e,i}_{t+2}$ is total consumption, c^i_{t+2} is consumption from trading, c^e_{t+2} is consumption from the adoption decision, $\hat{W}^i_{t+1}$ is the wealth of such agent (equals to wage income if the agent is a local entrepreneur alone) and $\hat{h}^i_t$ his risky asset demand. Notation $P_{t+2}(\tilde{1}_{I_{t+1}} = 1)$ and $P_{t+2}(\tilde{1}_{I_{t+1}} = 0)$ is to point out that asset price will be different, depending on the adoption decision (as profit and asset price depends on the quality of technology A^*_{t+3} if $\tilde{1}_{I_{t+1}} = 1$ or A^*_{t+2} if $\tilde{1}_{I_{t+1}} = 0$).

With the linear approximation of Mills ratio specified in Appendix C, the equilibrium asset price (39) depends of three uncertainty terms,

$$P_{t+2} = \frac{\Gamma A_{t+3}}{R}\left(1-\eta_2\right)\left(\theta_{t+3} + z_{t+2}\epsilon_{\tilde{\theta},t+3} + z_{s,t+2}\Gamma A_{t+2} s_{t+2} + time\_specific\_cons\right)$$

This implies that

$$\text{Cov}(c^e_{t+2}, c^i_{t+2}) \propto \text{Cov}(\theta_{t+2} + u_{t+2}, \theta_{t+3} + z_{t+2}\epsilon_{\tilde{\theta},t+3} + z_{s,t+2}A_{t+2}s_{t+2}) = 0,$$

because by assumption there is no correlation between the shocks and no serial correlation. Using this, the moments of $c^{i,e}_{t+1}$ can be expresses as

$$\begin{aligned} E[c^{e,i}_{t+1}|\Omega^i_{t+1}, \theta_{t+3}] &= E[c^i_{t+1}|\Omega^i_{t+1}] + E[c^e_{t+1}|\theta_{t+3}] \\ \text{Var}[c^{e,i}_{t+1}|\Omega^i_{t+1}, \theta_{t+3}] &= \text{Var}[c^i_{t+1}|\Omega^i_{t+1}] + \text{Var}[c^e_{t+1}|\theta_{t+3}]. \end{aligned}$$

The utility function used implies that optimal asset demand does not depend on wealth. Therefore utility from asset trading and developing can be solved separately as (20) and

$$\max_{\tilde{1}_{I_{t+1}}} E[c^e_{t+1}|\theta_{t+3}] - \tfrac{\tau}{2}\,\text{Var}[c^e_{t+1}|\theta_{t+3}],$$

which is equivalent to (29) and (30) for $t+1$.

E Local goods' market clearing

First, consider the case in which the initial owners are local entrepreneurs alone. The aggregate budget constraint for all local agents in the first period of their lives is

$$\mu w_t = \tilde{1}_{I_{t-1}} H_t P_t(\tilde{1}_{I_{t-1}} = 1) + (1 - \tilde{1}_{I_{t-1}}) H_t P_t(\tilde{1}_{I_{t-1}} = 0) + M_t + \tilde{1}_{I_t} I_t,$$

where M_t is aggregate risk-free foreign asset demand by local agents and $H_t \equiv (\mu^I_t \hat{h}^I_t + (\mu - \mu^I_t)\hat{h}^U_t + s_t)$ and is the aggregate risky asset demand by local agents. Due to the lack of wealth effects with CARA utility, local and foreign informed and uninformed investors' risky asset demand is the same, i.e. $h_t = h^{*I}_t = \hat{h}^I_t$ and $h_t = h^{*I}_t = \hat{h}^I_t$. The aggregate consumption of these agents during next period will be

$$C_{t+1} = \mu c_{t+1} + c^N_{t+1} = \pi_{t+1} H_t + RM_t + \tilde{1}_{I_t} P_{t+1}(\tilde{1}_{I_t} = 1) + (1 - \tilde{1}_{I_t}) P_{t+1}(\tilde{1}_{I_t} = 0).$$

