KNOWLEDGE, TECHNOLOGY ADOPTION AND FINANCIAL INNOVATION

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Abstract

Why are new financial instruments created? Why are they needed and what purpose do they serve? This paper proposes the view that financial development arises as a response to the contractual needs of emerging technologies. Exogenous technological progress generates a demand for new financial instruments in order to share risk or overcome private information, for example. A model of the dynamics of technology adoption and the evolution of financial instruments that support such adoption is presented. Early adoption may be required for financial markets to learn the technology; once learned, financial innovation boosts adoption further. An implication of the analysis is the notion that financial development promotes economic growth only to the extent that it enhances the adoption of new technologies.

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1 Introduction

In most of the work addressing the relationship between economic progress and financial development, there is reference to the divide amongst well-known economists concerning the nature and importance of the relationship between those phenomena.[1] For example, in his *Theory of Economic History*, John Hicks [8] argues that the development of financial markets in England was a pivotal condition for the industrialization process started in 18th century England. Other classical references on the topic of growth and financial development include Joseph Schumpeter [19] and Joan Robinson [17]. While the views of the former are qualitatively similar to those of Hicks (finance spurs growth), Robinson argues that economic entrepreneurship leads to financial innovation.

This paper proposes the view that financial development and economic growth are linked through the characteristics of technology, as follows. Perhaps the most obvious connection between technology and financial innovation emerges through risk-sharing. Technology is modeled as a distribution function over output values. Technological progress occurs when Nature makes new distribution functions available to economic agents. In choosing which technology to operate, agents simultaneously select the risk profile of their income source. While progress allows higher output values to be attained, it also changes the risk profile faced by economic agents. The financial sector provides risk intermediation among agents who face distinct risk profiles.

How does financial intermediation affect technology adoption and, as a consequence, growth? Financial innovation is understood here as the broadening of the set of contracts that are offered to agents as a means of risk intermediation. Technology adoption depends on the ability of the financial sector to price the new output contingencies, therefore expanding the set of risk-sharing contracts offered to economic agents. The financial sector is less knowledgeable about new technologies relative to entrepreneurs. It is formed of two types of institutions: banks and venture capitalists. The former have a comparative advantage at intermediating risk over known technologies, while the latter's comparative advantage concerns *learning* about new ones. Specifically, venture capitalists may pay a learning cost and engage in direct learning of the new technology, which will allow them to offer intermediation to entrepreneurs. In addition to this direct learning form, there is the possibility of indirect learning: banks and venture capital may learn from the observation of early adopters, if there are any. As a function of the direct learning cost, there will be two types of equilibria.

[1] See Levine [13] for a survey.

If the direct learning cost is too high, no financial intermediation is offered initially. Banks and venture capital learn from early adopters and insurance will be offered once learning is complete. For early adoption to take place, however, there must be sufficiently skilled entrepreneurs who are willing to adopt the new technology despite the lack of insurance. Early adoption enables learning; only once insurance is granted by the financial sector will the bulk of adoption take place. There is a feedback from early adoption to insurance through learning; in turn, after learning, insurance boosts adoption further as even the least able entrepreneurs will now adopt the new technology. Skill plays a key role in this setting since the high learning costs prevent early financial intermediation.[2]

When the direct learning cost is low, venture capitalists offer (second-best) insurance contracts to entrepreneurs as soon as the technology becomes available. Competition among venture capitalists forces contracts to extract a flat fee for the provision of insurance to all adopting entrepreneurs. The dynamics of adoption are similar to the previous case in that insurance is only offered to the highest skilled of entrepreneurs (who can afford to pay for the learning cost); banks will learn from observation as before and offer more competitive contracts to entrepreneurs once the learning process is complete. The final boost in adoption takes place once the banking sector offers generalized (and first-best) insurance. A low learning cost may however be crucial to ensure adoption when entrepreneurs would not adopt on their own (no one is sufficiently skilled). In both cases (high and low learning cost), financial development promotes economic growth only to the extent that it enhances the adoption of new technologies.

This paper also proposes a new link for diffusion (adoption with a lag) of new technologies. In fact, despite a better technology being available, generalized adoption does not take place right away. Adoption requires new financial contracts to handle the new risks. Since the financial sector takes time to learn the technology and offer the corresponding first-best contracts, only the most able entrepreneurs will be able to adopt early on. Learning about new forms of finance, therefore, acts as a diffusion mechanism.

A historical episode where the broadening of the set of financial contracts offered to economic agents enabled technology adoption is the British industrialization process. According to Hicks [8], the core feature of modern industry, born in England's Industrial

[2] Skill raises output in this paper. As such, and assuming log utility, a more skilled person becomes naturally less risk averse in absolute terms. This is why the more skilled adopt first. The model could also be reinterpreted as a setting where there is a fixed set-up investment cost, required to operate the technology; in this case, it would be natural to think of skill as a metaphor for private wealth.

Revolution, is the fact that fixed capital takes center stage and replaces circulating capital in the production process. In turn, financing fixed capital required the commitment of sizeable investments for long periods of time. Partly as a consequence of the Revolution of 1688, "that established Parliament as the key agency in managing national fiscal affairs,"[3] as well as the need to finance the British warfare, financial markets in England experienced significant developments. The financial revolution was centered around the crucial reforms regulating the placement of public debt, taking place between the first placement of government-backed annuities, in 1693-94, and the South Sea Bubble crisis, in 1719 and 1720. The resulting financial instrument was the perpetual and redeemable annuity, the 'Three Per Cent Bank Annuity,' of 1726, the precursor of the 'Three Per Cent Consol,' of 1751. "Financial investment activity thereafter focussed on this nearly ideal security, that essentially gave the holder an equity position in the financial fortunes of the state. But its attractiveness to the investing public depended on the relative ease by which it could be acquired and disposed of, the clear terms of the interest payments and the readily available information about its current price and the military and political events likely to affect its price. [...] The large stock of government debt and its ease of transfer provided English businessmen with the ideal short-term 'intervention' asset into which they could place idle balances and from which they could withdraw quickly the funds needed for transactions of any size. In other words, the government debt created by the financial revolution in England furnished a liquid asset for business as well as a relatively risk-free asset for women, orphans and timid investors."[4]

The crucial role played by a liquid, and transparent market, whose prices were widely circulated,[5] is also a subtle one. The entrepreneurs' needs for external financing, arising from the need to build up their fixed capital stocks, were not – at this time – directly met by issuing equity on the firm at the London stock market. Entrepreneurs relied first on the net supply of their circulating capital, then on credit from friends or institutions to meet their demand for fixed capital. However, the wide availability and reliability of public debt made it the reference asset for all other financial operations, namely

[3] Quotation from Baskin and Miranti [3].

[4] Quotation from Neal [15].

[5] As described in Neal [15], "Transfers were easily and quickly done in whatever amount was mutually convenient to buyer and seller, title was secure and, moreover, current prices were made transparent by an active stock exchange with regularly published price lists. Indeed, from at least 1698, prices of all the major government securities as traded on the London stock exchange were printed twice weekly and circulated widely through London, the provinces and the continent."

those associated with credit. Intense exchange in the public debt market also set the stage for savers to seek other – more profitable – alternatives. Credit to firms was granted in a number of different forms, using as support a number of other instruments also introduced in England at the time of the Glorious Revolution. The foreign bill of exchange, for example, became the major source of credit for British merchants engaged in the growing trade with North Atlantic colonies, accounting for about half of the credit extended by British merchants to American planters in the American tobacco trade around 1774, just before American independence. The inland bill of exchange, which, just like the foreign, could be used both as a means of payment as well as credit instrument, became the dominant form for the medium of exchange in Britain. Neal [15] provides a vivid account of the web of credit that linked institutions, entrepreneurs and savers, as well as the financial instruments used as support for the credit operations. It also illustrates the reference role of the public debt markets, which were both the true center of gravity of British finance as well as the lubricant that made all other pieces in the financial system run smoothly and in a synchronized way. He argues:

"From 1723, when the pre-eminence of the Bank of England as the premier financial institution in England was assured and the state had developed the perpetual annuity as its primary form of long-term debt, this web of credit was anchored securely in the City of London. Without this anchor, it is very doubtful whether the British economy could have made the structural changes in techniques, products and markets that characterized its transformation from 1760 to 1850. The financial revolution was necessary, even if not sufficient, for the industrial revolution."

Another example of the relationship between the emergence of new financial arrangements and economic development was the establishment of trade in forward contracts, at the inception of the Chicago Board of Trade.[6] Immediately after native Indians were forced to sell their ancestral lands, in 1833, Chicago experienced a burst of activity. Immigrants from the East moved to the region as soon as the ice broke in the Great Lakes. Many of the newcomers were New England and New York entrepreneurs who settled on fertile soils of northern Illinois and southern Wisconsin. By 1860, "the Old Northwest was the nation's granary made so by a mighty immigration from Europe and the eastern United States in the preceding decade."[7] Uncertainty about the final price of grain was an important factor in this trade. Early in the settling and trading process,

[6] See Ferris [6].

[7] Ferris [6].

as described in historical accounts of the Chicago Board of Trade [4], the transportation of grain to the East was a process which depended on weather conditions. River merchants bought crop proceeds from entrepreneurs in the early Fall and needed to ship it to processors. Shipping required a not too cold Winter, so that the river would not freeze and shipments could sail away, and low humidity, in order not to damage the cereal. Often, as these two conditions failed them, river merchants ended up storing the grain all Winter. Early transactions in forward contracts were sought by these intermediaries. They allowed them to insure away the price variability between the time they purchased the grain, in the Fall, until the time of the final sale, by June of the following year.

