Technology adoption with exit in imperfectly informed equity markets

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October, 2007

Abstract

This paper focuses on the importance of equity markets in facilitating the exit of entrepreneurs investing in technology. The willingness of entrepreneurs to invest in frontier technology and aggregate output is affected in two opposite ways. First, uncertainty about equity price or lack of market liquidity discourages technology adoption. This can explain slow technology adoption and limited participation by venture capitalists in underdeveloped equity markets. Second, imperfectly informed market participants take fast adoption as a positive signal. The resulting increase of expected market value encourages technology adoption. Fast technology adoption is most probable at an intermediate number of informed investors.

JEL classification: D82, E44, G10, 030
Keywords: Technology adoption, equity market, exit opportunities, transparency

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I would like to thank Margaret Bray, Francesco Caselli, Afonso Goncalves da Silva, Christian Julliard, Nobuhiro Kiyotaki, Danny Quah, Rachel Ngai, Manisha Shah and Evangelia Vourvachaki for helpful comments.

1 Introduction

There is a growing interest in channels through which more developed financial markets promote entrepreneurial and innovative activities and thereby long-term growth.[1] The benefits of more developed financial markets are most often analyzed through their positive impact on availability of external financing. This paper takes a different approach by emphasizing that in addition to providing funding[2], equity markets have an important role in facilitating ownership transfers from talented entrepreneurs investing in technology to managers running these firms once the technology is adopted. Good exit opportunities are also important for venture capitalists who can provide funding for investments in technology. The paper suggests a new mechanism that shows how the development of equity markets can determine the incentives to invest in technology and aggregate output even if credit constraints are not binding.

The paper focuses on technology adoption or innovation decisions made by risk averse entrepreneurs who sell their firms in equity markets. In the basic setup, the equity market is liquid, but there is a potential double-sided information asymmetry. On the one hand, entrepreneurs are likely to have superior information about the fundamental value of their firms as compared to the average equity market participant. On the other hand, they do not know what information equity market participants will receive in the future.

The main results in this paper arise from two opposite forces affecting the incentives for entrepreneurs to invest in the newest and most expensive technologies. First, high uncertainty can discourage investment in the most advanced technologies – the "fear of unstable markets" force. Second, provided that the market accepts that entrepreneurs have superior information about the value of their firms, their decision to invest in the newest available technology becomes a positive signal to the market. This increases the

[1] See Levine (2005) for a comprehensive review of theoretical and empirical literature on the relationship between finance and growth.

[2] Empirical studies (e.g. Beck and Levine 2004, Rousseau and Wachtel 2000) find that the development of equity markets has an important effect on growth even after controlling for the access to credit.

expected market value of firms and encourages entrepreneurs to invest in fast technology adoption – the "adoption to signal" force. The number of informed investors determines which of these two forces is predominant.

When the number of informed investors is small, entrepreneurs choose to adopt technology slowly. This mechanism can also lead a country to persistently slow technology adoption. Furthermore, underdeveloped equity markets can explain why foreign agents, who are able to reduce technology adoption costs, may not participate in projects they would find profitable in perfect equity markets. Fast technology adoption is most likely with an intermediate number of informed investors. In this case, entrepreneurs have the highest expected gains from issuing a positive signal to the uninformed participants in the market by investing in expensive frontier technology. In countries with very developed financial markets and a large number of informed investors, both the discouraging "fear of unstable markets" and the encouraging "adopting to signal" force disappear, as the information asymmetries between the entrepreneur and potential buyers disappear. The implied non-monotonic relationship between investments in technology or GDP growth and equity market development is consistent with correlations in transition economies and high and upper-middle-income countries (see Appendix A).

The number of informed investors is likely to be higher in countries with good institutions for facilitating access to information (e.g. accounting standards and laws) and therefore more developed equity markets.[3] Furthermore, the number of informed investors is likely to be affected by purely exogenous factors such as a country having strong cultural links with foreign countries (e.g. the Baltic States with Scandinavia and Hungary with Austria). Investors from such foreign countries may face lower information costs and/or have more incentives to acquire information about the country. The basic setup takes the number of informed investors as exogenous.

[3] La Porta, de Silanes, Shleifer and Vishny (2005) show that laws mandating disclosure benefit stock markets.

To analyze the endogenous determinants of the number of informed investors, the basic model is extended to endogenize the number of informed investors through information costs and allow the local policy maker to choose this cost. The paper demonstrates that a local policy maker would not choose zero information costs (i.e. full transparency), if he aims to maximize the probability of fast technology adoption or growth in output and wages of local agents. Setting the information cost to zero would eliminate the gains from "adopting to signal".

In addition to information imperfections, equity markets can also lack liquidity. While the effect of imperfect information is non-monotonic, lack of liquidity always reduces the expected market value of firms and has a negative effect on incentives to invest in fast technology adoption. This effect is highlighted in an extension that considers the possibility of gains from restricting foreign portfolio investments. When foreign portfolio investors are largely uninformed[4], such restrictions may reduce the negative effect of "fear of unstable markets". However, by reducing the liquidity of the local equity market, the potential benefit only emerges under very specific circumstances.

The setup of the model relies on two crucial assumptions. First, an entrepreneur must 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 Jr. (1990). Moreover, venture capitalists can be seen as agents who are skilled in judging whether it is worth investing in a particular technology adoption. They are generally not constrained in credit markets and prefer to exit fast (Jovanovic and Szentes 2007). Lack of good exit opportunities is a major concern for these agents when assessing investments in developing countries (Lerner and Pacanins 1997). Figure 1 shows that venture capitalists perceive the concerns about successful exit to be a larger

[4]Empirical studies (e.g. Garibaldi, Mora, Sahay and Zettelmeyer 2002, Kose, Prasad, Rogoff and Wei 2004, Prasad, Rajan and Subramanian 2006) show that portfolio capital flows to emerging markets and transition economies are largely unrelated to fundamentals.

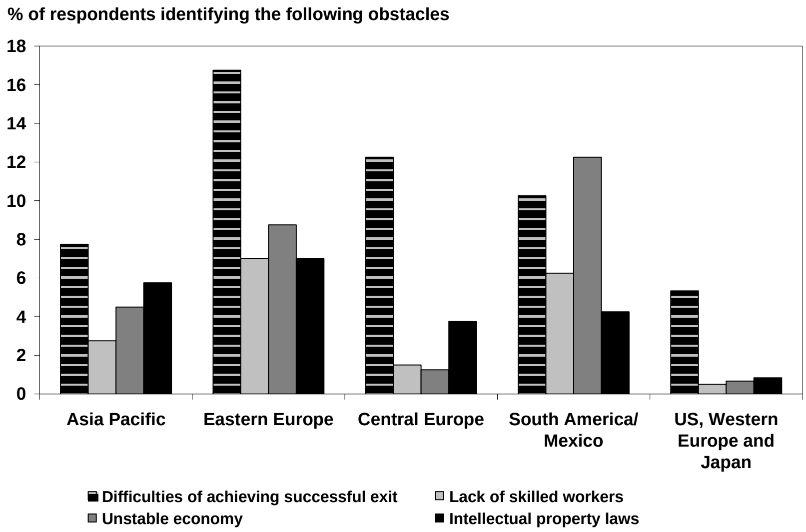

Figure 1: Impediments for venture capital investor (US and European respondents), data source: Deloitte Touche Tochmatsu and EVCA, 2006.

impediment than the lack of skilled workers or weak intellectual property laws[5]. Among the less developed countries, Asia is often considered as one of the most attractive locations for venture capital (Aylward 1998, Survey by Deliotte Touche Tochmatsu and EVCA 2006). While this region does not have more skilled labor than competing regions, it has more developed equity markets and a better legal and regulatory environment[6].

While this paper assumes that entrepreneurs sell their firms in the equity market, the suggested mechanism is valid more generally if agents deciding about investments in technology care about the future market value of their firms. This could be due to executive compensation packages that depend on equity prices (see Murphy 2002) or entrepreneurs' aims at raising equity funds in the future.

[5]The venture capitalists surveyed are not necessarily investing in these regions. Important impediments that are excluded from 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.

[6]According to WDI data for 1996-2004, the median share of the labor force with secondary education in Asia is 28.2% as compared to 33.3% in Latin America, 62.2% in transition countries that entered EU and 56.6% in other transition countries. At the same time, the median stock market capitalisation to GDP in these regions is 44.5%, 24.5%, 13.4% and 10.4%, respectively. The same is true for alternative measures of stock market development or with the exception of EU entrant transition countries for more general proxies of institutional quality (see Kaufmann, Kraay and Mastruzzi 2006)

The second crucial assumption relies on rational, but imperfectly informed equity market participants, whose expectations are affected by a noisy public signal as in Allen, Morris and Shin (2006) and Bacchetta and van Wincoop (2006). Such **a** public signal could be interpreted as "market sentiment" or any other factor that affects equity market participants' common beliefs about the value of a firm.[7]

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 in certain countries which makes the frontier technologies inappropriate for these countries (e.g. Acemoglu 2002). While the 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 current paper, the speed of technology adoption depends on the interaction of the number of informed investors with the productivity of the labor force using technology. If the productivity of the 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 with a similar labor force.

As mentioned above, obstacles **to** technology adoption can also be commitment problems and credit constraints (e.g. Gertler and Rogoff 1990, Aghion, Bacchetta and Banerjee 2004, Aghion, Comin and Howitt 2006). 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.[8]

Closer to the this paper are Bencivenga, Smith and Starr (1995) and Levine (1991)

[7] There is a wide empirical literature on deviations of equity prices from their fundamentals and the impact of market sentiment (see e.g. Cutler, Poterba and Summers 1991, Lee, Shleifer and Thaler 1991, Jegadeesh and Titman 1993, Swaminathan 1991, Chan, Jegadeesh and Lakonishok 1996).