The asset market clearing condition (2) can be rewritten as $\mu^I_t \hat{h}^I_t + (\mu - \mu^I_t)\hat{h}^U_t + \mu^{*I}_{t+1}\hat{h}^I_t + \mu^{*U}_{t+1}\hat{h}^U_t + s_{t+1} = 1$ or $H_t + H^*_t = 1$, where total risky asset demand by foreigners is $H^*_t = \mu^{*I}_{t+1}\hat{h}^I_t + \mu^{*U}_{t+1}\hat{h}^U_t$. Replacing this in aggregate consumption, it becomes

$$C_{t+1} = \pi_{t+1}(1 - H^*_t) + RM_t + \tilde{1}_{I_t} P_{t+1}(\tilde{1}_{I_t} = 1) + (1 - \tilde{1}_{I_t}) P_{t+1}(\tilde{1}_{I_t} = 0).$$

From the first period of life budget constraint, the aggregate holdings of risk-free asset are

$$M_t = \mu w_t - (1 - H_t^*) \left(\tilde{1}_{I_{t-1}} P_t(\tilde{1}_{I_{t-1}} = 1) + (1 - \tilde{1}_{I_{t-1}}) P_t(\tilde{1}_{I_{t-1}} = 0)\right) - \tilde{1}_{I_t} I_t$$

It is clear that if a country invests in technology adoption in period t, it's foreign asset holdings will be smaller (or foreign debt higher).

The net foreign asset position of the country (F_{t+1}) has following components:

1. $\tilde{1}_{I_t} H_{t+1}^* P_{t+1}(\tilde{1}_{I_t} = 1) + (1 - \tilde{1}_{I_t}) H_{t+1}^* P_{t+1}(\tilde{1}_{I_t} = 0)$ inflow if foreign investment to local asset;

2. $H_t^* \pi_{t+1}$ outflow of profits from previous period investments;

3. M_{t+1} outflow of locals' investment to the world asset (or inflow of debt);

4. RM_t inflow of previous period world asset revenues (or outflow of debt repayment).

   $$F_{t+1} = \tilde{1}_{I_t} H_{t+1}^* P_{t+1}(\tilde{1}_{I_t} = 1) + (1 - \tilde{1}_{I_t}) H_{t+1}^* P_{t+1}(\tilde{1}_{I_t} = 0) - H_t^* \pi_{t+1} - M_{t+1} + RM_t$$

   Using that $\tilde{1}_{I_{t+1}}(j) = \tilde{1}_{I_{t+1}}$ and $I_{t+1}(j) = I_{t+1}$ from Section 2.2, domestic good's market clearing (9) becomes

   $$F_{t+1} + Y_{t+1} = C_{t+1} + \int_0^1 x_t(j)dj + \tilde{1}_{I_{t+1}} I_{t+1}.$$

   It can be shown to hold. Replacing F_{t+1}, C_{t+1} and M_{t+1}in the goods' market clearing condition and simplifying we obtain

   $$-\mu w_{t+1} + Y_{t+1} = \pi_{t+1} + \int_0^1 x_t(j)dj$$

   Using (11), (13) and (14) this simplifies to

   $$\pi_{t+1} = \Gamma \gamma_t A_{t+1}$$

   and holds by (12). The goods' market clears.