Price uncertainty associated with weather was soon relegated to second stage with the emergence of railways.[8] But events such as the civil war and the invention of the telegraph brought new sources of price variability to the grain trade. Telegraph communications allowed price information to travel much faster between the New York and Chicago markets. By then, and following regulations from the Chicago Board of Trade in 1865, forward contracts have given place to futures, a standardized form of forward contract where quality, quantity and delivery time and place were regulated. Taking advantage of arbitrage opportunities between the two main markets intensified the use of these contracts; interestingly enough, it also gave rise to speculative trade where the commodity was no longer the grain but the price of grain. Speculation further exposed farmers and processors to price variability. Futures contracts were therefore two sides of the same coin: they allowed market participants to acquire insurance against price variability while such variability was itself potentiated by those very contracts.

This paper explores the relationship between financial innovation and technology adoption from the point of view of risk-sharing arrangements. There are other dimensions of technology that link financial arrangements to technology adoption. One example is asymmetric information. To the extent that technology forces shareholders to delegate on a manager the ability to run their firm given his greater expertise, contracts must be designed to convey adequate incentives to the manager. The literature on corporate finance addresses precisely the properties of such contracts. Yet another example is the presence of indivisibilities, discussed earlier in reference to the Industrial Revolution, as they require the matching of different patterns of liquidity requirements over time.

Going back to the initial debate concerning the direction of causality between finance

[8] See Cronon [5] for a lively account of how the setting of the rails changed the landscape of the region in drastic ways.

and growth, the ideas presented here suggest that technological progress may require new contracts in order to materialize into economic activity. If this is the case, without such contracts, growth will not take place; but likewise, the arbitrary expansion of the set of financial contracts (financial innovation) without a technological demand for those contracts will not spur growth. The industrial revolution was an example where technological development had to wait for an adequate financial infrastructure that would support it. But such an infrastructure responded to specific technological needs that preceded financial innovation. River merchants in Chicago needed forward markets to insure against price risk. Had the Chicago Board of Trade not been created, this would have likely hampered the farming activity in the Midwest. But had the weather not been a factor in the transportation of grain during Winter, the Chicago Board of Trade would have witnessed no early trade in forward contracts. The response of finance to the needs of technology seems to be perfectly summarized in Joan Robinson's [17] claim that "where enterprise leads finance follows." In the present context, enterprise is understood both as a new technology in a strict sense (that of scientific discovery), or as a new form of organizing one's business or conducting trade. The logical conclusion of the approach presented here is therefore that the positive correlation found empirically between financial development and growth (see King and Levine [10], Levine and Zervos [12], among many others) reflects an adequate response of the financial system to technological progress, but that there should be small gains from the implementation of an arbitrary financial reform, not targeted at specific technological needs.

2 Related Literature

This work relates to different strands of the literature: growth and finance, I.O. (diffusion), common knowledge and asymmetric information between market participants. On the theory side of the relationship between growth and financial development, the closest links are Acemoglu and Zilibotti [1], Greenwood and Jovanovic [7], Bencivenga and Smith [2] and Saint-Paul [18]. Acemoglu and Zilibotti focus on conditions under which a more productive but riskier technology can be adopted and its implications for the volatility of output throughout the process of development. At early stages of development, the minimum size requirements of the risky project prevent its generalized adoption; as these projects bear idiosyncratic risk, the more projects adopted, the lower the aggregate risk for the economy. In their work, however, the set of technologies is fixed, and, conditional on the adoption decision, financial markets are complete. Similarly, in Greenwood and Jovanovic, the set of technologies is given and adoption depends on whether or not individual investors have become sufficiently wealthy to bear the fixed cost that financial intermediation entails. The current paper focuses on the rather different question of the implications of market incompleteness for technology adoption. Here, technology evolves exogenously and the adoption of more recent productive processes depends on the ability of the financial sector to provide new contracts that conform to the risk profile of the latest tier technology.

Bencivenga and Smith's work is centered around the comparative advantage of the financial system as a provider of liquidity to economic agents. In an economy with financial intermediation, individual needs to hold on to liquid but unproductive assets are reduced and the economy will grow faster as more funds are devoted to a more productive technology. Although the provision of liquidity to economic agents is one important dimension in which technology and financial innovation are related, as argued above, in this paper only the risk-sharing dimension of financial innovation is explored.

Saint-Paul has a model where productivity growth occurs through the specialization of labor. Firms determine their degree of specialization by selecting a particular technology from a given set. Higher specialization exposes the firm to greater (demand) uncertainty. Financial markets allow firms to insure against uncertainty, leading to a higher degree of specialization and, consequently, to greater productivity gains. This paper takes the opposite direction of Saint-Paul's approach. It asks the question of how the performance of financial markets will affect the adoption of exogenous technological progress.

A survey on the theoretical and empirical developments on the topic of growth and finance can be found in Levine [13]. As argued above, this paper has implications for the interpretation of the positive correlation found empirically between indicators of financial development and growth. King and Levine [10], Levine and Zervos [12], Rajan and Zingales [16], are some examples of the prolific body of literature on the topic.

Concerning the lags in adoption of new technologies, this paper proposes "financial learning" as a new channel for diffusion. Stoneman [20] provides an overview of the diffusion literature. While several dimensions of learning have been emphasized concerning diffusion (Jovanovic and Rousseau [9] is one such instance), the novelty here is the need for financial institutions to adjust to technological change.

The paper also relates to issues concerning equilibria in markets where traders and some trade centralizing institution (a market maker) are asymmetrically informed about the value of objects being traded. Examples of this literature are Kyle [11], and Milgrom and Stokey [14]. This paper relates to those in that the fundamental friction in the economy is the information asymmetry between market participants (entrepreneurs) and financial institutions. The focus on technology adoption leads us to pursue a simpler informational setup here.

3 The Model

There are three types of agents in the economy: savers, entrepreneurs and financial intermediaries called banks. Savers own a perfectly safe technology which grants them a constant income y, $y > 0$; they are risk-neutral and maximize expected discounted utility. In addition to operating the safe technology, savers may choose to perform risk intermediation in the financial market. Their financial technology will be described below. Entrepreneurs run a risky project and face endowment uncertainty; they are strictly risk-averse expected utility maximizers, with Bernoulli utility function $u(\cdot)$.[9] Entrepreneurs and savers are infinitely lived and discount the future with discount factor $\beta \in (0, 1)$. There is an identical mass of savers and entrepreneurs, n, which we normalize to unity. Banks perform financial intermediation between entrepreneurs and savers. Their technology will be described below.

Entrepreneurs operate a risky technology. Technologies are characterized by a probability density function (pdf) over output values (the positive real numbers). For simplicity, and without loss of generality, they will assume a very simple structure. Specifically, technologies will have two mass points and share a common probability profile over output realizations. Let the set $\mathcal{O}$ be defined as follows:

$$\mathcal{O} = \{(\theta_i, \theta_j) : \theta_i, \theta_j \in \mathbb{R}_+, \, \theta_i < \theta_j\}.$$

Then, the set $\mathcal{F}$ of all technologies is the set of all probability density functions whose support is an element of $\mathcal{O}$, and where

$$prob\,(\theta_i) = q, \quad prob\,(\theta_j) = 1 - q, \quad \text{for } (\theta_i, \theta_j) \in \mathcal{O},$$

with $q \in (0, 1)$. Let f denote the representative element of $\mathcal{F}$. While $\mathcal{F}$ contains all technologies that could possibly be operated, only a strict subset of $\mathcal{F}$ is known at a given

[9] The assumption of risk-neutrality for savers is made for simplicity; the results would be qualitatively similar if one considered risk-averse savers, instead, but risk-aversion would come at a substantial cost in terms of the tractability of the model.

moment in time. $\mathcal{F}_t$ denotes the technologies that entrepreneurs know how to operate in period t. As time passes, Nature reveals new technologies to economic agents.[10] It follows that $\mathcal{F}_{t+1} \supseteq \mathcal{F}_t$.

In this paper, we will consider the process of technology adoption as a new technology becomes available, and how such a process is affected by the nature and depth of financial intermediation. At the beginning of time, only f_1 is known: $\mathcal{F}_0 = \{f_1\}$. Technology f_1 has support over $\Theta_1 = \{\theta_1, \theta_3\}$. Later, in period $t > 0$, as a result of technological progress, f_2 becomes available: $\mathcal{F}_t = \{f_1, f_2\}$. Technology f_2 has support over $\Theta_2 = \{\theta_2, \theta_4\}$. For the remainder of the paper, we will assume that the subindexes reflect an ordering in terms of magnitudes:

$$\theta_i > \theta_j \Longleftrightarrow i > j.$$

Technologies f_1 and f_2 are independent.

It is appropriate to think of f_1 as an earlier generation technology. The idea of technological progress suggests that newer technologies should allow higher output levels to be attained, and this is indeed the case when we compare f_2 with f_1. Technological progress need not be associated with first-order stochastic dominance, however, but as this assumption makes it more likely that entrepreneurs prefer f_2 relative to f_1, it makes the results sharper.

Contingencies in $\mathcal{O}$ represent sector-wide shocks. That is, all entrepreneurs operating a given technology f_l whose support is (θ_i, θ_j) will face a common output draw (all receive θ_i, or else all experience θ_j); there is no idiosyncratic risk in this economy.

Entrepreneurs are identical concerning their ability to run the old technology f_1. If they choose to operate f_1, their income will be θ_1, with probability q, and θ_3, with probability $1 - q$.