[8] Credit constraints could also arise endogenously when foreign agents (e.g. venture capitalists) that can alleviate these constraints do not enter because of bad exit opportunities.

who analyze the impact of liquidity of equity markets and the need for exit in a closed economy. As in this paper, lack of liquidity reduces the incentives to invest in technology adoption. However, explicit modeling of the equity market in the current paper allows me to separate the negative effect of lack of liquidity from the non-monotonic effects that arise from imperfect 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 and imply slower technology adoption. Marimon and Quadrini (2006) model more specific frictions such as the interaction between start-up cost and limited contract enforceability that affects the incentives for new entries to the innovation sector. While additional institutional frictions (e.g. property rights, taxation, or other obstacles to establishing or running a firm) could be incorporated in the model, the two main forces found would still remain important. An innovative result in this paper is a non-monotonic relationship between fast technology adoption and institutions that facilitate the access to information, i.e. too easily accessible information can lead to a lower aggregate output.

Finally, the mechanisms discussed in this paper could apply to investments in general. This paper focuses on incentives for investments in technology for the following reasons. First, investment in technology is a driver of long-term growth (e.g. Romer 1990, Aghion and Howitt 1992) and is therefore likely to have a larger aggregate impact. Second, these investments are likely to require higher entrepreneurial skills and thus, the potential efficiency gains from ownership transfers are higher. Third, as venture capital is arguably a better source of funding for technology firms than debt, the importance of good exit opportunities is likely to be more important for investments in technology than investment in capital. Consistent with this, Appendix A shows that R&D expenditures are more strongly correlated with equity market development than investments.

The remainder of this 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 discussion on the possibility of gains from forbidding foreign portfolio equity investment in the local asset market. Section 5 concludes.

2 The basic 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 1992, Aghion et al. 2006) and the rational expectations literature (e.g. Grossman 1976, Allen et al. 2006, Kodres and Pritsker 2002, Yuan 2006).

2.1 Setup

2.1.1 Consumers

The local economy is populated with overlapping generations of rational agents endowed with one unit of raw labor in each period. These agents work and invest in asset markets 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, can be informed (type $i = I$) or uninformed (type $i = U$) in their trading decisions. 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 $\hat{\mu}_t^I = \mu_t^I + \mu_t^{*I}$ informed and $\hat{\mu}_t^U = (\mu - \mu_t^I) + \mu_t^{*U}$ uninformed investors.[9]

In addition, some rational local agents have special skills to be entrepreneurs and 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

[9] 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.

is said to be established by an "initial owner" where the exact ownership structure is not important.

All rational agents have mean-variance preferences

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

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

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

In addition to rational investors, there are noise traders who demand a stochastic quantity $s_t(j)$ of the shares of each firm. Their demand is perfectly correlated across all firms, $s_t(j) = s_t \sim N\left(0, \frac{1}{\breve{\beta}_{s,t}}\right)$, and uncorrelated across time or with any other shocks. All noise traders are assumed to be local unless otherwise specified and they do not receive any wage income.[10] The existence of noise traders is necessary for risky asset prices not to be fully revealing (the Grossman and Stiglitz (1976) paradox).

Noise traders, informed and uninformed rational agents trading in the equity market are called "investors".

2.1.2 Production of final and intermediate goods

The production side of the economy consists of a competitive final good production sector and a monopolistic intermediate goods sector that also invests in technology adoption (or innovation).

[10] Their location has no impact on conclusions besides those in Section 4. With 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 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, $x_t(j)$, is of 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. Final good producers take the price of intermediate goods ($p_{x,t}(j)$) and wages (w_t) as given and solve

$$\max_{L, x_t(j)} Y_t - w_t L - \int_0^1 p_{x,t}(j) x_t(j) dj, \tag{2}$$

where the production function is

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

and ϕ_t measures the productivity of the local labor force in using the technology.

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

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

where θ_t is the explainable part of productivity that is uncorrelated across time and with any other shocks, and $u_t \sim N(0, 1/\beta_u)$ is the unexplainable part that is also uncorrelated across time and with any other shocks.[11] The explainable component measures factors such as education, training, working culture, management practices, etc. The unexplainable component could be affected by factors such as the health of the workers, natural

[11] The normality assumption, while being unrealistic by allowing negative output, greatly simplifies the solution. It is also a widely used assumption in the finance literature about the liquidation value of assets. With 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.

disasters, etc.

The final good producer buys each intermediate good, $x_t(j)$, from a local monopolist in sector j. Intermediate good producers in each sector j use one unit of final good to produce one unit of intermediate good and maximize the profit $\pi_t(j)$

$$\max_{p_{x,t}(j),x_t(j)} \pi_t(j) = p_{x,t}(j)x_t(j) - x_t(j) \text{ st. } p_{x,t}(j) = \frac{\partial Y_t}{\partial x_t(j)}. \tag{5}$$

All intermediate goods depreciate fully in one period. Section 2.3 shows how the uncertainty about the productivity of the labor force in using technology (ϕ_t) translates into uncertainty about the future demand for intermediate goods and the profits of local monopolists.[12]

2.1.3 Technology adoption

Each intermediate goods firm j is established two periods before it produces intermediate goods (i.e. a firm established in t produces in period $t+2$) by an initial owner. Given that the initial owner must 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.

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 paying a fixed cost in final goods.

The frontier technology (A_t^*)[13] that can be adopted grows at an exogenous rate,

$$g^* \equiv \frac{A_{t+1}^* - A_t^*}{A_t^*} \text{ for any } t. \tag{6}$$

[12] Differentiated intermediate goods are introduced only to justify the monopolistic power of the intermediate goods sector, which is necessary for initial owners to have incentives for fast technology adoption. As the uncertainty considered is aggregate, Section 2.2 shows that all firms are identical. Allowing for idiosyncratic uncertainty would not eliminate the main mechanisms and would complicate the model.

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

The 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 (6) allows for new firms to produce with a 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 only be sustained for one period.[14]

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

$$I_t = \left(A^*_{t+2} - A^*_{t+1}\right) \hat{\zeta}(\cdot). \tag{7}$$

The cost of fast technology adoption is assumed to be proportional to the gain in technology from fast adoption in the period in which 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 participating potential foreign agent. 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

[14] 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 the initial owner chooses slow technology adoption $A_{t+2}(j) = A^*_{t+1}$in t, while the initial owner born in $t-1$ adopted fast $A_{t+1}(j) = A^*_{t+1}$. It is assumed that in this case, the new monopoly will still drive the old incumbent out of the market. The implicit assumption behind this is that an intermediate good firm cannot sustain exactly the same quality for more than one period.

technology slowly is zero. The technology adoption decision is denoted by

$$\tilde{1}_{I_t}(j) = \begin{cases} 1, \text{ if fast adoption is chosen in } t \text{ in sector } j \\ 0, \text{ if slow adoption is chosen in } t \text{ in sector } j. \end{cases} \tag{8}$$

2.1.4 Information and timing

The initial owner born in t knows the explainable component of productivity (θ_{t+2}). The firm established in t is bought by investors (local and foreign) trading in the period $t+1$ equity market. Informed investors trading in $t+1$ 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 the 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 $t+1$,

$$\tilde{\theta}_{t+2} = \theta_{t+2} + \epsilon_{\tilde{\theta},t+2}, \text{ where } \epsilon_{\tilde{\theta},t+2} \sim \mathcal{N}(0, 1/\beta_{\tilde{\theta}}). \tag{9}$$

The public signal could also capture the "market sentiment". The 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 an intermediate firm j, who is an investor of type $i \in \{U, I\}$ born in $t+1$, has the information set $\Omega^{i,e(j)}_{t+1} = \{\theta_{t+3}, \Omega^i_{t+1}\}$.

Figure 2 summarizes the main mechanism and timing of the events.

2.1.5 Markets

The final goods are used in the local market for aggregate consumption (C_t), capital ($\int_0^1 x_t(j)dj$) and investments in technology adoption ($\int_0^1 \tilde{1}_{I_t}(j) I_t(j)dj$). These expenditures must equal aggregate production Y_t and the net inflow of goods from abroad (F_t).

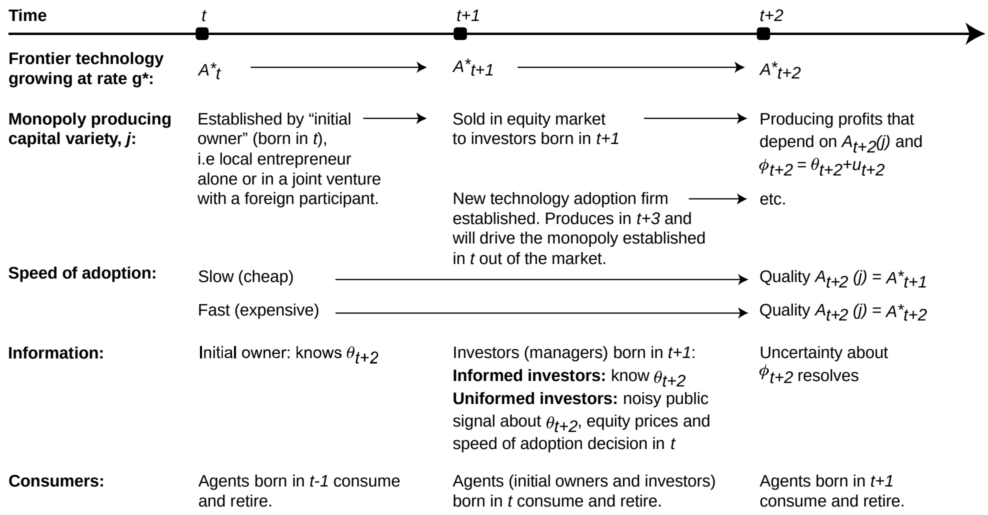

Figure 2: Timeline of events

The local goods market clearing condition is

$$C_t + \int_0^1 x_t(j)dj + \int_0^1 \tilde{1}_{I_t}(j)I_t(j)dj = F_t + Y_t. \tag{10}$$

The final good production sector employs the entire local labor force. Hence, the labor market clearing condition is

$$L = \mu. \tag{11}$$

The equity market consists of the shares of j local monopolistic firms. As all initial owners sell their firms, the supply of each risky asset is 1 and the equity market clearing is

$$\hat{\mu}_t^I \hat{h}_t^I(j) + \hat{\mu}_t^U \hat{h}_t^U(j) + s_t = 1, \tag{12}$$

for every j. The demand of firm j's shares by each informed and uninformed investor is $\hat{h}_t^I(j)$ and $\hat{h}_t^U(j)$, respectively.