As analyzed in Section 2.4.3, if initial owners include a foreign investor, the speed of technology adoption must be fast, $\tilde{1}_{I_{t-1}} = 1$. First, if fast technology adoption is possible only with the participation of foreign investor

$$C_{t+1} = \pi_{t+1}(1 - H_t^*) + RM_t + P_{t+1}(\tilde{1}_{I_t} = 0).$$

$$M_t = \mu w_t - (1 - H_t^*) P_t(\tilde{1}_{I_{t-1}} = 1)$$

There will be an additional capital inflow, because the foreign participant will bear all the technology adoption cost $I_{t+1} = \zeta(A_{t+3}^* - A_{t+2}^*)$ and an additional outflow of foreigners' earnings from exiting $P_{t+1}(\tilde{1}_{I_t} = 1) - P_{t+1}(\tilde{1}_{I_t} = 0)$. The resulting net foreign asset position

$$\begin{aligned} F_{t+1} = & H_{t+1}^* P_{t+1}(\tilde{1}_{I_t} = 1) - H_t^* \pi_{t+1} - M_{t+1} + RM_t \\ & + I_{t+1} - P_{t+1}(\tilde{1}_{I_t} = 1) + P_{t+1}(\tilde{1}_{I_t} = 0). \end{aligned}$$

Replacing these in the goods' market clearing condition, simplifies to the same condition as above.

Second, if foreign investors participate for reducing the fast adoption cost, then capital additional capital inflow and outflow are $\zeta(A_{t+2}^* - A_{t+1}^*)$ and $R\zeta(\cdot)(A_{t+2}^* - A_{t+1}^*)$. Consumption, risk-free asset holdings and net foreign asset position are

$$C_{t+1} = \pi_{t+1}(1 - H_t^*) + RM_t + P_{t+1}(\tilde{1}_{I_t} = 1) - R\zeta(\cdot)(A_{t+2}^* - A_{t+1}^*)$$

$$M_t = \mu w_t - (1 - H_t^*) P_t(\tilde{1}_{I_{t-1}} = 1)$$

$$\begin{aligned} F_{t+1} = & H_{t+1}^* P_{t+1}(\tilde{1}_{I_t} = 1) - H_t^* \pi_{t+1} - M_{t+1} + RM_t \\ & + \hat{\zeta}(A_{t+3}^* - A_{t+2}^*) - R\zeta(\cdot)(A_{t+2}^* - A_{t+1}^*). \end{aligned}$$

Using $I_{t+1} = \hat{\zeta}(A_{t+3}^* - A_{t+2}^*)$ market clears similarly to the previous scenarios analyzed. As the foreign participation always compensates the opportunity cost for local agents, forming a joint venture does not have an impact on aggregate consumption in $t+1$. It can also be seen from the relations above that the net foreign asset position is always lower if the country adopts fast technology. Similarly, local good's market clears in any period t.

F Proof of Proposition 5.

The demand of uninformed investors with wealth (or wage income), $\hat{W}_{t+1}^U$, is given by (21) and (24). They know this demand with certainty. The utility from staying uninformed is given by

$$\begin{aligned} & E\left[U_{t+1}^U | \Omega_{t+1}^U\right] = \\ & = \tfrac{E(\pi_{t+2}|\Omega_{t+1}^U) - RP_{t+1}}{\tau \operatorname{Var}(\pi_{t+2}|\Omega_{t+1}^U)} E\left[\pi_{t+2} - RP_{t+1})|\Omega_{t+1}^U\right] \\ & + R\hat{W}_{t+1}^U - \tfrac{\left[E(\pi_{t+2}|\Omega_{t+1}^U) - RP_{t+1}\right]^2}{2\tau \operatorname{Var}(\pi_{t+2}|\Omega_{t+1}^U)^2} \operatorname{Var}(\pi_{t+2}|\Omega_{t+1}^U) \end{aligned}$$

This simplifies to

$$E\left[U^U_{t+1}|\Omega^U_{t+1}\right] = \frac{\left[E(\pi_{t+2}|\Omega^U_{t+1}) - RP_{t+1}\right]^2}{2\tau \operatorname{Var}(\pi_{t+2}|\Omega^U_{t+1})} + R\hat{W}^U_{t+1}.$$