Concerning f_2, entrepreneurs are characterized by a skill level $s_i \in S$, $S = [1, \hat{s}]$. The number s_i is the marginal product of individual i in the risky sector. Comparing individuals i and j for whom $s_i > s_j$, if both adopt f_2, output for individual i will be $s_i\theta_l$, for $\theta_l \in \Theta_2$, and only $s_j\theta_l$ for individual j. The distribution of skill over S is given by the pdf $g(\cdot)$. We will interpret $g(s)$ as the number of entrepreneurs whose skill is s. Let $\mathcal{G}$ be the set of all pdfs with support in S. The density $g(\cdot)$ and the support set Θ_2 are jointly drawn by Nature in period t, when f_2 is made available, according to pdf

[10] Agents do not affect the rate of technological progress. That is, the stochastic process by which Nature reveals new technologies in period t relative to those known in period $t-1$ is know by the agents but unaffected by their choices.

$f(\cdot) : \mathcal{G} \times \mathcal{O} \to [0, 1]$. We further denote by $\bar{s}$ the highest real number assigned positive density by $g(\cdot)$, $\bar{s} \leq \hat{s}$. The number $\bar{s}$ defines the highest skill level associated with the particular technology to which density $g(\cdot)$ corresponds. Further, we assume $g(s) > 0$ for all $s \leq \bar{s}$.

Since savers and entrepreneurs experience different risk profiles, they could engage in mutually beneficial insurance arrangements. As mentioned, there are two types of agents who can perform financial intermediation: banks and individual savers, provided the latter choose to take up the intermediation activity. Insurance is provided through the posting of contracts. Consider the case when only f_1 is known. Then, financial intermediaries complete the insurance markets by posting prices over the contingencies in Θ_1 and buying or selling claims over these contingencies. For each transaction (buying or selling), intermediaries bear a cost: $c_s^{\text{int}} \geq 0$ for savers, and $c_b^{\text{int}} = 0$, for banks. Should a new technology become available, intermediaries can learn some features of this technology after paying the cost c_j^{learn}, $j = b, s$. Intermediation and learning costs satisfy $c_b^{\text{learn}} > c_s^{\text{learn}} + c_s^{\text{int}}$. Therefore, savers have a comparative advantage in learning, whereas banks have a comparative advantage performing intermediation over known technologies.

4 Equilibrium with One Technology

We start at time 0, when only f_1 is known by economic agents. We assume that all the agents (entrepreneurs, savers and banks) are fully and symmetrically informed about the features of this technology (that is, everybody knows the support of f_1 and how productive entrepreneurs are in its operation).

We model the banking sector as a machine, one who can only operate one type of financial contract. Specifically, banks buy or sell contingent claims over states of the world, which they do after posting a price vector on such contingencies. For example, at time 0, since only f_1 is known and operated, banks trade contingent claims over Θ_1 after posting the price vector p:

$$p : \Theta_1 \to \mathbb{R}_+.$$

The interpretation of $p(\theta)$ is the price at which banks promise to trade contingent claims on the state of the world θ. At price $p(\theta)$, they will buy or sell any amount of contingent claims that entrepreneurs or savers demand of them. After uncertainty is resolved, if θ materializes, banks will give one unit of the consumption good to an agent who bought one contingent claim on the state of the world θ, and will collect an identical amount from agents who hold short positions on the same contingency. The price vector $p(\cdot)$ is chosen to satisfy market clearing for contingent claims. This reduced form treatment of the banking sector is a convenient description of a fully competitive financial sector with constant returns to scale and small intermediation costs (implicitly assumed zero as there are no intermediation margins: banks buy and sell contingent claims at the same price $p(\theta)$).

Savers could take up financial intermediation as well, and offer the same contingent contracts to entrepreneurs. However, given the cost $c_s^{\text{int}} \geq 0$ they face for each transaction, competition from the banking sector would force them to make negative profits while doing so. For this reason, savers stay out of the financial market at this stage.

Let $c(\theta) = \{c_e(\theta), c_s(\theta)\}$ denote the consumption of entrepreneurs and savers when the state of the word is θ. Likewise, $a(\theta) \equiv \{a_e(\theta), a_s(\theta)\}$ represents the quantity of contingent claims bought by each type of agent as a function of θ. A consumption allocation $c(\theta)$ is feasible if $c_j(\theta) \geq 0$, for $j = e, s$.

Entrepreneurs and savers maximize utility taking the price vector $p(\theta)$ as given. There is no intertemporal transfer of resources in this economy (saving). When technology f_1 is used, individual entrepreneurs solve:

$$\max_{c_e(\theta)} \{qu(c_e(\theta_1)) + (1-q)u(c_e(\theta_3))\}$$

subject to:

$$\sum_{\theta \in \Theta_1} p(\theta)\, c_e(\theta) \leq \sum_{\theta \in \Theta_1} p(\theta)\, y_e(\theta).$$

Given $\theta \in \Theta_1$, the optimal amount of contingent claims $a_e(\theta)$ is given by the difference $c_e(\theta) - y_e(\theta)$. Savers solve an identical problem, but with the concave function $u(\cdot)$ replaced with linear utility.

We say that the market for securities clears if, given $p(\theta)$,

$$a_e(\theta) + a_s(\theta) = 0,$$

for all $\theta \in \Theta_1$.

Definition 1 *An equilibrium in the economy where only f_1 is known is a feasible allocation $\{c_e(\theta), c_s(\theta)\}$ and a price vector $p(\theta)$, $\theta \in \Theta_1$, such that: given the price vector, the consumption allocation maximizes the utility of entrepreneurs and savers; the securities' market clears.*

The linearity in the utility of savers forces bankers to set the relative price $p(\theta_3)/p(\theta_1)$ equal to the ratio of probabilities across the corresponding states: $(1-q)/q$. (Otherwise, savers would buy or sell short infinite amounts of contingent claims on one of the states $\theta \in \Theta_1$, and force banks to very large negative expected profits.)

We use the normalization $p(\theta_1) = 1$ to define:

$$p \equiv \frac{p(\theta_3)}{p(\theta_1)} = \frac{1-q}{q}.$$

Solving the problem of entrepreneurs, we assume for simplicity that their utility function is logarithmic. Consumption $c_e(\theta)$ is given by:

$$c_e(\theta_1) = q(\theta_1 + \theta_3 p), \qquad c_e(\theta_3) = (1-q)\left(\frac{\theta_1}{p} + \theta_3\right),$$

whereas the corresponding demand functions for Arrow securities are:

$$\begin{aligned} a_e(\theta_1) &= c_e(\theta_1) - \theta_1 = q\theta_3 p - (1-q)\theta_1 \\ a_e(\theta_3) &= c_e(\theta_3) - \theta_3 = (1-q)\frac{\theta_1}{p} - q\theta_3. \end{aligned}$$

Substituting in the price ratio for p, we get:

$$c_e(\theta_1) = \bar{\theta}_1 = c_e(\theta_3),$$

where $\bar{\theta}_1$ equals the expected income of entrepreneurs:

$$\bar{\theta}_1 = q\theta_1 + (1-q)\theta_3.$$

Since savers are risk neutral, we obtain a predictable outcome: entrepreneurs are fully insured against the variability of their income stream by savers. Entrepreneurs have constant consumption in every period, equal to the expected value of their income process.

Finally, we check the feasibility requirement by verifying that the income y of savers is enough to meet the entrepreneurs' insurance demand in any state of the world. Feasibility will only be of concern in the bad state of the world for f_1 entrepreneurs (when θ_1 occurs). We need:

$$y \geq a_e(\theta_1) \Leftrightarrow y \geq (\theta_3 - \theta_1)(1-q). \tag{1}$$

We assume equation (1) is satisfied.

5 Technological Progress

We now go to period t, the period when Nature makes f_2 known to entrepreneurs: $\mathcal{F}_t = \{f_1, f_2\}$.

The fundamental friction in this economy is the asymmetry of information between entrepreneurs and the remaining agents of the economy concerning new technologies. When f_2 is drawn by Nature, entrepreneurs learn its support, Θ_2, the distribution of skill, $g(\cdot)$, as well as their own skill type, $s \in S$. Banks and savers are less knowledgeable about f_2 relative to entrepreneurs: although they know the prior $f(\cdot)$ from which Θ_2 and $g(\cdot)$ are drawn, they do not know the particular realizations of the skill distribution and the technology support set. Further, banks and savers cannot tell apart the skill level of different entrepreneurs. These dimensions in which entrepreneurs are better informed relative to other economic agents reflect two realistic features of the interaction between the financial system and entrepreneurs: as a new technology becomes available, the latter typically know more about its profitability. Further, information asymmetries and adverse selection concerning the talent and ability of individual entrepreneurs are well-known to affect the functioning of credit markets.

Once f_2 becomes available, the set of relevant contingencies (states of the world) becomes

$$\Theta \equiv \{(\theta_1, \theta_2), (\theta_1, \theta_4), (\theta_3, \theta_2), (\theta_3, \theta_4)\}.$$

Although entrepreneurs know Θ, at t, banks and savers only know Θ_t:

$$\Theta_t = \{\{(\theta_1, \theta_i), (\theta_1, \theta_j)\}, \{(\theta_3, \theta_i), (\theta_3, \theta_j)\}\},$$

for $(\theta_i, \theta_j) \in \mathcal{O}$, $(\theta_i, \theta_j) \neq (\theta_1, \theta_3)$.