2.2 Equilibrium profits and identical technology adoption decisions

The optimal solution for the final (2) and intermediate goods sector (5) implies that the demand for an intermediate good is linear in labor productivity and quality of technology,

$$x_{t+2}(j) = \left(\alpha^2\right)^{\frac{1}{1-\alpha}} \phi_{t+2} L A_{t+2}(j) \tag{13}$$

and **the** equilibrium profit in sector j is

$$\pi_{t+2}(j) = \Gamma A_{t+2}(j)\phi_{t+2};\ \Gamma \equiv \frac{1-\alpha}{\alpha}\left(\alpha^2\right)^{\frac{1}{1-\alpha}} L. \tag{14}$$

Initial owners are not borrowing constrained and can always finance their investment in technology. From (14) the only difference between firms in different sectors is $A_{t+2}(j)$. The productivity of the labor force and information about this productivity (θ_{t+2}), the cost of technology adoption and the frontier technology are 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. Modeling all these firms and their owners is equivalent to modeling one risky asset and one initial owner for all monopolists in the country. Since noise trading is also perfectly correlated across the shares of firms, 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 the previous section and (4), the profits of local monopolists can be expressed as

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

Assuming that the precision of noise trading $\breve{\beta}_{s,t} = \Gamma^2 A_{t+1}^2 \beta_s$, the demand of noise traders becomes

$$s_{t+1} \sim \mathcal{N}(0, 1/\Gamma^2 A_{t+2}^2 \beta_s). \tag{18}$$

The assumption that the variance of noise trading is proportional to the level of technology in the next period guarantees that the variance of the price signals of uninformed investors does not increase over time. As will be pointed out later in the paper, relaxing this assumption would strengthen the results.

Some rational agents trading in the equity market are initial owners of local monopolistic firms. 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.[15]

Given the results from Section 2.3, the demand for the shares of each firm j by an investor of type $i \in \{U, I\}$ is the same, i.e. $\hat{h}_{t+1}^i(j) = \hat{h}_{t+1}^i$. Their optimal demand for equity is given by

$$\hat{h}_{t+1}^i = \frac{E\left[\pi_{t+2}|\Omega_{t+1}^i\right] - RP_{t+1}}{\tau \operatorname{Var}(\pi_{t+2}|\Omega_{t+1}^i)}. \tag{19}$$

As described in Section 2.4.1, the information set that is relevant for informed investors is $\Omega_{t+1}^I = \{\theta_{t+2}\}$. Therefore, if the investor is informed

$$\begin{aligned} E\left[\pi_{t+2}|\Omega_{t+1}^I\right] &= \Gamma\theta_{t+2}A_{t+2}, \\ \operatorname{Var}(\pi_{t+2}|\Omega_{t+1}^I) &= \Gamma^2 A_{t+2}^2 \frac{1}{\beta_u}. \end{aligned} \tag{20}$$

[15] Independence is first assumed to be the case. Later, this is formally approved in Appendix D.

Uninformed investors obtain information from asset prices, public signal (9) and technology adoption decisions (8) and (15). Using the optimal demand of informed investors ((19) and (20)) in the asset market clearing condition (12), the price signal observed by uninformed investors is[16]

$$\tilde{P}_{t+1} = \theta_{t+2} + \frac{\tau \Gamma A_{t+2}}{\hat{\mu}^{I}_{t+1}\beta_u} s_{t+1} \tag{21}$$

and their information set 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, $\tilde{1}_{I_t} = 0$) technology adoption implies that $\theta_{t+2} \geq \bar{\theta}_{t+2}$ ($\theta_{t+2} < \bar{\theta}_{t+2}$). This conjecture is verified in Section 2.5.1 where it is also shown 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

$$\begin{aligned} E\left[\pi_{t+2}|\Omega^U_{t+1}\right] &= \Gamma A_{t+2}\left(z_{t+1}\tilde{\theta}_{t+2} + (1-z_{t+1})\tilde{P}_{t+1} + \sqrt{z_{v,t+1}}\lambda_{\tilde{1}_{I_t},b_{t+1}}\right), \qquad (22)\\ \mathrm{Var}(\pi_{t+2}|\Omega^U_{t+1}) &= \Gamma^2 A^2_{t+2}\left[z_{v,t+1}\left(1-\lambda^2_{\tilde{1}_{I_t},b_{t+1}} + b_{t+1}\lambda_{\tilde{1}_{I_t},b_{t+1}}\right) + \frac{1}{\beta_u}\right], \end{aligned}$$

where

$$\begin{aligned} b_{t+1} &\equiv \frac{1}{\sqrt{z_{v,t+1}}}\left(\bar{\theta}_{t+2} - z_{t+1}\tilde{\theta}_{t+2} - (1-z_{t+1})\tilde{P}_{t+1}\right), \qquad (23)\\ z_{v,t+1} &\equiv \left(\beta_{\tilde{\theta}} + \left(\frac{\hat{\mu}^I_{t+1}\beta_u}{\tau}\right)^2 \beta_s\right)^{-1}, \qquad z_{t+1} \equiv \beta_{\tilde{\theta}} z_{v,t+1} \end{aligned}$$

and $\lambda_{\tilde{1}_{I_t},b_{t+1}}$ is the inverse Mills ratio that depends on the technology adoption decision in the previous period and b_{t+1}[17]. The derivation of these expressions is presented in Appendix B.

Uninformed investors' expectations can differ from informed investors' expectations

[16] See Appendix B for further details.

[17] 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.

for two reasons. First, the public and price signals they receive can be incorrect, i.e. $z_{t+1}\tilde{\theta}_{t+2} + (1 - z_{t+1})\tilde{P}_{t+1} \neq \theta_{t+2}$. For example, this could be due to "market sentiment". Second, the inverse Mills ratio, $\lambda_{\tilde{1}_{I_t},b_{t+1}}$, is always positive (negative) if the technology was adopted fast (slow). So even if both the public and price signals were correct $z_{t+1}\tilde{\theta}_{t+2} + (1-z_{t+1})\tilde{P}_{t+1} = \theta_{t+2}$, uninformed investors would expect higher (lower) profits of the firms that adopted fast (slow). The technology adoption decision will remain an informative signal and affect uninformed investors' expectations in such manner as long as $z_{v,t+1} > 0$, i.e. neither the public nor the price signal is perfect ($\beta_{\tilde{\theta}}$, β_s and $\hat{\mu}^I_{t+1}$ are finite).

The equilibrium price can be derived by replacing (19), (20), (21) and (22) into the market clearing condition (12). 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 lengthy, and only the relevant limiting cases are analyzed, the full details are found in Appendix B.

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

$$P^{PI}_{t+1} = \frac{\Gamma A_{t+2}}{R}\theta_{t+2}. \tag{24}$$

In such a 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 to this benchmark.

In a more realistic environment, the number of informed investors is limited. Given that this paper analyzes 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 as compared to the size of the local market. If the number of uninformed investors approaches infinity, the excess returns of uninformed investors approach zero. Using (21) and (22),

equilibrium asset prices can be expressed as

$$P_{t+1} = \frac{\Gamma A_{t+2}\left(z_{t+1}\tilde{\theta}_{t+2} + (1-z_{t+1})\theta_{t+2} + \sqrt{z_{v,t+1}}\lambda_{\tilde{1}_{I_t},b_{t+1}}\right)}{R} + \frac{(1-z_{t+1})\tau\Gamma^2 A_{t+2}^2}{\hat{\mu}_{t+1}^I \beta_u R} s_{t+1}. \tag{25}$$

In this case, asset prices are affected by the public signal ($\tilde{\theta}_{t+2}$), noise trading (s_{t+1}) and an additional term that captures the impact of the signal from the adoption decision. Looking at the expressions for z_{t+1} and $z_{v,t+1}$ (23), it is clear that the larger the number of informed investors ($\hat{\mu}_{t+1}^I$), the closer will the asset price be to the perfect financial markets benchmark ($\hat{\mu}_{t+1}^I \longrightarrow \infty \Longrightarrow z_{t+1}, z_{v,t+1} \longrightarrow 0$).

Without an infinite number of investors (whether uninformed or informed), asset prices would be lower ceteris paribus, because the local asset market would not be sufficiently liquid. Noise trader demand would have a direct impact on asset prices, in addition to its impact on uninformed investors' price signals. This question will be revisited in Section 4, when analyzing the impact of forbidding foreigners to invest in local asset markets. 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 market perception in the next period (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

$$U_t(\tilde{1}_{I_t} = 1) \geq U_t(\tilde{1}_{I_t} = 0) + RI_t, \tag{26}$$

where the utility **of** adopting a particular technology $\tilde{1}_{I_t} \in \{0,1\}$ is

$$U_t(\tilde{1}_{I_t}) = E\left[P_{t+1}|\theta_{t+2}, \tilde{1}_{I_t}\right] - \frac{\tau}{2}\mathrm{Var}(P_{t+1}|\theta_{t+2}, \tilde{1}_{I_t}). \tag{27}$$

It can be seen from (25) that the selling price of firms that adopt technology fast is always higher since asset prices are proportional to A_{t+2} and from (6) $A^*_{t+2} > A^*_{t+1}$.