It they decide to become informed their demand is given by (21) and (22). However, they do not know what productivity they will observe after becoming informed and therefore their demand as informed. Replacing the demand as informed in the utility function, the utility can be expressed as

$$U^I_{t+1} = \frac{(\Gamma A_{t+2}\theta_{t+2} - RP_{t+1})^2}{2\tau\Gamma^2 A^2_{t+2}\frac{1}{\beta_u}} + \frac{\Gamma A_{t+2}u_{t+2}(\Gamma A_{t+2}\theta_{t+2} - RP_{t+1})}{\tau\Gamma^2 A^2_{t+2}\frac{1}{\beta_u}} + R\hat{W}^U_{t+1}.$$

Taking expectations of this conditional on the information the uninformed investor has

$$E\left[U^I_{t+1}|\Omega^U_{t+1}\right] = \frac{\Gamma^2 A^2_{t+2}\operatorname{Var}\left(\theta_{t+2}|\Omega^U_{t+1})\right) + \left[E(\pi_{t+2}|\Omega^U_{t+1}) - RP_{t+1}\right]^2}{2\tau\Gamma^2 A^2_{t+2}\frac{1}{\beta_u}} + R\hat{W}^U_{t+1}$$

As the number of uninformed investors is infinite, asset prices correspond to the expectations of uninformed investors. This means $E(\pi_{t+2}|\Omega^U_{t+1}) - RP_{t+1} = 0$. An investor will decide to become informed if $E\left[U^I_{t+1}|\Omega^I_{t+1}\right] - RD_{t+1} \geq E\left[U^U_{t+1}|\Omega^U_{t+1}\right]$. This implies the following condition

$$\frac{\operatorname{Var}\left(\theta_{t+2}|\Omega^U_{t+1})\right)}{2\tau\frac{1}{\beta_u}} \geq RD_{t+1}$$

The conditional variance of the productivity has to be high enough, such that the cost of becoming more informed is compensated by better expected arbitrage opportunities as an informed investor. Using $D_{t+1} = \delta_{t+1}\vartheta_{t+1}$, $\operatorname{Var}\left(\theta_{t+2}|\Omega^U_{t+1})\right) = z_{v,t+1}\vartheta_{t+1}$ from (38) and $\vartheta_{t+1} \equiv \left(1 - \lambda_{\tilde{1}_{I_t}}^{\;2}(b_{t+1}) + b_{t+1}\lambda_{\tilde{1}_{I_t}}(b_{t+1})\right)$, this becomes

$$\delta_{t+1} \leq \frac{\beta_u z_{v,t+1}}{R2\tau} \equiv \bar{\delta}_{t+1}$$

Investors find it optimal to invest adoption as long as δ_{t+1} is small enough. However, $z_{v,t+1} = \frac{1}{\beta_{\tilde{\theta}} + \left(\frac{\hat{\mu}^I_{t+1}\beta_u}{\tau}\right)^2 \beta_s}$ is a decreasing function of the number of informed investors. This is because with the higher number of informed investors makes asset price more revealing, thereby reducing the gains from being informed. If the number of local investors is large enough, such that $\delta_{t+1} > \frac{\beta_u}{R2\tau}\frac{1}{\beta_{\tilde{\theta}} + \left(\frac{\hat{\mu}^I_{t+1}\beta_u}{\tau}\right)^2 \beta_s}$ holds, no uninformed investor will decide to become informed. If this is not the case, investors will become informed until the gains from becoming informed are driven to 0. This means that in equilibrium, the number of uninformed investors is

$$\hat{\mu}_{t+1}^{I} = \sqrt{\frac{\tau}{\beta_u \beta_s}\left(\frac{1}{R2\delta_{t+1}} - \frac{\beta_{\tilde{\theta}}\tau}{\beta_u}\right)}.$$

This root is always real, it being negative implies that $\delta_{t+1} > \frac{\beta_u}{\beta_{\tilde{\theta}}\tau R2}$, which is satisfied as long as any investor decides to become informed in addition to those who are informed for a zero cost.