Potential financial intermediaries also differ with respect to the way in which they *learn* the new technology. Banks learn exclusively from the observation of adopting entrepreneurs. That is, if some entrepreneurs undertake f_2, banks will be able to observe the output they generate. If entrepreneur i undertakes f_2, banks will see total output, $s_i\theta_2$, if θ_2 occurs, or $s_i\theta_4$, should θ_4 take place instead. Banks are further able to remember this information over time: once they observe $s_i\theta_j$, they will know, in all future periods, that individual i produces $s_i\theta_j$ when θ_j occurs. Therefore, if a group of entrepreneurs adopts f_2 before financial intermediation is provided, observation of the outcomes allows banks to learn about the ratio θ_4/θ_2. For this ratio to be learned, banks need to observe output draws for the *same* entrepreneur across different periods t and

$t+j$, $j \geq 1$, corresponding to the two possible draws of θ; say, for example, that θ_2 occurs in t and θ_4 in $t+j$ (or the other way round).

In addition to the observation of output over time, savers have an alternative way of learning. They may choose to pay the cost c_s^{learn} after which they will learn the support of the technology (the numbers in Θ_2), as well as the distribution of skill, $g(\cdot)$.

We first examine the dynamics of technology adoption under the assumption that the cost c_s^{learn} is high enough to prevent savers from learning. In the next section, we relax this assumption.

5.1 Equilibrium without Interim Intermediation

Given that the knowledge of banks is limited to Θ_t, intermediation over f_2 cannot be provided right away. In fact, after observing output generated by f_2, banks would not know which of the two states just occurred, whether it was θ_2 or θ_4. But intermediation over f_1 can be provided as the banking sector remains able to distinguish between θ_1 and θ_3.[11] Therefore, previous to learning the new contingencies in Θ_2, banks are only able to operate the same type of contract they were operating before f_2 was made available.[12]

Provided some entrepreneurs adopt f_2 repeatedly over time, banks will learn about the new technology by observing the output draws. The first time output differs from a previous draw obtained by the same entrepreneur, banks will have learned to distinguish the high from the low state of the world under f_2. The period immediately after this

[11] We assume banks can exclude f_2 adopters from participating in the market for f_1 contingencies. At any rate, in equilibrium this restriction will not be binding: f_2 adopters do not wish to purchase any amount of f_1 insurance.

[12] We ignore any inference over the support of the new technology and/or on the output realization (high or low) that the observation of adoption decisions of entrepreneurs could allow. For example, suppose that θ_2 could in fact be smaller than θ_1. If output were observed to fall below θ_1 for all entrepreneurs, and if entrepreneurs were assumed to behave rationally and nonstrategically, banks could correctly conclude that the low output value of $\theta \in \Theta_2$ had been observed: the high output realization in Θ_2 would have to exceed θ_3 for entrepreneurs to adopt without insurance being provided. While the resulting information environment is indeed contrived, the focus of the model is to study settings where asymmetries of information lead to temporary financial frictions such as market incompleteness. Alternatively, one could think of the analysis as applying to a subset of technologies over which no such inference was possible (the low value of $\theta \in \Theta_2$ is high enough so as to not be fully informative concerning the realization of the low state).

occurs, the contract machine is once again able to post prices over the new contingencies and enforce such contracts. Banks will then announce the price vector:[13]

$$p : \Theta \to \mathbb{R}_+,$$

completing insurance markets. In general, bank intermediation in period $t+j$ is summarized by the price vector $p_{t+j} : \Theta_{t+j} \to \mathbb{R}_+$.

Let

$$c^l_{e,s,t+j} : \Theta_t \times \Theta \to \mathbb{R}_+$$

denote the consumption in period $t+j$ of an entrepreneur with skill s, who chooses to operate technology l in that period. Consumption depends on the state of the world perceived by banks as well as on the true output contingencies. Likewise, we define

$$c_{s,t+j} : \Theta_t \to \mathbb{R}_+$$

as the consumption in period $t+j$ of a saver. Savers' consumption depends on the knowledge of banks, only. Feasibility in consumption requires that consumption of savers and entrepreneurs be positive in all time periods and states of the world. Further, we denote by

$$\tau_{s,t+j} : \Theta_{t+j} \to \{1, 2\}$$

the technology choice of an entrepreneur whose skill is s. If $\tau_{s,t+j} = 1$, this entrepreneur chose to operate technology f_1 in period $t+j$.

We define an equilibrium in this economy as follows.

Definition 2 *An equilibrium in the economy without interim intermediation is a feasible consumption allocation* $\left\{c^1_{e,s,t+j}, c^2_{e,s,t+j}, c_{s,t+j}\right\}_{j=0}^{\infty}$*, a sequence of adoption decisions* $\{\tau_{s,t+j}\}_{j=0}^{\infty}$*, and a sequence of prices* $\{p_{t+j}\}_{j=0}^{\infty}$ *such that: given the prices, the consumption allocation and adoption decisions maximize the utility of entrepreneurs; given the*

[13] In fact, the possibility to distinguish across states of the world and enforce contracts over contingencies in Θ_2 requires additionally that at least one of the entrepreneurs who adopted earlier continues to adopt after prices are posted. This is so since, assuming banks cannot distinguish skill from θ draws in observing output, what they learn is the ratio θ_4/θ_2, not the levels of $\theta \in \Theta_2$. As we will see below, all early adopters optimally choose to continue to adopt after the ratio θ_4/θ_2 is learned. Alternatively, one could assume that the observation of output allows banks to learn how to interpret a signal perfectly correlated with $\theta \in \Theta_2$. In this case, once learning is complete, the signal allows them to offer intermediation irrespective of the identity of adopters. Given these arguments, we disregard the issue.

prices, the consumption allocation maximizes the utility of savers; the securities' market clears.

Definition 3 *A steady-state in the economy without interim intermediation is an equilibrium where* $c^1_{e,s,t+j} = c^1_{e,s}$*,* $c^2_{e,s,t+j} = c^2_{e,s}$*,* $c_{s,t+j} = c_s$*,* $p_{t+j} = p$*,* $\forall j \geq 0$*, and where the adoption decisions of individual entrepreneurs remain constant over time.*

We make the following assumption:

Condition 4 *Technologies* f_1 *and* f_2 *satisfy:*

$$q \ln(\theta_2) + (1-q) \ln(\theta_4) < \ln\left(\bar{\theta}_1\right).$$

Condition 4 states that, for the lowest skilled entrepreneur in the economy (whose skill is unity), the old technology with full insurance is preferred to the new one uninsured. If this condition is violated, adoption will trivially take place as soon as f_2 becomes available: the new technology is so productive that the higher income it generates, even for its lowest skilled adopter, outweighs the greater uncertainty prevailing under lack of insurance.

We next characterize equilibria under this environment. Given the linearity of the savers' utility function, prices will always be given by the relative probability across the elements of Θ_{t+j}. Let $t+l$ denote the period (a random variable) when banks learn the technology. In $t+l+1$, intermediation over both f_1 and f_2 will be provided. Since intermediation over f_1 remains possible, f_1 adopters will be able to fully insure in all time periods. Therefore, the consumption of an f_1 adopter in any period $t+j$, $j \geq 0$ is given by $\bar{\theta}_1$, the expected value of output under f_1.

We define the following thresholds. Let s_i denote the skill level of an entrepreneur who is indifferent between the per-period expected payoff from f_2 uninsured and the per-period payoff under f_1 under full insurance:

$$q \ln(s_i\theta_2) + (1-q) \ln(s_i\theta_4) = \ln\left(\bar{\theta}_1\right).$$

Entrepreneurs whose skill is at least as high as s_i are willing to adopt f_2 despite not receiving insurance.

We also define $\tilde{s}_i$, with $\tilde{s}_i < s_i$, as the skill level of an entrepreneur for whom adoption at t under the probability of future insurance (as given by the banks' learning process) leaves him indifferent between adopting f_2 uninsured or sticking to f_1 with full insurance. This skill level satisfies:

$$\left(q\ln\left(\tilde{s}_i\theta_2\right)+(1-q)\ln\left(\tilde{s}_i\theta_4\right)\right)\underbrace{\left(1+\beta+\beta^2\left(q^2+(1-q)^2\right)+...\right)}_{\equiv a}+$$
$$\ln\left(\tilde{s}_i\bar{\theta}_2\right)\beta^2\underbrace{\left(1-\left(q^2+(1-q)^2\right)+\beta\left(1-\left(q^3+(1+q)^3\right)\right)+...\right)}_{\equiv b}=\frac{\ln\left(\bar{\theta}_1\right)}{1-\beta}.$$

The parcels in a reflect the discounted probabilities that learning will not have occurred up to some future period. Learning does not take place for sure in periods t and $t+1$; with probability q^2, the observed values of output corresponded to two consecutive draws of θ_2 and, in period $t+2$, insurance will still not be offered; likewise, with probability $(1-q)^2$, output corresponded to two draws of θ_4 and no insurance will be provided in period $t+2$. The parcels in b reflect the complementary probability, that of learning having already taken place.

There may be three different equilibria in this economy, depending on how $\tilde{s}_i$ and s_i compare with $\bar{s}$. We outline each of the possible cases below.

Case 1: $s_i \in (1, \bar{s}]$**.** The dynamics are as follows. Entrepreneurs whose skill is at least s_i adopt f_2 at t. No other entrepreneur wishes to adopt as entrepreneurs whose skill is below s_i experience a per-period utility cost associated with the lower expected utility they get under f_2 uninsured relative to f_1 with full insurance.