An explicit derivation of $E\left[P_{t+2}|\theta_{t+2}, \tilde{1}_{I_t}\right]$ and $\mathrm{Var}(P_{t+2}|\theta_{t+2}, \tilde{1}_{I_t})$ is complicated by the fact that asset prices (25) 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 the initial owner who is deciding on the 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. For simplicity, the results presented in this paper employ the linear approximation. This is sufficient because the most interesting cases for analysis occur in the neighborhood of $\lambda_{\tilde{1}_{I_t}}(0)$, where the initial owners are close to being indifferent between fast and slow technology adoption.[18]

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*

$$\bar{\theta}_{t+2} = \frac{R^2}{\Gamma}\hat{\zeta}(\cdot) - \sqrt{z_{v,t+1}}\Lambda_{ATS} + z_{v,t+1}A^*_{t+1}\Lambda_{FUM} \tag{28}$$

$$\Lambda_{ATS} \equiv \frac{2+g^*}{g^*}\eta_1;\ \Lambda_{FUM} \equiv \frac{\tau}{2}\frac{\Gamma\left(2+g^*\right)}{R}\left(1-\eta_2\right)^2 \tag{29}$$

[18] From (23) $E[b_{t+1}|\theta_{t+2}] = \frac{1}{\sqrt{z_{v,t+1}}}(\bar{\theta}_{t+2} - \theta_{t+2})$, $\bar{\theta}_{t+2}$ is the threshold above which fast technology adoption will be undertaken.

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. See Appendix C. ■

It can be seen from above 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 $\bar{\theta}_{t+2}$. Proposition 1 thereby verifies the conjecture in Section 2.4.

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

$$\bar{\theta}^{PI}_{t+2} = \frac{R^2}{\Gamma}\hat{\zeta}(\cdot). \tag{30}$$

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 (28) yields (30).

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 $z_{v,t+1}A^*_{t+1}\Lambda_{FUM}$ in (28). 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 (30).

The "adoption to signal" term is captured by $\sqrt{z_{v,t+1}}\Lambda_{ATS}$ in (28). Initial owners know that uninformed investors will take fast adoption as an indication of higher profitability and are willing to pay a higher price for it (25). Therefore, technology investment decision becomes a natural signal that increases initial owners' incentives to invest in fast technology adoption. The possibility of gains from this remains despite the fact that uninformed investors are rational and aware of the force.

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

Corollary 3 *If productivity of labor is such that the initial owners are indifferent between fast or slow technology adoption in perfect financial markets ($\theta_{t+2} = \bar{\theta}^{PI}_{t+2}$), they will*

be discouraged from adopting fast due to the "fear of unstable markets" in imperfectly informed financial markets if

$$2R < \tau\Gamma g^* A^*_{t+1} \frac{(1-\eta_2)^2 \sqrt{z_{v,t+1}}}{\eta_1}. \tag{31}$$

Indifference between fast or slow adoption in perfect markets implies that $\theta_{t+2} = \frac{R^2}{\Gamma}\hat{\zeta}(\cdot)$ from (30). Applying this to (28) and using constants from (25) and (29) gives (31). Corollary 3 has some interesting implications.

Through its impact on the quality of uninformed investors' information $(z_{v,t+1})$, a lower number of informed investors $(\hat{\mu}^I_{t+1})$ magnifies the "fear of unstable markets". We can consider 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 slowly adopt frontier technology.

An increase in 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, the potential gains are negligible.

Figure 3 illustrates how the threshold for fast technology adoption (28) depends on the number of informed investors. It plots the relationship between productivity (θ_{t+2}), the number of informed investors $(\hat{\mu}^I_{t+1})$ and the speed of technology adoption. In perfect financial markets, fast (slow) adoption occurs in areas A and B (C and D). In imperfect markets, fast (slow) adoption occurs in areas A and C (B and D). In B slow technology adoption is due to 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, which makes initial owners care more about uncertainty in the following period. There is also a secondary effect, since

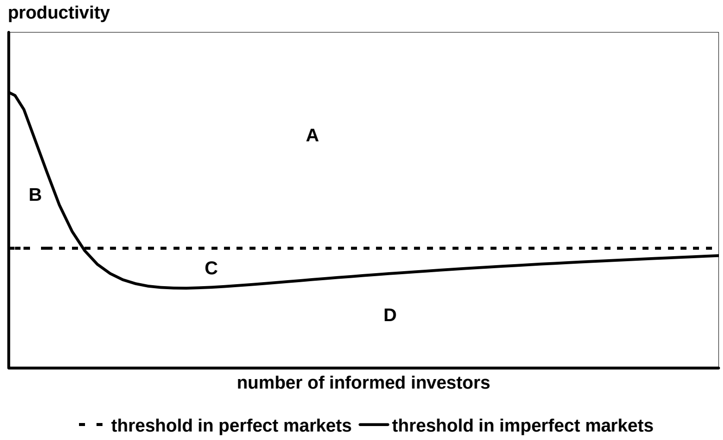

Figure 3: Threshold productivity for fast technology adoption

higher risk aversion reduces the quality of price information (23) through lower demand for the risky asset from informed investors. A higher variance for the unexplainable component of productivity $(1/\beta_u)$ has a similar effect on the quality of the price signal. With an infinite number of traders, the unexplainable component of productivity only affects initial owners 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 $(z_{v,t+1})$, thereby 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 the fundamentals (see (23) and (25)). However, this force is not strong enough to eliminate the negative direct impact of higher uncertainty.

An increase in the risk-free rate has a dual effect on incentives to invest in fast technology adoption. First, there is a direct effect where the threshold productivity must be higher to make investment in fast adoption worthwhile (28). This effect is also present in perfect financial markets (30). Second, (31) 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 in the risk-free rate (R) leads to a smaller reduction in the probability of fast technology adoption in imperfect equity markets.

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 the cost of adoption for a given change in technology to be constant, $\hat{\zeta}(\cdot) = \hat{\zeta}$. In this case, it is clear from (30) that if productivity were to remain 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 (31). Keeping up with the adoption of the newest technology with imperfectly informed investors must imply an increase in the number of informed investors (or other variables that would lower the threshold for 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 the initial owners from adopting fast in period t, the next generations will not adopt fast either, 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 the uncertainty regarding the productivity of using any level of technology is the same.[19]

If, in addition, we assume the cost of adoption to be an increasing function of the distance to the frontier as in Aghion et al. (2006) (e.g. $\hat{\zeta}(\frac{A^*_{t+2}}{A_t}) = \hat{\zeta}(\frac{1+g}{(A_t/A^*_{t+1}})$, $\hat{\zeta}'(\cdot) > 0$), the improvements in the frontier will be even more discouraging. Failing to adopt fast in some period will in that case also make it more costly to adopt fast in the following period and the threshold (28) increases.[20]

Assuming that the variance of the price signal has a constant quality over time (18)

[19] 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.

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

eliminated another mechanism that would imply an increased impact of "fear of unstable markets" with the growth of technology. If the variance of noise trading did 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 that case, the tendency towards persistently slow technology adoption would also be stronger.

Countries with large 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 a high technology level. The model suggests that this outcome does not require developed countries to have neither a more skilled labor force (higher θ_t) nor lower technology adoption costs.

2.4.2 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 also be present and the dominating force would not depend on the adoption cost (Corollary 3). Nevertheless, the threshold $\bar{\theta}_{t+2}$ is lower than the threshold if the local entrepreneur operates alone:

$$\bar{\theta}_{t+2}^{loc} \equiv \frac{R^2}{\Gamma}\zeta(\cdot) - \sqrt{z_{v,t+1}}\Lambda_{ATS} + z_{v,t+1}A_{t+1}^{*}\Lambda_{FUM}.$$

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

First, the local entrepreneur alone might choose slow technology adoption, while fast adoption would be undertaken in a joint venture ($\bar{\theta}_{t+2} \leq \theta_{t+2} < \bar{\theta}^{loc}_{t+2}$). 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 receive 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 by providing funding and receiving a risky return.

Second, the local entrepreneur 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 that case, the local entrepreneur's utility from the joint venture equals his opportunity cost $q_{fa,t+1} = U_t(\tilde{1}_{I_t} = 0) - R\zeta(\cdot)(A^*_{t+2} - A^*_{t+1})$ and the foreigner pays for the 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 the local entrepreneur. This essentially means that the local entrepreneur will hire the foreigner as a consultant to reduce his costs. It requires highly productive labor, little negative impact from uncertainty related to imperfect information and a low cost of fast technology adoption for locals. This case is less realistic in developing countries.

2.5 Aggregate output, wages and local goods market clearing

Replacing the labor market clearing condition (11) and demand for intermediate capital goods, (13) for period t in the production function (3), the aggregate final good production also becomes linear in the level of technology and the productivity of the labor force

$$Y_t = \left(\alpha^2\right)^{\frac{\alpha}{1-\alpha}} L A_t \phi_{t+2} = \frac{1}{\alpha(1-\alpha)} \Gamma \phi_t A_t. \tag{32}$$

The equilibrium wages are proportional to aggregate final good production:

$$w_t = (1 - \alpha)\frac{Y_{t+2}}{\mu}. \tag{33}$$

The local goods market condition is given by (10). 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 the risk-free asset (the investment local investors/consumers made in period t) and foreigners' investment in the local risky asset (monopolistic firms established in 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 the local entrepreneur, foreign investors participate in technology adoption, there are additional capital inflows and outflows from their investment to technology and exit.

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

Given that the foreign partner always compensates the local entrepreneur for the opportunity cost (Section 2.5.2), foreign participation in technology adoption projects does not affect the aggregate consumption of the generation that forms a joint venture with foreign agents (see Appendix E).[21] If foreign investors are capable of adopting fast technology which locals do not, the consumption of future generations is higher because of higher wages ((32) and (33)).

[21] 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 **the** optimal speed of adoption is slow.

3 Endogenous number of informed investors and incentives for transparency

3.1 Equilibrium number of informed investors

Section 2.5 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 at a fixed cost (D_{t+1}) during the trading period. An uninformed investor will decide to become informed if

$$E\left[U^I_{t+1}|\Omega^U_{t+1}\right] - RD_{t+1} \geq E\left[U^U_{t+1}|\Omega^U_{t+1}\right]. \tag{34}$$

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 more easily discover if a technology adoption decision issues a false signal.[22]

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 superior knowledge of the local labor force and the business environment and more soft 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 the gains from becoming informed and the equilibrium*

[22] 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 the information cost is lower if, according to other signals, uninformed investors expect productivity to be low (high), and the country nevertheless adopts fast (slowly). Therefore, this assumption works against the distortions analyzed by limiting the initial owner's potential gains from "adopting to signal". This simplifies the analysis because ϑ_{t+1} is unknown to the initial owner in period t.

number of informed investors

$$\hat{\mu}^I_{t+1} = \begin{cases} \mu^I_{t+1}, \text{ if } \delta_{t+1} > \bar{\delta}_{t+1} = \frac{\beta_u}{R2\tau}\left(\beta_{\tilde{\theta}} + \frac{\mu^2\beta_u^2}{\tau^2}\beta_s\right)^{-1} \\ \sqrt{\frac{\tau}{\beta_u\beta_s}\left(\frac{1}{R2\delta_{t+1}} - \frac{\beta_{\tilde{\theta}}\tau}{\beta_u}\right)}, \text{ otherwise.} \end{cases} \tag{35}$$

Proof. See Appendix F. ■

Becoming informed is profitable as long as the cost is not too high as 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 informed that investors become, the lower is the variance of price signals and 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 the 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 at a zero cost.