The dependence of equilibrium number of informed investors on R, δ_{t+1}, $\beta_{\tilde{\theta}}$ and β_s is straightforward. Sufficient condition for $\frac{\partial \hat{\mu}_{t+1}^{I}}{\partial \tau} > 0$ and $\frac{\partial \hat{\mu}_{t+1}^{I}}{\partial \beta_u} < 0$ is $\delta_{t+1} < \frac{\beta_u}{\beta_{\tilde{\theta}}\tau R2}$ (the condition for a real root).

G Proof of Proposition 6

This is a simple optimization problem. Define constants $Q_1 \equiv \frac{R^2}{\Gamma}\hat{\zeta}(\cdot) > 0$; $Q_2 \equiv \frac{2+g^*}{g^*}\sqrt{\frac{R2\tau}{\beta_u}}\eta_1 > 0$; $Q_3 \equiv \frac{\tau}{2}\frac{\Gamma(2+g^*)}{R}A_{t+1}^{*}(1-\eta_2)^2\frac{R2\tau}{\beta_u} > 0$. Then $\delta_{t+1}^{opt} = \underset{\delta_{t+1}}{\arg\min}\left(Q_1 - Q_2\delta_{t+1}^{\frac{1}{2}} + Q_3\delta_{t+1}\right)$. First order condition of this gives $\delta_{t+1}^{opt} = \left(\frac{Q_2}{2Q_3}\right)^2$. Second order condition, $\frac{\partial^2\left(Q_1 - Q_2\delta_{t+1}^{\frac{1}{2}} + Q_3\delta_{t+1}\right)}{\partial^2\delta_{t+1}} = \frac{Q_2}{4\delta_{t+1}{}^{\frac{3}{2}}} > 0$ confirms it as minimum. Replacing the constants back in δ_{t+1}^{opt} gives the proposition.

H Policy maker choosing the precision of public signal

Assume that instead of information cost, the local policy issues the public signal and chooses the precision of it. The policy maker chooses in period t how precise signal he would get about θ_{t+2} in period $t+1$ and commits to issuing his observed signal in $t+1$. For example, the local policy maker could establish an independent research department and choose the size of it.[23] The policy maker solves

[23] The approach with the choise of information cost is preferred, because local policy maker could have incentives to declare higher productivity to encourage faster technology adoption. This can make the public signal he issues not credible. The assumed independent research department that would avoid such problem may be less realistic than facilitating investors to access information directly.

$$\beta^{opt}_{\tilde{\theta},t+1} = \arg\min_{\beta_{\tilde{\theta}}} \left(\bar{\theta}_{t+2}\right),$$

where $\bar{\theta}_{t+2}$ is given by (31).As the chosen precision can chance over time, consider $\beta_{\tilde{\theta},t+1}$ instead of $\beta_{\tilde{\theta}}$, which means that $z_{v,t+1} = \frac{1}{\beta_{\tilde{\theta},t+1}+\left(\frac{\hat{\mu}^I_{t+1}\beta_u}{\tau}\right)^2\beta_s}$.

The solution of this problem is

$$\beta^{opt}_{\tilde{\theta},t+1} = \begin{cases} 0, \text{ if } \hat{\mu}^I_{t+1} > \frac{g^*\tau\Gamma A^*_{t+1}(1-\eta_2)^2\tau}{R\eta_1\sqrt{\beta_s}\beta_u} \\ \left(\frac{g^*\tau\Gamma A^*_{t+1}(1-\eta_2)^2}{R\eta_1}\right)^2 - \left(\frac{\hat{\mu}^I_{t+1}\beta_u}{\tau}\right)^2\beta_s, \text{ otherwise} \end{cases}$$

It is clear that $\beta^{opt}_{\tilde{\theta},t+1}$ is finite. Perfect public signal would require $\beta^{opt}_{\tilde{\theta},t+1} \to \infty$. Therefore, similarly to Section 3.2, local policy maker does not choose full transparency. Here, if the number of informed investors is sufficiently high, the policy maker would issue no public signal $\beta^{opt}_{\tilde{\theta},t+1} = 0$, in such case there is no reason to aim to offset the "fear of unstable markets" force and more precise public signal would limit the gains from "adoption to signal".