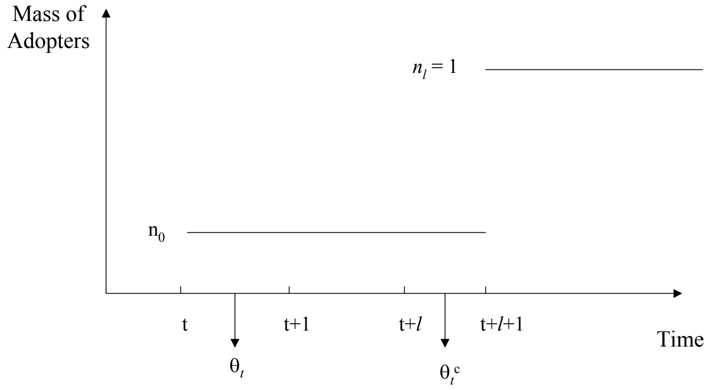
The mass of early adopters, n_0, is given by:

$$n_0=\int_{s_i}^{\bar{s}} g(s)\,ds.$$

Banks observe the output produced by these entrepreneurs over time. In period $t+l$, they learn the difference between high and low output levels under f_2. Starting in period $t+l+1$, banks offer intermediation over Θ. At time $t+j+1$, all entrepreneurs operate f_2 since $s\bar{\theta}_2>\bar{\theta}_1$ for all $s\in S$. The steady-state mass of adopters, n_l, is identical to the mass of entrepreneurs (assumed to be 1). Adoption dynamics are described in Figure 1.

Consumption of f_1 adopters during the learning period is always identical to $\bar{\theta}_1$. Those who adopt f_2 before intermediation is provided simply consume the output they generate. The steady-state is reached in period $t+l+1$, where all entrepreneurs adopt f_2 starting then and forever, and consume $\bar{\theta}_2$ in every period. Feasibility is assumed throughout.

Figure 1: Adoption Dynamics without Intermediation (Case 1)



Case 2: $s_i > \bar{s} \geq \tilde{s}_i$**.** Early adoption will be carried out by one entrepreneur only, whose skill is at least $\tilde{s}_i$. Given that one entrepreneur is adopting the new technology, and since early adoption entails a per-period utility cost previous to intermediation being offered, all other entrepreneurs prefer to stick to f_1 until f_2 is learned. Further, the adoption of one entrepreneur is all that is required for banks to learn f_2. In period $t + l + 1$, all entrepreneurs adopt f_2. The adoption dynamics are qualitatively similar to the previous case, although now early adoption is restricted to the bare minimum. There are multiple equilibria as far as the identity of the early adopter is concerned. However, all equilibria have the same outcome concerning adoption decisions (a single entrepreneur adopts f_2 between t and $t + l$).

Case 3: $\tilde{s}_i > \bar{s}$**.** In this case, there will be no adoption: the skill level that would make an entrepreneur indifferent between adopting or sticking to f_2, $\tilde{s}_i$, is too steep relative to the economy's endowment, $\bar{s}$.

Discussion. This section illustrates the complementarity between technology adoption and financial innovation, the latter understood as the broadening of the set of (insurance) contracts offered to economic agents. Despite the advantages of the new technology (recall that f_2 dominates f_1 in the first-order stochastic sense), entrepreneurs whose skill is too low will not adopt f_2 prior to financial intermediation being offered. Only once learning occurs and insurance is offered will the bulk of adoption take place. In case 1, there exist sufficiently high skilled entrepreneurs such that, even prior to being offered insurance, their skill raises the value of output by a sufficient amount so as to compensate for the increased volatility of their consumption profile. This group of very able individuals forms the mass of early f_2 adopters. In case 2, however, no such individuals are around. In this case, early adoption is undertaken by an entrepreneur who experiences an expected utility loss in every period previous to being granted insurance; however, the skill level of an early adopter is high enough for the probability of future insurance to prompt adoption. In this scenario, it is the prospect of future insurance that justifies early adoption. Finally, in case 3, despite a better technology being available, no entrepreneur is sufficiently skilled to willingly bear the cost of early adoption. As a consequence, no learning takes place and insurance will never be offered. In turn, this causes adoption not to take place at all.

Concerning cases 1 and 2, it is worthwhile to notice the feedback from adoption to finance and then back to adoption. Early adoption enables learning, making it possible for financial institutions to offer insurance; in turn, insurance boosts adoption further as entrepreneurs can take full advantage of the new technology.

We next consider the case when the costs c_s^{learn} and c_s^{int} are low enough for savers to act as insurance providers. For simplicity, we assume $c_s^{\text{int}} = 0$.

5.2 Equilibrium with Interim Intermediation

The interaction between savers and entrepreneurs is described by the following sequential game. Savers know the distribution $f(\cdot)$ with which Nature jointly draws Θ_2 and $g(\cdot)$. In the current scenario, we assume that, conditional on the prior $f(\cdot)$, they choose to pay the learning cost c_s^{learn}; they simultaneously offer contracts to entrepreneurs, conditional on the technology support Θ_2 – to be subsequently drawn by Nature. As will be argued below, the contract can be summarized by the expected cost of transfers to be made to an entrepreneur whose skill is s, denoted $c(s, \Theta_2)$. Despite not observing skill directly, savers observe output. Although output need not always be completely informative regarding skill, contracts are designed to elicit a skill report from the entrepreneur in an incentive compatible way.[14] This enables the menu of contracts to be formulated in terms of skill. If savers do not which to offer intermediation to particular skill levels in S, the contract will specify zero transfers at all times.[15] Nature draws the skill distribution and the technology support set, $g(\cdot)$ and Θ_2, according to pdf $f(\cdot)$. Savers and entrepreneurs learn the realization of these objects. Entrepreneurs further learn their individual skill type. Having observed the menu of contracts offered to them and Nature's move, entrepreneurs decide which technology to operate. Production takes place and skill is revealed (see section 5.2.1, below).

The menu of contracts offered, together with adoption decisions and subsequent skill revelation, determine the properties of a matching process between entrepreneurs and savers. For example, if all entrepreneurs are offering identical contracts to entrepreneurs, then matching is random and entrepreneurs who adopt f_2 simply distribute themselves randomly through savers. The properties of the matching process will be described below. Once entrepreneurs and savers are matched, transfers are made according to the promised contracts and payoffs follow. The sequential game between savers and entrepreneurs is illustrated in Figure 2.

We solve for the equilibria of this game by backwards induction. We start when an entrepreneur and a saver are matched together and the saver has promised $c(s)$ to the entrepreneur.[16]

5.2.1 Properties of the Optimal Contract Given $c(s)$

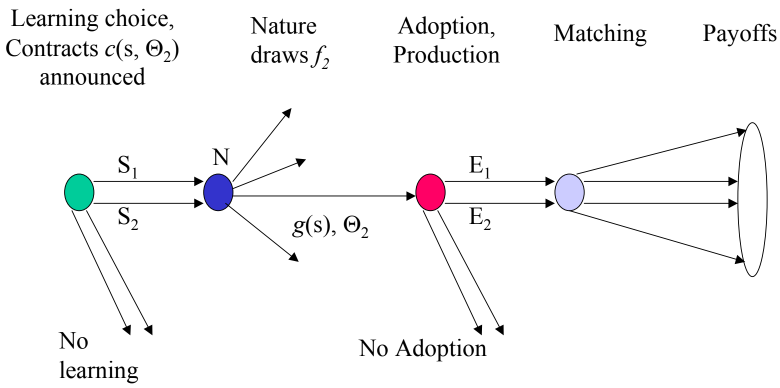
The number $c(s) \in \mathbb{R}$ is the expected amount of transfers to be given to the entrepreneur. Since savers are risk-neutral, they do not care about the particular path of transfers over time provided they do not exceed $c(\cdot)$ in expectation. Without loss of generality, we assume transfers are chosen to maximize the expected utility of the entrepreneur, subject to being incentive compatible concerning the report of skill. In fact, competition would

[14] To simplify matters, we will in fact assume below that, once θ_2, θ_4 and $\bar{s}$ are known, output is indeed fully informative regarding skill.

[15] In the notation used below concerning the expected transfers associated with a contract, a contract specifying zero transfers in expectation is indistinguishable from the intention of excluding that particular entrepreneur. The distinction between the two cases could be accommodated through more dense notation; although not losing sight of the difference, we choose not to use more involved notation for simplicity.

[16] In what follows, provided no ambiguity results, the argument Θ_2 will be omitted from all functions.

Figure 2: Dynamic Game Between Entrepreneurs and Savers



force savers to provide the best possible contract to entrepreneurs for any given $c(s)$. Savers provide insurance for a length of time of $t+l$ periods; that is, up to (and including) the period banks learn the new technology. Given the comparative advantage of banks in intermediation, once they have learned the new technology, they can offer insurance at a lower cost for entrepreneurs and drive savers out of the insurance market.

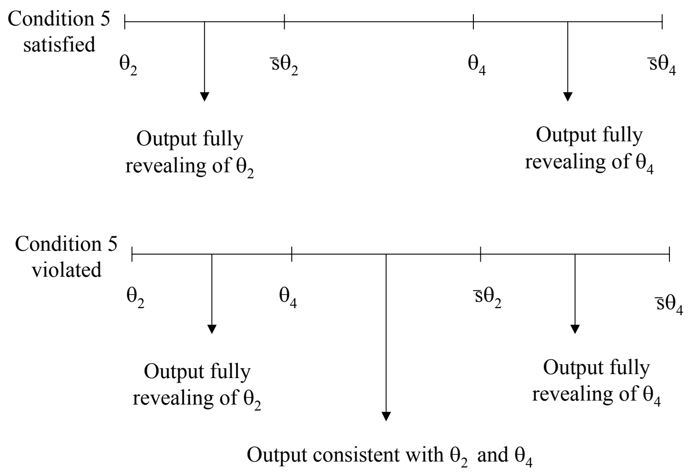
We make the following assumption:

Condition 5 *The numbers θ_2, θ_4, and $\bar{s}$ satisfy:*

$$\theta_4 > \bar{s}\theta_2.$$

Condition 5 ensures that output is fully informative regarding the entrepreneur's skill. Notice that the complete range of output values is the interval $[\theta_2, \bar{s}\theta_4]$. When the low shock θ_2 occurs, feasible output values fall in the interval $[\theta_2, \bar{s}\theta_2]$. When the high shock takes place, output is contained in $[\theta_4, \bar{s}\theta_4]$. Suppose that condition 5 did not hold. That would imply that these two intervals overlap. Consequently, despite the acquired knowledge of the values of θ_2, θ_4 and $\bar{s}$, transfers would have to be designed in an incentive compatible way in order to elicit a skill report from the entrepreneur

Figure 3: Informativeness of output draws



when output fell in the interval $[\theta_4, \bar{s}\theta_2]$. We choose not to consider this possibility for simplicity. The two alternatives are illustrated in figure 3.