As can be seen from (35), the number of informed investors is higher if either the risk-free return (R) or the information costs (δ_{t+1}) are low. If the public signal is more informative (high $\beta_{\tilde{\theta}}$) or the variance of noise trading is low (high β_s), thus implying more precise price signals, less investors decide to become informed. Higher risk aversion (τ) and variance of the unexplainable component of productivity ($1/\beta_u$) affect the incentives to acquire costly information in two opposite ways. First, they reduce investors' willingness to pay information costs, because the optimal risky asset demand is lower. Second, they increase the incentives to bear information costs, because a 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 ($\delta_{t+1} \leq \bar{\delta}_{t+1}$).

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 **in financial** markets. The equity price adjusts to take this improvement into account for any number of informed investors.[23]

3.2 Adoption with an 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 (23) in (28) and simplifying, the threshold becomes

$$\bar{\theta}_{t+2} = \frac{R^2}{\Gamma}\zeta(\cdot) - \Lambda_{ATS}\sqrt{\frac{R2\tau}{\beta_u}}\sqrt{\delta_{t+1}} + \Lambda_{FUM}A^*_{t+1}\frac{R2\tau}{\beta_u}\delta_{t+1}. \tag{36}$$

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}.

To investigate the policy maker's incentives to pursue policies towards transparency, consider an extreme case where it has full control over δ_{t+1}. Suppose that the policy maker's objective is to maximize the probability for the country of adopting fast. This objective can be justified, because it allows for output and wages ((32) and (33)) to increase earlier and therefore increases the consumption of local agents benefiting from this. Maximizing the probability of fast technology adoption is equivalent to minimizing the threshold, i.e.

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

[23] This result relies on the assumption that variance on noise trading decreases over time (18). If this is not the case, less informative asset prices at a higher technology level would give more incentives to pay the information costs. However, this would only offset the additional negative impact of "fear of unstable markets" that is eliminated in the current setup.

where $\bar{\theta}_{t+2}$ is given by (36).[24]

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

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

Proof. See Appendix G. ■

This proposition suggests that the local policy maker does not choose full transparency ($\delta_{t+1}^{opt} = 0$) due to the "adopting to signal" force. As long as some investors are uninformed, the initial owners will find it optimal to adopt fast at a lower level of productivity than what would be possible in perfectly informed equity markets. It is important to point out that the counter-intuitive policy encouraging a "too fast" technology adoption is justified because the policy maker is local. The additional opportunities of fast technology come at the expense of losses of foreign uninformed investors.[25]

Both the higher level and the growth rate of frontier technology imply more incentives towards transparency. As discussed in Section 2.5, the evolution of frontier technology implies higher uncertainty. Therefore, countries that try to keep up with improvements in the frontier technology are expected to aim at becoming more transparent over time,

$$\frac{\delta_{t+2}^{opt}}{\delta_{t+1}^{opt}} = \left(\frac{A_{t+1}^*}{A_{t+2}^*} \right)^2 = \left(\frac{1}{1+g^*} \right)^2.$$

Other variables that increase the optimal transparency are higher risk aversion (τ), variance of the unexplainable component of productivity ($1/\beta_u$) and a lower risk-free

[24] The results are similar, if the local policy maker chooses the precision of the public signal, for the same policy objective and are available upon request.

[25] Policy makers' objective might 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 of the local policy maker. However, it would not alter the optimal information cost being above zero. Agents affected by the choice of δ_{t+1} are 1) local entrepreneurs born in t, 2) local investors born in $t+1$ and 3) workers born in $t+2$. A higher probability of fast technology adoption is always beneficial for agents 1) and 3). Lower transparency is beneficial for local informed investors and has marginal effect on local uninformed investors. Therefore, the local policy with such an objective function is likely to set the information cost higher and not lower as compared to the one analyzed.

interest rate (R). As can be seen from (36), 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 the policy maker would give further incentives to acquire costly information through higher transparency.

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 analyzes if preventing foreigners from trading 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 capital, assume that all potential foreign investors are uninformed and all local investors are informed but limited in number ($\mu_{t+1}^{I} = \mu$ is finite). Consider that the restrictions imply that none of the foreign investors can invest in local equity ($\mu_{t+1}^{*U} = \mu_{t+1}^{*I} = 0$) and that a proportion γ of noise traders is foreign.

In that setting, the expected equity prices are always lower, because the local equity market lacks liquidity (see Appendix H). At the same time, there may be less uncertainty because uninformed foreign investors do not participate.

Lemma 7 *The probability of fast technology adoption is not increased by forbidding foreign portfolio investments if*

$$\mu \rightarrow 0 \text{ or } \mu \geq \bar{\mu}, \text{ where } \bar{\mu} = \arg \underset{\mu}{\text{solve}} \left(\bar{\theta}_{t+2} = \bar{\theta}_{t+2}^{PI} \right). \tag{37}$$

If $0 < \mu < \bar{\mu}$, *the probability of fast technology adoption is increased if the following*

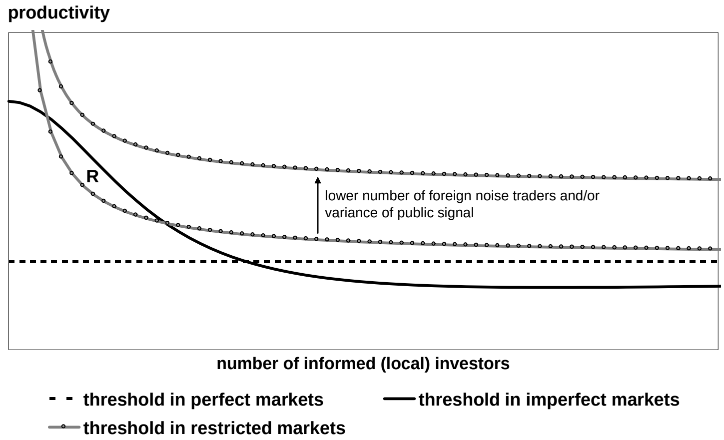

Figure 4: **The possibility** of gains from restricting foreign portfolio investments is **shown in area R**.

condition holds

$$\frac{(1-\eta_2)-(1-\gamma)}{2} > K > 0, \tag{38}$$

where K is decreasing in A^*_{t+1}, g^*, γ, increasing in R, β_θ and ambiguous in other parameters.

Proof. See Appendix H. ■

Figure 4 illustrates Lemma 7. The first part of the lemma (37) implies that restrictions cannot increase the probability of fast technology adoption if the local market is very small. The liquidity premium is higher if the number of local investors is lower. In a very small local equity market ($\mu \to 0$), the liquidity premium and the threshold of fast technology adoption become infinite. At the same time, the threshold is always finite if foreign uninformed investors participate in the local equity market.

The lemma also implies that the restrictions cannot increase the probability of fast technology adoption if the "adoption to signal" force were to dominate the "fear of unstable markets" force in the case of an open market (37). If there are no uninformed investors, investment in fast technology adoption does not reveal any additional information to rational investors and initial owners' incentives cannot be affected by this. This

implies that if the local equity market is sufficiently large, additional liquidity and gains from "adoption to signal" compensate the negative effects of imperfect information among foreign investors.

From (38), it can be seen that in the small but not very small local equity markets, the gains may be possible (area "R" in Figure 4). In that case, there is a trade-off between the negative effect of lower liquidity and the positive effect of lower uncertainty. Therefore, the gains are more likely if there is a great deal of uncertainty about the behavior of foreign traders: they receive very imprecise signals (low β_θ) and a large share of the noise traders is foreign (γ). As the level (A^*_{t+1}) and growth rate (g^*) of technology increase the magnitude of "fear of unstable markets" force, an increase in these two variables increases the likelihood of the gains from restrictions.

In the extreme case, where all noise traders are local ($\gamma = 0$), restrictions to foreign uninformed investors cannot be beneficial.[26] In an illiquid market, local noise traders have a large impact on equity prices, which creates an even higher uncertainty about whether these prices reduce the incentives to invest in technology.

To summarize, the possibility of gains from forbidding foreign portfolio investments cannot be ruled out. However, such gains are only likely in very specific circumstances, where local investors are substantially better informed than foreign investors and the local equity market is small.

5 Concluding remarks

This paper analyzes alternative mechanisms for explaining the differences in the speed of technology adoption across countries. It argues that if ownership transfers of firms that engage in technology adoption are made in imperfectly informed equity markets, two opposite forces arise: a negative "fear of unstable markets" force and a positive

[26] If $\gamma = 0$, (38) implies $\frac{(1-\eta_2)^2-1}{2} > K > 0$. This is never satisfied, because $0 < \eta_2 < 1$.

"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 on which uninformed traders base their decisions, the stronger are these forces. 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, the recent overpricing of the technology sector assets in the United States and other developed countries 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 the cost of technology adoption do not change, the evolution of the frontier technology implies an increasing importance of the "fear of unstable markets". This is due to the fact that uncertainty about the ability of labor in using any technology creates a higher uncertainty about profits if the technology is more advanced.

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 equity markets.