I Extreme case of restrictions on foreigners portfolio equity investments

Case 1. All noise traders are local. Let as assume that there exits a threshold $\bar{\theta}^R_{t+2} < \bar{\theta}_{t+2}$, such that adoption is more likely in the case of restricting foreign capital.

Using the equilibrium price in the case of $\mu^{*U}_{t+1} = \mu^{*I}_{t+1} = 0$ and $\mu^I_{t+1} = \mu$

$$\begin{aligned} E[P^R_{t+1}|\theta_{t+2}] &= \frac{\Gamma A_{t+2}\theta_{t+2}}{R} - \left(\frac{\tau}{\mu\beta_u}\right)\frac{\Gamma^2}{R}A^2_{t+2} \\ \text{Var}[P^R_{t+1}|\theta_{t+2}] &= \left(\frac{\tau}{\mu\beta_u}\right)^2 \frac{\Gamma^2 A^2_{t+2}}{R^2}\frac{1}{\beta_s} \end{aligned}$$

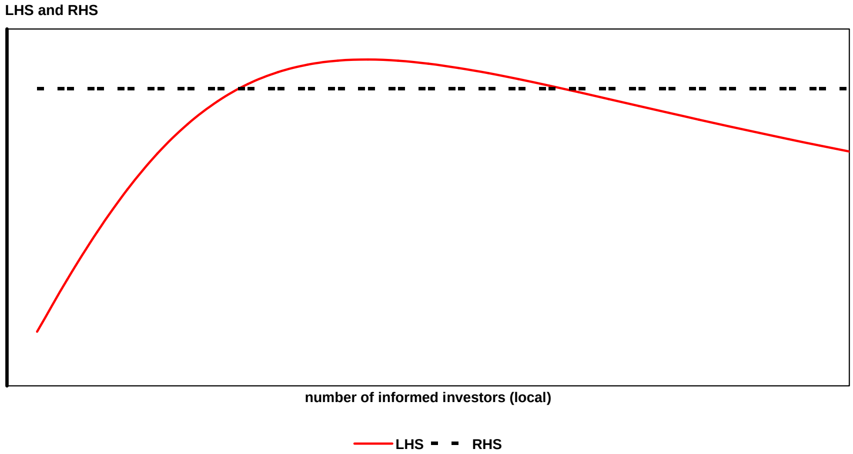
It is optimal to pursue fast adoption if $U_t(\tilde{1}_{I_t} = 1) \geq U_t(\tilde{1}_{I_t} = 0)$. At the threshold $\bar{\theta}_{t+2} = \bar{\theta}^R_{t+2} \Longrightarrow U_t(\tilde{1}_{I_t} = 1) \geq U_t(\tilde{1}_{I_t} = 0)$. Using the moments above, the threshold can be expressed as

$$\bar{\theta}^R_{t+2} = \frac{R^2}{\Gamma}\hat{\zeta}(\cdot) + \left(\frac{\tau}{\mu\beta_u}\right)\frac{\Gamma}{R}(2+g)A^*_{t+1}\left(R + \frac{\tau}{2\beta_s}\left(\frac{\tau}{\mu\beta_u}\right)\right)$$

Using $z_{v,t+1} = \frac{1}{\beta_{\tilde{\theta}}+\left(\frac{\mu\beta_u}{\tau}\right)^2\beta_s}$, after simplification $\bar{\theta}^R_{t+2} < \bar{\theta}_{t+2}$ implies.