Each contract is characterized by four transfers values (we omit making the skill level an explicit argument for notational simplicity): τ_{0L}, τ_{lL}, τ_{0H} and τ_{lH}. Transfer τ_{0L} is the (possibly negative) transfer made to the entrepreneur should low output be observed first. This transfer will be continued for as long as output realizations remain constant. When output takes the complementary value $s\theta_4$, in period $t+l$, transfer τ_{lL} will be provided. The contract ends with this last transfer as $t+l$ coincides with the period banks learn the technology and start offering more competitive insurance contracts to entrepreneurs. Likewise, τ_{0H} is the initial transfer made should high output be observed first, whereas τ_{lH} is the final transfer made once the low output is observed.

Optimal transfers solve:

$$\max_{\tau_{0L},\tau_{lL},\tau_{0H},\tau_{lH}} \left\{ q \left(\frac{\ln (s\theta_2 + \tau_{0L})}{1-\beta q} + \beta (1-q) \frac{\ln (s\theta_4 + \tau_{lL})}{1-\beta q} \right) + \right. \tag{2}$$

$$\left. (1-q) \left(\frac{\ln (s\theta_4 + \tau_{0H})}{1-\beta (1-q)} + \beta q \frac{\ln (s\theta_2 + \tau_{lH})}{1-\beta (1-q)} \right) \right\}$$

s.to:

$$q\frac{\tau_{0L}+\beta\left(1-q\right)\tau_{lL}}{1-\beta q}+\left(1-q\right)\frac{\tau_{0H}+\beta q\tau_{lH}}{1-\beta\left(1-q\right)}\leq c. \tag{3}$$

As expressions (2) and (3) make clear, the optimal contract maximizes the expected utility of the entrepreneur subject to the expected cost of transfers not exceeding c. To understand the way expected utility is computed, notice the following. With probability q, low output is first observed. The contract then specifies that the agent receive τ_{0L} in all time periods up to the moment when high output is observed. Since θ draws are iid over time, the expected utility associated with receiving τ_{0L} given that low output was observed first is:

$$\ln\left(s\theta_2+\tau_{0L}\right)\left(1+q\beta+q^2\beta^2+\ldots\right)=\frac{\ln\left(s\theta_2+\tau_{0L}\right)}{1-q\beta}.$$

Again, given that low output was observed, τ_{lL} will only be given out once to the entrepreneur, and this will take place in the first period that high output is observed (after sequences of repeated θ_2 draws). Given that θ_2 occurred first, the expected utility associated with transfer payment τ_{lL} is:

$$\ln\left(s\theta_4+\tau_{lL}\right)\left(\beta\left(1-q\right)+\beta^2q\left(1-q\right)+\beta^3q^2\left(1-q\right)+\ldots\right)=$$
$$\beta\left(1-q\right)\frac{\ln\left(s\theta_4+\tau_{lL}\right)}{1-\beta q}.$$

The term multiplied by $(1-q)$ follows from similar reasoning, as does the restriction on the expected cost of transfers, in (3).

Let μ be the multiplier associated with (3). First-order conditions are:

$$\frac{1}{s\theta_2+\tau_{0L}}=\frac{1}{s\theta_4+\tau_{lL}}=\frac{1}{s\theta_4+\tau_{0H}}=\frac{1}{s\theta_2+\tau_{lH}}=\mu, \tag{4}$$

$$q\frac{\tau_{0L}+\beta\left(1-q\right)\tau_{lL}}{1-\beta q}+\left(1-q\right)\frac{\tau_{0H}+\beta q\tau_{lH}}{1-\beta\left(1-q\right)}=c. \tag{5}$$

We obtain the intuitive result that marginal utilities will be equated across all possible output realizations and histories: risk-neutral savers fully insure risk-averse entrepreneurs both across time as well as across possible output sequences. These contracts are very similar to first-best contracts in that marginal utilities (and therefore consumption) are kept constant across states. They are, however, not exactly identical to the optimal contract that will be provided by banks once the technology is learned since some rents must be extracted from entrepreneurs to allow savers to recover the learning cost (the expected transfer amount c will be negative). The expected utility attained by entrepreneurs under interim risk-sharing is, therefore, lower than the one they will obtain once the banking sector learns the technology.

Some tedious algebra shows that the consumption of an entrepreneur whose skill is s and who has been assigned an expected transfer amount of c, denoted $C(c, s)$ is:

$$C(c,s) = s\bar{\theta}_2 + \frac{c(1-\beta(1-q\beta(1-q)))}{1-q\beta^2(1-q)}. \tag{6}$$

Consumption equals the level attained under full insurance, $s\bar{\theta}_2$, subtracted of the rents intermediaries must collect (as reflected in the second parcel, since $c < 0$).

The indirect utility function for an entrepreneur whose skill level is s and to whom the assigned expected cost of transfers is c, $U(c, s)$, is given by

$$U(c,s) = \ln(C(c,s)) \frac{1-\beta^2 q(1-q)}{(1-\beta q)(1-\beta+\beta q)}. \tag{7}$$

Using (6) and (7), it follows that $\partial U/\partial s, \partial U/\partial c > 0$ and $\partial^2 U/\partial s^2, \partial^2 U/\partial c^2 < 0$: skill and transfer amounts have a positive but decreasing impact on utility.

We next turn to the matching process by which savers and entrepreneurs meet.

5.2.2 Matching

We assume that a saver cannot finance more than one entrepreneur. Below, we postulate one possible configuration for the matching process. The assumptions made ensure that any saver who wishes to be certain of capturing a client of skill type s may do so by posting the highest value of $c(s, \Theta_2)$, relative to what other savers are offering, and announcing zero transfers to all other types. They assume away search or matching costs, in the same way as those costs are similarly ignored when dealing with transactions with banks, focussing instead on the forces of competition amongst savers.

For general configurations of the menu of contracts offered by different savers, we assume the following. First, we consider the intersection of the skill sets of skill values for whom contracts are offered and the skill values of adopting entrepreneurs. Matching takes place sequentially and from lowest to highest skill. Entrepreneurs whose skills correspond to the offered contract types are matched first with the saver who offers them a cheaper contract, next to the second best saver and so on. Once a saver is matched with an entrepreneur of a given skill type, he will no longer be assigned to other types. Individual entrepreneurs with a common skill s have an equal chance of being matched with any one saver who has offered contracts for their type. If there are fewer savers than entrepreneurs for a given type, and after the first round of matching ends, the remaining entrepreneurs are randomly matched with the remaining savers. As argued earlier, by offering the best contract over a particular skill type and zero transfers for all other skill values, a saver is certain of getting a client of the skill type for which he posted the contract. Knowledge of the matching process allows savers to compute the probabilities with which they will get different skill types as clients (together with the strategies of other savers and the adopting strategies of entrepreneurs); likewise, they allow entrepreneurs to compute the probability of matching with particular savers (again given the strategies of other players).

Consider a particular skill type s who is offered insurance. Suppose that, as the outcome of the matching process, the number of savers assigned to insure this skill type is n_s^i while the number of adopting entrepreneurs of the same type s is $n_e(s)$. Then, the probability that any individual entrepreneur will get insurance is:

$$\min\left\{\frac{n_s^i}{n_e(s)}, 1\right\}.$$

The probability for an entrepreneur with skill s of getting insurance is, therefore, weakly decreasing with the number of adopting entrepreneurs of the same type, $n_e(s)$. If there are more savers than entrepreneurs, for the latter, the probability of being matched with one saver is unity. If savers are offering identical contracts, the probability of not finding a client is $1 - n_e(s)/n_s^i$.

The assumptions of sequential (ascending order) matching is innocuous; other forms of matching (randomizing across skill levels, for example), would deliver identical results in what concerns the equilibrium outcome of this sequential game.

5.2.3 Equilibrium

We consider the adoption choices of entrepreneurs, confining attention to subgame perfect, pure strategies. All proofs are given in Appendix A. Entrepreneurs choose to adopt f_2 provided their expected utility from doing so exceeds their outside option. Given a menu of contracts posted by savers and the adoption choices of other entrepreneurs, in computing their expected utility, they weigh $U(c(s), s)$ according to the probability of matching with individuals savers and getting the corresponding announcements $c(s)$. Optimal adoption decisions of entrepreneurs are Nash-equilibria of this proper subgame. Nash-equilibria always exist, although they need not be symmetric. (That is, entrepreneurs with the same skill s may make different adoption choices.)

Lemma 6 *All Nash-equilibria in adoption decisions have the same outcome. That is, the number of adopters of skill s is identical across equilibria.*

Given the requirement of subgame perfection in adoption, and the menu of contracts posted by all savers, it is possible for an individual saver to compute the participation decisions of entrepreneurs. Together with the assumptions on the matching function, taking the strategy of other savers as given, individual savers may therefore compute all the elements of the stochastic "demand" function they will face: the probability with which they will match with particular types of entrepreneurs, and how these probabilities depend, in turn, on that saver's particular strategy, as well as the profit associated with each particular match.