When the number of informed investors is made endogenous, by letting the local policy maker 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 enhance 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. Estonia is a stark example of a country that has been very active in adopting Internet and Communication Technologies in the 1990s. With its ability to attract investors from Scandinavian countries, this could be 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 this. In countries where the local equity markets are smallest, the need for attracting foreign portfolio equity flows to generate liquidity is pressing, and the 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. First, local equity markets must be small, such that the "fear of unstable markets" would dominate in open equity capital markets. Second, local investors should be well informed, while the baheviour of foreign investors should be highly uncertain. Only in such a case could the benefits from lower uncertainty potentially offset the losses due to a higher liquidity premium. In countries with intermediate and large 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 paper assumes that the firms are listed in the local stock exchange. Listing in a well established stock exchange (e.g. NASDAQ) can allow a firm to access a larger number of informed potential buyers. Moreover, the regulations of a well developed stock exchange can reduce the information costs. Nevertheless, for the mechanisms analyzed in this paper to be valid, this assumption is not crucial, because the uncertainty is about the local economy. Interpreting the equity market to be local is more natural, because for most firms from developing countries, the fixed costs associated with an initial public offering in NASDAQ are likely to be too high and they must rely on the local equity market. Therefore, this possibility is only available for the most successful and innovative firms.

Furthermore, local firms could be sold directly 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 directly transferred between local agents, potentially both the low number of informed buyers and the lack of liquidity are likely to discourage fast technology adoption.

A Income per capita and R&D expenditure[27]

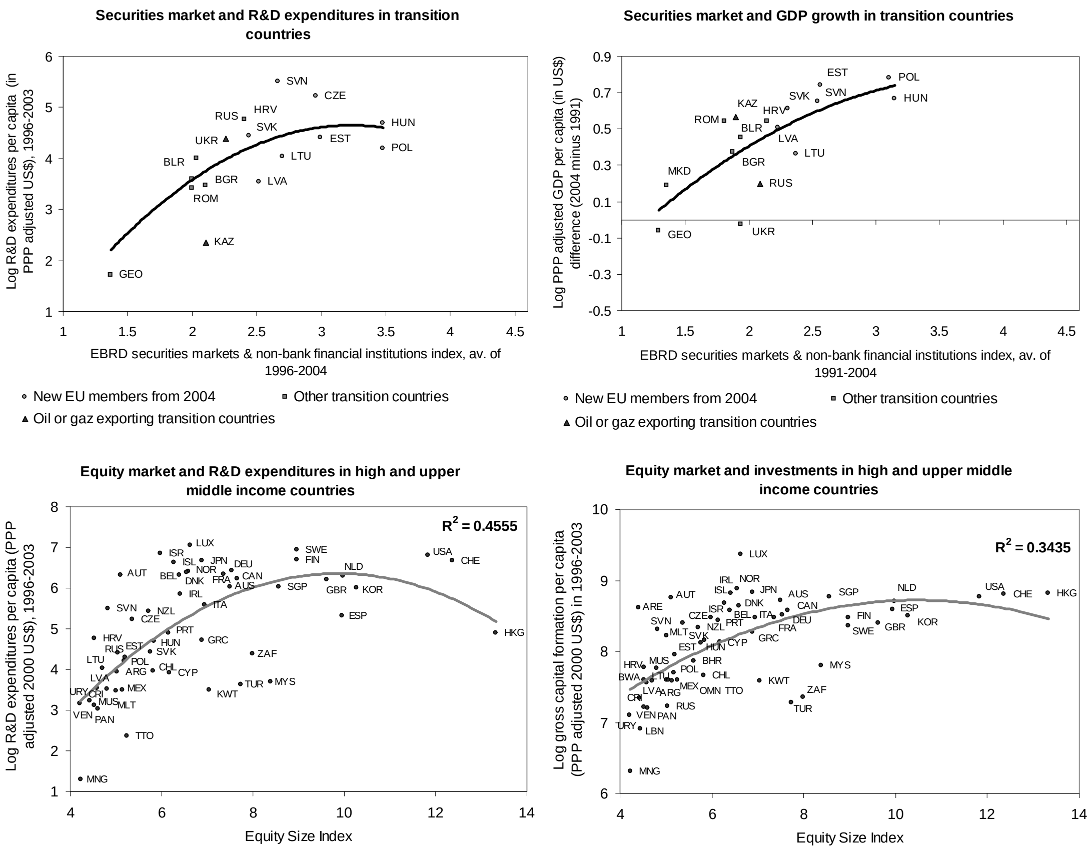

Figure 5: Data sources: GDP, R&D expenditures and investments from WDI, World Bank; "Equity Size Index" from FSDI, World Bank and securities market index for transition countries: Transition Report, EBRD.

[27] Transition countries provide a good comparison group, because they are similar in their high share of educated labor force, institutions and lack of securities markets at the time when Soviet Union dissolved and the initial level of GDP. The figures exclude five transition countries that had a substantially lower initial PPP adjusted GDP per capita (below 3.0 thousand USD) in 1991. The remaining countries have a mean of 6.6 thousand USD and a standard deviation of 2.0 thousand USD. The pattern is similar for R&D expenditures in high and upper-middle income countries as classified by World Bank. The patterns are also similar if using other available measures of equity market development (e.g. the number of IOSCO principles implemented, realized equity return volatility) or technology adoption (e.g. the number of personal computers or internet users per 1000 individuals and GDP growth). In addition to investments in technology, the mechanisms analyzed in this paper are arguably more generally valid for investments. However, these effects are likely to be smaller, as the importance of entrepreneurial talent and the potential gains from exit are likely to be smaller. The correlations presented are consistent with this conjecture.

B Equity market equilibrium

The optimal demand of informed traders is specified in (19) and (20). Replacing this into the asset market clearing condition (12) implies

$$\hat{\mu}^I_{t+1}\frac{\Gamma\theta_{t+2}A_{t+2}-RP_{t+1}}{\tau\Gamma^2A^2_{t+2}\frac{1}{\beta_u}}+\hat{\mu}^U_{t+1}\hat{h}^U_{t+1}+s_{t+1}=1. \tag{39}$$

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

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

which is the same as (21).

Defining coefficients z_{t+1} and $z_{v,t+1}$ as in (23), the updated distribution of θ_{t+2} is

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

In addition, uninformed investors also get information from knowing the adoption decision of local informed investors. Conjecture that fast technology adoption ($\tilde{1}_{I_t}=1$) implies that $\theta_{t+2}\geq\bar{\theta}_{t+2}$ and slow technology adoption ($\tilde{1}_{I_t}=0$) implies that $\theta_{t+2}<\bar{\theta}_{t+2}$. This conjecture is verified in Section 2.5.2. Following pp. 899 in Green (2000) for the moments of truncated normal and (17) gives (22).

Plugging the demand of uninformed investors (19) and (22) into (39), the equilibrium

equity price is

$$P_{t+1} = \frac{\hat{\mu}^I_{t+1} \dfrac{\Gamma\theta_{t+2}A_{t+2}}{\tau\Gamma^2 A^2_{t+2}\frac{1}{\beta_u}} + \hat{\mu}^U_{t+1} \dfrac{E\left[\pi_{t+2}|\Omega^{*U}_{t+1}\right]}{\tau \operatorname{Var}\left(\pi_{t+2}|\Omega^{*U}_{t+1}\right)} - 1 + s_{t+1}}{R\left(\dfrac{\hat{\mu}^I_{t+1}}{\tau\Gamma^2 A^2_{t+2}\frac{1}{\beta_u}} + \dfrac{\hat{\mu}^U_{t+1}}{\tau \operatorname{Var}\left(\pi_{t+2}|\Omega^{*U}_{t+1}\right)}\right)}. \tag{40}$$

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

$$P_{t+1} = \frac{E\left[\pi_{t+2}|\Omega^U_{t+1}\right]}{R}.$$

Using (21) and (22) gives (25).

C Proof of Proposition 1

Assume that there exists a threshold level of productivity $\bar{\theta}_{t+2}$ above which fast technology adoption is optimal. Moreover, assume 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 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 $\eta_2 < 1$. 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 equity prices can be expressed as

$$P_{t+1} \approx \frac{1}{R}\Gamma A_{t+2}\left(\begin{array}{l} z_{t+1}\tilde{\theta}_{t+2} + (1-z_{t+1})\theta_{t+2} + z_{s,t+1}\Gamma A_{t+2}s_{t+1} + \\ +\sqrt{z_{v,t+1}}(\eta_2 b_{t+1} + (-1)^{1-\tilde{1}_{I_t}}\eta_1) \end{array}\right).$$

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

$$\begin{aligned} E\left[P_{t+1}|\theta_{t+2}, 1_{I_t}\right] &= \frac{\Gamma A_{t+2}}{R}\left[(1-\eta_2)\,\theta_{t+2} + \eta_2\bar{\theta}_{t+2} + \sqrt{z_{v,t+1}}(-1)^{1-\tilde{1}_{I_t}}\eta_1)\right] \\ \mathrm{Var}\left(P_{t+1}|\theta_{t+2}, 1_{I_t}\right) &= \frac{\Gamma^2 A_{t+2}^2}{R^2}\left(1-\eta_2\right)^2 z_{v,t+1}. \end{aligned}$$

By definition, if $\tilde{1}_{I_t} = 1$, then $A_{t+2} = A^*_{t+2}$ and if $\tilde{1}_{I_t} = 0$, then $A_{t+2} = A^*_{t+1}$. Using this in (26) and (27) and noting that indifference between fast or slow technology adoption implies $\theta_{t+2} = \bar{\theta}_{t+2}$, we find (28). Plugging (28) into the technology adoption decision ((26) and (27)) proves Proposition 1.