$$\frac{1}{g^*}\sqrt{z_{v,t+1}}\eta_1 < -\frac{\Gamma}{R}A^*_{t+1}\left(\frac{\frac{\tau}{2}(1-(1-\eta_2)^2)+\beta_{\tilde{\theta}}\left(\frac{\tau}{\mu\beta_u}\right)\left(R+\frac{\tau}{2\beta_s}\left(\frac{\tau}{\mu\beta_u}\right)\right)+\left(\frac{\mu\beta_u}{\tau}\right)\beta_s R}{\beta_{\tilde{\theta}}+\left(\frac{\mu\beta_u}{\tau}\right)^2\beta_s}\right)$$

Figure H.1:



As all variables and constants in this inequality are positive and $(1-\eta_2)^2 < 1$, this implies $LHS > 0$ and $RHS < 0$. This contradicts existence of threshold where adoption is more likely with restricting foreign portfolio equity investments.

Case 2. None of the noise traders are local. As before, assume that there exits a threshold $\bar{\theta}^R_{t+2} < \bar{\theta}_{t+2}$*, such that adoption is more likely in the case of restricting foreign capital.*

In the absence of noise traders $E[P^R_{t+1}|\theta_{t+2}]$ is as above and $\mathrm{Var}[P^R_{t+1}|\theta_{t+2}] = 0$. The threshold for fast adoption becomes

$$\bar{\theta}^R_{t+2} = \tfrac{R^2}{\Gamma}\hat{\zeta}(\cdot) + \left(\tfrac{\tau}{\mu\beta_u}\right)\Gamma(2+g)A^*_{t+1}$$

First, from (32) it is clear that $\bar{\theta}^R_{t+2} > \bar{\theta}^{PI}_{t+2}$. This implies that potential gains from closing the access to foreign uninformed investors could arise only if the number of local informed investors is sufficiently small. In such case the "fear of unstable markets" force is stronger than "adopting to signal" force (area B in Figure 3 in Section 2.4.1). Using 33, we can find the following condition, where "fear of unstable markets" force is stronger

$$\mu < \bar{\mu} \equiv \frac{\tau}{\beta_u}\sqrt{\frac{1}{\beta_s}\left(\tau\Gamma g^* A^*_{t+1}\frac{(1-\eta_2)^2}{\eta_1 2R}\right)^2 - \frac{\beta_{\tilde{\theta}}}{\beta_s}}$$

Comparing the thresholds, with imperfect equity markets, $\bar{\theta}^R_{t+2} < \bar{\theta}_{t+2}$

implies that

$$RHS = R < \frac{\frac{\mu\beta_u}{\tau}}{\sqrt{\beta_{\tilde{\theta}} + \frac{\mu^2\beta_u^2}{\tau^2}\beta_s}} \left(\frac{\tau}{2}(1-\eta_2)^2 \frac{1}{\sqrt{\beta_{\tilde{\theta}} + \frac{\mu^2\beta_u^2}{\tau^2}\beta_s}} - \frac{R}{\Gamma g^* A_{t+1}^*}\eta_1 \right) = LHS \tag{40}$$

This condition cannot also be met in very small number of local informed investors ($\mu \to 0$ implies contradiction).

It can hold for some parameters for $0 < \mu < \bar{\mu}$. This requires that the variance in foreign noise trading is high and/or unexplainable component of productivity, $(1/\beta_s)$ and/or $(1/\beta_u)$ is high. Furthermore, low risk-free interest rate and higher growth and level of technology make the condition to hold more easily. The graph below provides an illustration for this for values: $R = 1$, $\tau = 6$, $\beta_u = 2$, $\beta_s = 0.25$, $\beta_{\tilde{\theta}} = 0.25$, $\Gamma = 1$, $g^* = 0.1$, $A_{t+1}^* = 100$, $g^* = 0.1$ and $\eta_1 = 0.8377$, $\eta_2 = 0.6247$ (approximation of Mills ratio between -1 and 1). Closing the access to foreign investors implies lower threshold for fast adoption for the values of μ, where $LHS > RHS$ line in (40) on Figure H.1.

Case 3. Some noise traders are local. The results are in between Case 1 and Case 2.