Let $p\left(s, c\left(s, \Theta_2\right), c_-\left(s, \Theta_2\right)\right)$ denote the probability of a saver being matched with an entrepreneur of skill s. This probability depends on his own offers of contracts, $c\left(s, \Theta_2\right)$, those of his competitors, $c\_\left(s, \Theta_2\right)$, and the matching process. The objective function of individual savers is to:

$$\min_{c(s,\Theta_2)} \int_{\mathcal{G}} \int_{\mathcal{O}} c\left(s, \Theta_2\right) p\left(s, c\left(s, \Theta_2\right), c_-\left(s, \Theta_2\right)\right) f\left(z\right) dz, \tag{8}$$

subject to

$$U\left(s, c, \Theta_2\right) \geq out\left(s, \Theta_2\right) \text{ if } c\left(s, \Theta_2\right) \neq 0. \tag{9}$$

That is, savers seek to minimize the expected value of transfers made to entrepreneurs. Constraint (9) imposes that, for skill levels to whom intermediation is effectively offered (transfers are different from zero), the expected utility granted to those entrepreneurs must exceed their outside option. Naturally, savers will choose not to learn the technology if the expected value of $c\left(s\right)$, as given by (8), is greater than $-c_s^{\text{learn}}$.

Recall that $U\left(c, s, \Theta_2\right)$ was used to denote the entrepreneur's indirect utility function once optimal contracts were computed, under the knowledge of the true values of θ_2 and θ_4. Individual savers choose the vector $c\left(s, \Theta_2\right)$ taking the choices of other savers as given.

It will be useful to define the following object. Let $\bar{x}\left(s, \Theta_2\right)$ denote the maximum rent that can be extracted from an entrepreneur while still having him operate f_2. The number $\bar{x}\left(s, \Theta_2\right)$ solves:

$$U\left(-\bar{x}, s, \Theta_2\right) = out\left(s, \Theta_2\right).$$

In words, once $\bar{x}(s, \Theta_2)$ is extracted from an agent with skill s, he is indifferent between receiving interim financing or sticking to his outside option. Since f_2 first-order stochastically dominates f_1, and given equations (6) and (7), it follows that $\bar{x}(s, \Theta_2) > 0$ for all values of (s, Θ_2).[17] Further, as utility is increasing with s, it immediately follows that $\partial \bar{x}(s, \Theta_2) / \partial s > 0$: it is possible to extract higher rents from entrepreneurs as their skill increases, while making sure they still choose to operate f_2. The schedule $\bar{x}(\cdot, \Theta_2)$ is kinked at the value s_i, for which the outside option changes from f_1 to f_2. Figure 4 illustrates a possible configuration for $\bar{x}(\cdot)$.

Equilibrium contracts $c(s)$ offered by an individual saver are Nash-Equilibria at this node, where the continuation adoption decisions of entrepreneurs have been computed as described above. We refer to the dynamic game played by savers and entrepreneurs as Γ.

We assume that the learning cost is such that some, but not all savers, will choose to act as insurance providers. We next solve for the equilibrium choice of $c(\cdot)$.

Proposition 7 *Subgame perfect equilibria of the game Γ have a unique outcome. For $s \in S$ such that $c(s, \Theta_2) \neq 0$, $c(s, \Theta_2) = c(\Theta_2)$. Further, let $\underline{s}(\Theta_2, n_s^i)$ denote the smallest skill level still granted intermediation under Θ_2, when there is a mass of n_s^i savers offering insurance. Then, $c(\Theta_2) = -\bar{x}(\underline{s}(\Theta_2, n_s^i), \Theta_2)$ and all entrepreneurs whose skill exceeds $\underline{s}(\Theta_2, n_s^i)$ are offered intermediation. Given the mass n_s^i of savers offering intermediation, $\underline{s}(\Theta_2, n_s^i)$, satisfies:*

$$\int_{\underline{s}(\Theta_2, n_s^i)}^{\bar{s}} f(s, \Theta_2)\, ds = n_s^i. \tag{10}$$

The mass of savers offering intermediation, n_s^i, is uniquely determined by the zero profit condition:

$$\int_{\mathcal{G}} \int_{\mathcal{O}} \bar{x}\left(\underline{s}\left(\Theta_2, n_s^i\right), \Theta_2\right) f(z)\, dz = c^{learn}. \tag{11}$$

[17] The value of $\bar{x}(s)$ is computed by solving:

$$\ln\left(s\bar{\theta}_2 + \bar{x}\frac{(1-\beta(1-q\beta(1-q)))}{1-q\beta^2(1-q)}\right) = \ln(\bar{\theta}_1)$$

for $s \leq s_i$ (skill levels for whom the outside option is to operate f_1), or

$$\ln\left(s\bar{\theta}_2 + \bar{x}\frac{(1-\beta(1-q\beta(1-q)))}{1-q\beta^2(1-q)}\right) = q\ln(s\theta_2) + (1-q)\ln(s\theta_4)$$

for $s > s_i$ (those for whom the outside option is to adopt f_2 without insurance).

Figure 4: Optimal Contract

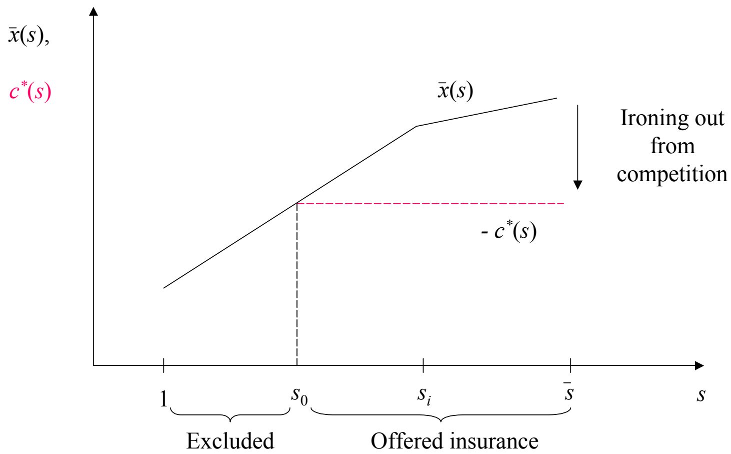


Figure 4 illustrates the optimal contract under the assumption that $s_i < \bar{s}$ and that $x^* \equiv -c^*(\Theta_2)$, is smaller than $\bar{x}(s_i)$. Competition forces savers to a flat schedule $c^*(s) = -x^*$, whereby a common fixed rent is extracted from all entrepreneurs who are given insurance, regardless of their skill type. Further, all entrepreneurs who can afford to pay x^* are granted insurance. There are multiple equilibria concerning the subset of skill types targeted by savers. That is, given that the same rent x^* is going to be charged to each skill type to whom insurance is given, savers are indifferent concerning posting contracts for all values of skill who are given insurance or posting contracts that apply to a subset of those skill values. For example, we could have half the savers offer insurance to the lower skill half of entrepreneurs to whom insurance will be granted, whereas the remaining half of savers offers insurance to the remaining half of skill types. Since competition forces expected profits to zero, equilibria also differ with respect to the identity of those who become insurance providers.

The intuition for these results is as follows. Suppose the equilibrium schedule offered by savers, $x^*(s)$, were not flat. Slopes are not consistent with competition as individual savers would compete for those skill values from whom the highest rents were being extracted by lowering $x(s)$ by a small amount and not posting contracts for any other skill type. By doing so, and given the properties of the matching process, an individual saver would be certain of getting one entrepreneur of the skill type he attracted and earn $x(s)$ with probability one. Likewise, it is not optimal to charge a flat schedule $c^*(s) = -x^*$, while excluding any entrepreneur who can afford to pay that much. The reason is that it would be profitable to target "excluded entrepreneurs" since the fact that they can afford x ensures that at least that much (or more) can be extracted from them. By targeting these left-out entrepreneurs and not posting contracts for any other skill type, a sure profit is attained. As Proposition 7 shows, the only contract that survives is a flat schedule $x^*(s) = x$, which is charged to all of those who can afford to pay it. Notice also that savers do not have an incentive to deviate from this contract and attract other entrepreneurs as, in equilibrium, they would be lowering their expected profits for sure. (Targeting entrepreneurs who cannot afford to pay x^* would necessarily force savers to charge them a lower amount.)

It follows from the properties of the schedule $\bar{x}(\cdot)$ and conditions (10) and (11) that the larger the learning cost, the higher the rent extracted from entrepreneurs and, as a consequence, the lower the mass of interim adopters (only the highest skilled can afford to pay those rents).

Discussion. The relevance of financial intermediation at the interim stage is crucial when $\tilde{s}_i > \bar{s}$. In this case, as seen in the previous section, without financial intermediation no entrepreneur is sufficiently skilled to adopt the new technology on his own, not even in the knowledge that he will be offered insurance once learning is complete. As a consequence, no adoption takes place whatsoever. In this scenario, provided $x^* < x^*(\tilde{s}_i)$, interim intermediation will induce early adoption and, as a consequence, learning, which will further reinforce adoption.

In the cases $s_i \leq \bar{s}$, or $s_i > \bar{s} \geq \tilde{s}_i$, adoption will take place regardless of interim intermediation. Financial intermediation may still have an important impact on the intensity of early adoption. (For example, when $s_i > \bar{s} \geq \tilde{s}_i$, if financial intermediation is granted to a positive mass of entrepreneurs, the mass of early adopters will exceed the corresponding figure when no interim financing is available.) But it is only when $\tilde{s}_i > \bar{s}$ that it becomes determinant in making early adoption possible, as it ensures also that learning will take place.