D Independence of adoption and trading decisions

In period $t+1$ some investors trading in the financial markets are also the 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 an 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 relevant for his technology adoption decision is θ_{t+3}. He solves

$$\begin{aligned} &\max_{\hat{h}^i_{t+1}, \tilde{1}_{I_{t+1}}} E[c^{e,i}_{t+2}|\Omega^i_{t+1}, \theta_{t+3}] - \tfrac{\tau}{2}\,\mathrm{Var}\left(c^{i,e}_{t+2}|\Omega^i_{t+1}, \theta_{t+3}\right), \\ &\text{st. } c^{e,i}_{t+2} = c^i_{t+2} + c^e_{t+2}, \end{aligned}$$

where total consumption ($c^{e,i}_{t+2}$) equals consumption from trading

$$c^i_{t+2} = (\Gamma(\theta_{t+2} + u_{t+2})A_{t+2} - RP_{t+1})\hat{h}^i_t + R\hat{W}^i_{t+1}, \tag{41}$$

and consumption from the gains from technology adoption

$$c^e_{t+2} = \tilde{1}_{I_{t+1}} P_{t+2,\tilde{1}_{I_{t+1}}=1} + (1 - \tilde{1}_{I_{t+1}})P_{t+2,\tilde{1}_{I_{t+1}}=0} - \tilde{1}_{I_{t+1}} RI_{t+1}. \tag{42}$$

$\hat{W}^i_{t+1}$ is the wealth of such an agent (equals wage income if the agent is a local entrepreneur and equals the sum of the local entrepreneur's wage and foreigners' exogenous wealth in a joint venture) and $\hat{h}^i_t$ his risky equity demand. The notations $P_{t+2,\tilde{1}_{I_{t+1}}=1}$ and $P_{t+2,\tilde{1}_{I_{t+1}}=0}$ point out that the equity price will be different depending on the adoption decision (as profit and equity price depend on the quality of technology, i.e. the profits depend on 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 equity price (25) depends on three uncertainty terms,

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

With assumed lack of correlation between different shocks and no serial correlation, this implies

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

Using this, the moments of $c^{i,e}_{t+1}$ can be expressed as

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

The utility function used implies that optimal equity demand does not depend on wealth. Therefore, the utility from equity trading and technology adoption can be solved separately as

$$\max_{\hat{h}^i_{t+1}} E[c^i_{t+2}|\Omega^i_{t+1}, \theta_{t+3}] - \tfrac{\tau}{2} \operatorname{Var}\left(c^i_{t+2}|\Omega^i_{t+1}, \theta_{t+3}\right) \text{ st. } (41)$$

$$\max_{\tilde{1}_{I_{t+1}}} E[c^e_{t+1}|\theta_{t+3}] - \tfrac{\tau}{2} \operatorname{Var}\left(c^e_{t+1}|\theta_{t+3}\right) \text{ st. } (42).$$

The latter is equivalent to (26) and (27) for $t+1$.

E Local goods market clearing

The consumption of each local rational agent from trading in the asset market is $c^i_t = h^i_{t-1}\pi_t + Rm^i_{t-1}$, where m^i_{t-1} is the the risk-free asset holding by an agent of type i. The consumption of local non-rational agents is $s_{t-1}\pi_t + Rm^N_{t-1}$, where m^N_{t-1} is the risk-free asset holding by non-rational agents. Define aggregate equity demand by foreign agents $H^*_t \equiv \mu^{*I}_t \hat{h}^I_t + \mu^{*U}_t \hat{h}^U_t$. Using the equity market clearing (12), aggregate equity demand by local agents is $\mu^I_t \hat{h}^I_t + \left(\mu - \mu^I_t\right) \hat{h}^U_t + s_t = 1 - H^*_t$. Defining the aggregate holdings of the risk-free asset $M_t \equiv \mu^I_t m^I_t + \left(\mu - \mu^I_t\right) m^U_t + s_t$, aggregate consumption of local agents from trading in period t is $\left(1 - H^*_{t-1}\right)\pi_t + RM_{t-1}$.

Some agents are also initial owners of firms that adopt technology. Consider the case when technology is adopted by local agents alone. In that case, local agents additionally consume P_t, the price of local monopolistic firms established in period $t-1$. Aggregate consumption of local agents $C_t = \left(1 - H^*_{t-1}\right)\pi_t + RM_{t-1} + P_t$.

There are μ young local agents who invest in equity, risk-free asset and technology. Each rational local agent receives wage income w_t and each non-rational agent has zero wealth. The aggregate budget constraint of local agents is $\mu w_t = (1 - H^*_t)\, P_t + M_t + \tilde{1}_{I_t} I_t$.

The net inflow of goods from abroad is determined by the net inflow of equity and risk-free asset, $F_t = H^*_t P_t + RM_{t-1} - M_t - H^*_{t-1}\pi_t$.

We can find

$$C_t - F_t = \pi_t + \mu w_t - \tilde{1}_{I_t} I_t. \tag{43}$$

From (13) aggregate capital $\int_0^1 x_t(j)dj = (\alpha^2)^{\frac{1}{1-\alpha}} \phi_t L A_t = \frac{\alpha}{1-\alpha}\Gamma\phi_t A_t$. Using this with (11), (15), (32), (33) and (43) in goods market condition (10) gives $\pi_t = \Gamma\phi_t A_t$ and holds by (4) and (17). Therefore, the local goods market clears.

When technology is adopted in a joint venture with a foreigner, the speed of technology adoption must be fast, $\tilde{1}_{I_t} = 1$ (see Section 2.5.2)

If fast technology adoption is only possible in a joint venture, the local entrepreneurs born in $t-1$ receive $P_{t,\tilde{1}_{I_{t-1}}=0}$, while the price of equity $P_t = P_{t,\tilde{1}_{I_{t-1}}=0}$. Aggregate consumption becomes $C_t = \left(1 - H^*_{t-1}\right)\pi_t + RM_{t-1} + P_{t,\tilde{1}_{I_{t-1}}=0}$ and the budget constraint of local young agents is $\mu w_t = (1 - H^*_t) P_t + M_t$. As foreigners bear the costs of technology adoption, they invest I_t and receive $P_t - P_{t,\tilde{1}_{I_{t-1}}=0}$. The net inflow of goods becomes $F_t = H^*_t P_t + RM_{t-1} - M_t - H^*_{t-1}\pi_t - P_t + P_{t,\tilde{1}_{I_{t-1}}=0} + I_t$, as $C_t - F_t$ simplifies to (43).

If local agents are able to adopt technology fast alone, but the cost is lower in joint venture, foreigners pay the adoption cost I_t and receive fixed compensation $R\zeta(\cdot)(A^*_{t+2} - A^*_{t+1})$. Aggregate consumption $C_t = \left(1 - H^*_{t-1}\right)\pi_t + RM_{t-1}$, budget constraint $\mu w_t = (1 - H^*_t) P_t + M_t$ and net inflow $F_t = H^*_t P_t + RM_{t-1} - M_t - H^*_{t-1}\pi_t - R\zeta(\cdot)(A^*_{t+2} - A^*_{t+1}) + I_t$ once more give (43).

As the remainder of the proof remains the same, the goods market also clears when technology is adopted in a joint venture.

F Proof of Proposition 5.

The demand of uninformed investors with wealth (or wage income), $\hat{W}^U_{t+1}$, is given by (19) and known with certainty. The expected utility from remaining uninformed is

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

If they decide to become informed, their demand is given by (19) and (20). However, they do not know what productivity they will observe after becoming informed and thus not their demand as informed either. Replacing the demand as informed in the utility function, the utility can be expressed as

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

Taking expectations

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

Given that the number of uninformed investors is infinite, asset prices correspond to the expectations of uninformed investors. This means $E\left[\pi_{t+2}|\Omega^U_{t+1}\right] - RP_{t+1} = 0$ and (34) simplifies to

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

The conditional variance of the productivity must be sufficiently high, 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 (22) and $\vartheta_{t+1} \equiv \left(1 - \lambda^2_{\tilde{1}_{I_t}}(b_{t+1}) + b_{t+1}\lambda_{\tilde{1}_{I_t}}(b_{t+1})\right)$, this becomes

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

If the number of local investors that become informed at zero cost is sufficiently large, such that $\delta_{t+1} > \frac{\beta_u}{R2\tau}\frac{1}{\beta_{\tilde{\theta}}+\left(\hat{\mu}^I_{t+1}\beta_u\right)^2\beta_s\tau^{-2}}$ 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

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

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

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

G Proof of Proposition 6

Define constants $Q_1 \equiv \frac{R^2}{\Gamma}\hat{\zeta}(\cdot) > 0$; $Q_2 \equiv \frac{2+g^*}{g^*}\sqrt{\frac{R2\tau}{\beta_u}}\eta_1 > 0$; $Q_3 \equiv \frac{\tau}{2}\frac{\Gamma(2+g^*)}{R}A^*_{t+1}\left(1-\eta_2\right)^2\frac{R2\tau}{\beta_u} > 0$. Then, $\delta^{opt}_{t+1} = \underset{\delta_{t+1}}{\arg\min}\left(Q_1 - Q_2\delta^{\frac{1}{2}}_{t+1} + Q_3\delta_{t+1}\right)$. The first-order condition of this gives $\delta^{opt}_{t+1} = \left(\frac{Q_2}{2Q_3}\right)^2$ and the second-order condition, $\frac{\partial^2\left(Q_1-Q_2\delta^{\frac{1}{2}}_{t+1}+Q_3\delta_{t+1}\right)}{\partial^2\delta_{t+1}} = \frac{Q_2}{4\delta_{t+1}{}^{\frac{3}{2}}} > 0$, confirms it as the minimum. Replacing the constants in δ^{opt}_{t+1} proves the proposition.

H Proof of Lemma 7

Assume a proportion $\gamma = [0, 1]$ of the noise traders to be foreign. With μ informed local agents, no foreign traders in the equity market and $(1-\gamma)s_{t+1}$ local noise traders the

equilibrium equity price (40) with restrictions to foreign portfolio investors becomes

$$P_{t+1}^{R}=\frac{\Gamma A_{t+2}\theta_{t+2}}{R}-\frac{\Gamma^{2}A_{t+2}^{2}}{\frac{\mu\beta_{u}}{\tau}R}+(1-\gamma)\frac{\Gamma^{2}A_{t+2}^{2}}{\frac{\mu\beta_{u}}{\tau}R}s_{t+1}. \tag{44}$$

The moments of this conditional on initial owners' information are

$$\begin{aligned} E[P_{t+1}^{R}|\theta_{t+2}] &= \tfrac{\Gamma A_{t+2}\theta_{t+2}}{R}-\frac{\Gamma^{2}A_{t+2}^{2}}{\frac{\mu\beta_{u}}{\tau}R} \\ \text{Var}\left(P_{t+1}^{R}|\theta_{t+2}\right) &= (1-\gamma)^{2}\,\frac{\Gamma^{2}A_{t+2}^{2}}{R^{2}\beta_{s}\left(\frac{\mu\beta_{u}}{\tau}\right)^{2}}. \end{aligned}$$

Using this in (26) and (27) with (6), the threshold of fast technology adoption with restrictions on foreign portfolio investors **is**

$$\bar{\theta}_{t+2}^{R}=\tfrac{R^{2}}{\Gamma}\hat{\zeta}(\cdot)+\frac{\Gamma\left(2+g^{*}\right)A_{t+1}^{*}}{\frac{\mu\beta_{u}}{\tau}R}+\frac{\tau}{2}\left(1-\gamma\right)^{2}\frac{\Gamma(2+g^{*})A_{t+1}^{*}}{R\beta_{s}\left(\frac{\mu\beta_{u}}{\tau}\right)^{2}},$$

where $\frac{\tau}{2}\left(1-\gamma\right)^{2}\frac{\Gamma A_{t+1}^{*}}{R\beta_{s}\left(\frac{\mu\beta_{u}}{\tau}\right)^{2}}$ is the "fear of unstable markets" force in the restricted market and $\frac{\Gamma(2+g^{*})A_{t+1}^{*}}{\frac{\mu\beta_{u}}{\tau}R}$ is the additional negative force from lack of liquidity in the local equity market. As $\bar{\theta}_{t+2}^{R}>\frac{R^{2}}{\Gamma}\hat{\zeta}(\cdot)=\bar{\theta}_{t+2}^{PI}$, the restrictions can never increase the probability of fast technology adoption if the "adoption to signal" force were to dominate with the same number of informed agents.

The threshold of fast technology adoption in a very small local equity market $\lim_{\mu\to 0}\bar{\theta}_{t+2}^{R}\to\infty$. At the same time, from (23) and (28) $\lim_{\mu=\hat{\mu}_{t+1}^{I}\to 0}\bar{\theta}_{t+2}=\frac{R^{2}}{\Gamma}\hat{\zeta}(\cdot)-\frac{\Lambda_{ATS}}{\sqrt{\beta_{\theta}}}+\frac{A_{t+1}^{*}\Lambda_{FUM}}{\beta_{\theta}}$ is finite. Therefore, technology adoption is never more likely if $\mu\to 0$.

More generally, the probability of fast technology adoption is higher with restrictions to foreign portfolio investors, if $\bar{\theta}_{t+2}^{R}<\bar{\theta}_{t+2}$, where $\bar{\theta}_{t+2}$ is given by (28) and $\hat{\mu}_{t+1}^{I}=\mu$. Using (23) and (29), the condition $\bar{\theta}_{t+2}^{R}<\bar{\theta}_{t+2}$ can be expressed as

$$\frac{\left(1-\eta_{2}\right)^{2}-\left(1-\gamma\right)^{2}}{2}>K\equiv\frac{R\beta_{\tilde{\theta}}}{\mu\beta_{u}}+\frac{R\mu\beta_{u}\beta_{s}}{\tau^{2}}+\frac{\eta_{1}R\sqrt{\beta_{\tilde{\theta}}+\frac{(\mu\beta_{u})^{2}\beta_{s}}{\tau^{2}}}}{A_{t+1}^{*}g^{*}\tau\Gamma}+\frac{\left(1-\gamma\right)^{2}\beta_{\tilde{\theta}}\tau^{2}}{2\beta_{s}\left(\mu\beta_{u}\right)^{2}}.$$

As $0 < \eta_2 < 1$, this condition is never satisfied if there are no foreign noise traders ($\gamma = 0$). The condition is more likely to be satisfied if γ, A^*_{t+1} and g^* are high and $\beta_{\tilde{\theta}}$ and R are low. While the impact of other parameters is ambiguous, with **a** sufficiently high share of foreign noise traders (γ), the condition is also more likely to be satisfied if τ is high and β_s is low.

References

Acemoglu, Daron, "Directed Technical Change," *Review of Economic Studies*, 2002, *69*, 781–810.

Aghion, Philippe and Peter Howitt, "A Model of Growth through Creative Destruction," *Econometrica*, 1992, *60*, 323–351.

——, **Diego Comin, and Peter Howitt**, "When Does Domestic Saving Matter for Economic Growth?," 2006. unpublished.

——, **Philippe Bacchetta, and Abhijit V. Banerjee**, "Capital Markets and the Instability of Open Economies," *Journal of Monetary Economics*, 2004, *51*, 1077–1106.

Allen, Franklin, Stephen Morris, and Hyun Song Shin, "Beauty Contests and Iterated Expectations in Asset Markets," *Review of Financial Studies*, 2006, *19*, 719–752.

Aylward, Anthony, "Trends in Venture Capital Finance in Developing Countries," The World Bank, IFC Discussion Paper No. 36 1998.

Bacchetta, Philippe and Eric van Wincoop, "Higher Order Expectations in Asset Pricing," 2006. unpublished.

Beck, Thorsten and Ross Levine, "Stock Markets, Banks and Growth: Panel Evidence," *Journal of Banking and Finance*, 2004, *28*, 423–442.

Bencivenga, Valerie, Bruce D. Smith, and Ross M. Starr, "Transaction Costs, Technological Choise and Endogeneous Growth," *Journal of Economic Theory*, 1995, *67*, 153–177.

Chan, Louis K. C., Narasimhan Jegadeesh, and Josef Lakonishok, "Momentum Strategies," *The Journal of Finance*, 1996, *51(5)*, 1681–1713.

Cutler, David M., James M. Poterba, and Lawrence H. Summers, "Speculative Dynamics," *Review of Economic Studies*, 1991, *58(3)*, 529–546.

Garibaldi, Pietro, Nada Mora, Ratna Sahay, and Jeromin Zettelmeyer, "What Moves Capital to Transition Economies?," IMF Working Paper No. 02/64 2002.

Gertler, Mark and Kenneth S. Rogoff, "North-South lending and endogeneous domestic capital market inefficiencies," *Journal of Monetary Economics*, 1990, *26*, 245–266.

Green, William H., *Econometric Analysis*, 4 ed., New Jersey: Prentice Hall International Inc., 2000.

Grossman, Sanford J., "On the Efficiency of Competitive Stock Markets where Traders Have Diverse Information," *Journal of Finance*, 1976, *31*, 573–585.

—— **and Joseph E. Stiglitz**, "On the Impossibility of Informationally Efficient Markets," *American Economic Review*, 1976, *70(3)*, 393–408.

Holmes, Thomas J. and James A. Schmitz Jr., "A Theory of Entrepreneurship and Its Application to the Study of Business Transfers," *Journal of Political Economy*, 1990, *98(2)*, 265–294.

Jegadeesh, Narasimhan and Sheridan Titman, "Returns to Buying Winners and Selling Losers: Implications for Stock Market Efficiency," *The Journal of Finance*, 1993, *48*, 65–91.

Jovanovic, Boyan and Balázs Szentes, "On the Return to Venture Capital," NBER Working Paper No. W12874 2007.

Kaufmann, Daniel, Aart Kraay, and Massimo Mastruzzi, "Governance Matters V: Governance Indicators for 1996-2005," 2006. World Bank.

Kodres, Laura E. and Matt G. Pritsker, "A Rational Expectations Model of Financial Contagion," *Journal of Finance*, 2002, *57*, 769–99.

Kose, M. Ayhan, Eswar S. Prasad, Kenneth S. Rogoff, and Shang-Jin Wei, "Competition, Innovation and Growth with Limited Commitment," NBER Working Paper No 10942 2004.

La Porta, Rafael, Florencio Lopez de Silanes, Andrei Shleifer, and Robert Vishny, "What Works in Securities Laws?," *Journal of Finance*, 2005, *61*, 1–32.

Lee, Charles, Andrei Shleifer, and Richard H. Thaler, "Investor sentiment and the Closed End Fund Puzzle," *The Journal of Finance*, 1991, *46*, 75–110.

Lerner, Josh and Gonzalo Pacanins, "A note on private equity in developing nations," Harvard Business School, Note 9-298-018 1997.

Levine, Ross, "Stock markets, Growth and Tax Policy," *Journal of Finance*, 1991, *46*, 36–67.

——, "Finance and growth: Theory and Evidence," in Philippe Aghion and Steven Durlauf, eds. Handbook of Economic Growth, The Netherlands: Elsevier Science. 2005.

Marimon, Ramon and Vincenzo Quadrini, "Competition, Innovation and Growth with Limited Commitment," NBER Working Paper No. W12474 2006.

Murphy, Keving J., "Explaining executive compensation: managerial power vs. the perceived cost of stock-options," University of Chicago Law Review 2002.

Parente, Stephen L. and Edward C. Prescott, "Barriers to Technology Adoption and Development," *Journal of Political Economy*, 1994, *102(2)*, 298–321.

Prasad, Eswar S., Raghuram Rajan, and Arvind Subramanian, "Foreign Capital and Economic Growth," 2006. unpublished.

Romer, Paul M., "Endogenous Technological Change," *Journal of Political Economy*, 1990, *98(5)*, S71–102.

Rousseau, Peter L. and Paul Wachtel, "Equity Markets and Growth: Cross-Country Evidence on Timing and Outcomes, 1980-1995," *Journal of Business and Finance*, 2000, *24*, 1933–1957.

Survey by Deliotte Touche Tochmatsu and EVCA, "Global Trends in Venture Capital 2006 Survey," available in the European Private Equity and Venture Capital Association webcite 2006.

Swaminathan, Bhaskaran, "Time-varying Expected Small Firm Returns and Closed-end Fund Discounts," *Review of Financial Studies*, 1991, *9*, 845–888.

Yuan, Kathy, "Asymmetric Price Movements and Borrowing Constraints: A REE Model of Crisis, Contagion, and Confusion," *Journal of Business and Finance*, 2006, *60*, 379–411.