Associated with interim intermediation is also a discontinuity in the types of contracts and institutions governing the access to finance during the learning and post-learning periods. Before learning is complete, we have a sort of second-best contracts (either because rents must be extracted from entrepreneurs or, in the more general case, when condition

5 is violated and output is not fully informative about skill and skill reports must be induced through second-best incentive compatible transfer mechanisms); further, insurance is provided by institutions whose comparative advantage is learning. Once banks learn the new technology, access to insurance is generalized and supported by first-best contracts, offered by institutions whose comparative advantage is intermediation.

Just as before, when there was no interim financing, we get a feedback effect from early adoption to finance: early adoption allows banks to learn to operate first-best insurance contracts. Once these contracts are offered, financial intermediation boosts adoption further.

5.2.4 Generalizations

Financial innovation has been modeled here as the expansion of the set of contracts offered to economic agents in response to a change in the structure of uncertainty caused by technological progress. Two issues are of extreme importance. The first one is the chronology of events: the enlargement of the set of contingencies over which financial intermediation is performed, from Θ_1 to $\Theta = \Theta_1 \times \Theta_2$, *follows* technological progress. The set of states of the world and associated risk profile of the economy change as a consequence of technological changes. Financial innovation responds to technological news (provided early adoption facilitates learning). The second aspect is the impact of financial innovation on economic growth in general. According to the model, financial deepening reinforces adoption but only to the extent that it conforms to the characteristics of the more recent technologies, and therefore meets the new insurance needs of entrepreneurs. These two implications of the model, in turn, suggest two testable propositions. One is that, if one could measure the exogenous component of scientific progress, such a measure should *cause* financial innovation. The other, that arbitrary financial reform — not targeted at specific technological needs — should not have an impact on economic growth.

The risk-neutrality of savers was a useful simplification of the model. It delivered the equivalence between relative prices and the ratio of probabilities across states and, more importantly, the invariability of prices throughout the adoption path. Allowing for risk-aversion would complicate the analysis somewhat in that the prices along the transition path would depend on the mass of the early adopters. It is doubtful, however, that any additional insight would be achieved by generalizing the analysis to risk-averse savers.

Going back to an interpretation matter stressed in the introduction, although this paper has dealt with the insurance aspects of technological progress, the relationship between financial innovation and technology adoption must be understood as broadly applying to all the features defining the implementation of new technologies. Other important such dimensions are private information and indivisibilities. To the extent that agency problems are associated with the implementation of new technologies, the financial system's response should, once again, be one of broadening the set of contracts offered to economic agents, allowing for the information-constrained implementation of the new technology. The same applies to indivisibilities, where the financial system ought to respond by finding adequate instruments to match the different liquidity needs of agents over time.

This paper also has implications for cross-country differences in technology adoption, closely tied to the merits of a country's institutions. Specifically, more efficient institutions in terms of their learning ability (*i.e.* institutions with low learning costs) may be determinant to foster the adoption of new technologies when a country's skill level is below the threshold that ensures early adoption. Although the relevance of institutions for growth and development is not a new topic in the relevant literature, the learning channel has not been explored before.

6 Conclusion

This paper proposes a novel link between financial innovation and growth through technology adoption. The properties of technology (risk-profile, indivisibilities, private information) determine an optimal set of contracts that allow economic agents to share the surplus associated with its implementation. The friction in this environment is the asymmetry of information regarding new technologies between entrepreneurs and financial intermediaries. The financial sector has an important role in making the adoption of new technologies possible by enlarging the set of financial contracts offered to the public as a response to the characteristics of new technologies. In order to do so, however, financial institutions need to learn about the new technologies. Only the link between risk-sharing and technology adoption has been explored here, although the implications of the analysis generalize in a straightforward way to other dimensions of technology.

The current work is to be interpreted as a first step in what seems to be an area of research with very broad implications. Specifically, the ideas presented here suggest that financial arrangements serve as a support for economic activity and that there would be little or no gain from an arbitrary financial reform, not targeted at the specific requirements of technology.

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A Proof of results in Section 5.2.3

Proof of Lemma 6

Individual entrepreneurs of skill s compete only with other entrepreneurs of the same type for insurance. Consider first the case of entrepreneurs whose skill is offered insurance by some savers after the matching process is taken into account (that is, there were savers offering contracts for these skill values and, after the matching was done, some of the savers were allocated to insurance provision of these skill types). Say that the number of savers allocated by the matching process to offering insurance to skill type s is $n_s^i > 0$. Given the adoption strategies of his competitors and the matching process, an entrepreneur may compute the probability of getting insurance. First, consider skill types who would not adopt on their own. That is, $s < s_i$, implying that the outside option of these entrepreneurs equals $\ln\left(\bar{\theta}_1\right)$. Let $p\left(\tau_{-s}\right)$ denote the probability of getting insurance if an entrepreneur with skill s adopts f_2, given the adoption decisions of the other entrepreneurs of the same skill type. (If different amounts $c\left(s\right)$ are being offered by different savers, then $p\left(\tau_{-s}\right)$ is understood to reflect the probability of matching with each of the different savers; consequently, the term associated with $U\left(c,s\right)$, below, should then incorporate a summation over the different values $c\left(s\right)$ that each s-skilled entrepreneur may encounter. Since the generalization is obvious, it is left implicit for simplicity.) Let $out\left(s\right)$ denote this entrepreneur's outside option. He will choose to adopt f_2 provided:

$$p\left(\tau_{-s}\right)U\left(c,s\right)+\left(1-p\left(\tau_{-s}\right)\right)\left(q\ln\left(s\theta_2\right)+\left(1-q\right)\ln\left(s\theta_4\right)\right)\geq out\left(s\right). \tag{12}$$

Clearly, $p\left(\tau_0\right)=1$ (since there are n_s^i savers offering insurance, the probability of getting insurance is unity for an infinitesimal change in the number of adopters). Further, it will remain at one provided the number of adopters does not exceed n_s^i. $p\left(\tau_{-s}\right)$ becomes strictly decreasing as the number of adopters grows in excess of n_s^i. It asymptotes to zero as the number of adopters goes to infinity.

Given that optimal contracts $c\left(s,\Theta_2\right)$ are constrained to satisfy (9), and that we are considering skill values s such that $s < s_i$, it follows that

$$U\left(c,s\right)\geq out\left(s\right)>q\ln\left(s\theta_2\right)+\left(1-q\right)\ln\left(s\theta_4\right).$$

Since $p\left(\tau_{-s}\right)$ is continuous in the number of adopters, so is the left-hand side of (12). Further, when $p\left(\cdot\right)=1$,

$$U\left(c,s\right)\geq out\left(s\right)$$

whereas, when $p(\cdot) = 0$,

$$q \ln (s\theta_2) + (1-q) \ln (s\theta_4) < out(s).$$

This implies that there exists a unique and well-defined number of adopters, $s_{\max}$, such that:

$$p(\tau_{-s_{\max}}) U(c,s) + (1 - p(\tau_{-s_{\max}})) (q \ln (s\theta_2) + (1-q) \ln (s\theta_4)) = out(s).$$

An entrepreneur will adopt provided the number of other adopters is smaller than $s_{\max}$. There will be multiple equilibria provided $s_{\max}$ is smaller than the number of entrepreneurs of that skill type, $g(s)$. Equilibria always have the same number of s-skilled adopters, $s_{\max}$, but their identity may be any combination of individuals whose skill is s, provided the number of adopters does not exceed $s_{\max}$.

For $s \geq s_i$, entrepreneurs will adopt the new technology regardless of whether or not they are matched with an insurance provider.

For entrepreneurs for whom no insurance is offered, $c = 0$, their adoption decision is independent of what other entrepreneurs do. They will adopt f_2 provided their skill exceeds s_i and stick to f_1 otherwise. ■

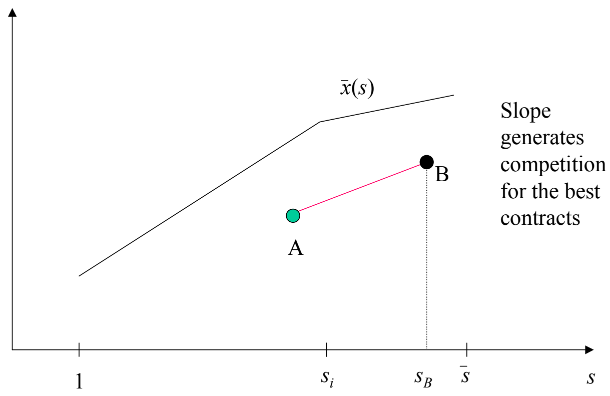
Proof of Proposition 7

We divide the proof in three steps. First, we show that the equilibrium schedule $c^*(s, \Theta_2)$ must be flat. Second, we show that it is not optimal to exclude entrepreneurs who can afford to pay the cost $c^*(s, \Theta_2)$. Third, we demonstrate the other results in the proposition enunciated in the text.

The equilibrium schedule $c^*(s, \Theta_2)$ is flat. Suppose that were not the case. As an example, and without loss of generality, consider the candidate equilibrium schedule represented in figure 5, the line going from point A to point B. Since we are not confining attention to symmetric equilibria, the line AB represents a set of equilibrium contracts offered by savers; however, individual savers may choose to specialize in different segments of AB.

Let S_{AB} denote the subset of S for whom contracts are offered according to line AB. Consider a particular saver posting contracts over a subset $\tilde{S}$ of S_{AB}. Then, it must be the case that the expected profits of this particular saver are strictly lower than B. Let $b > 0$ denote the strictly positive difference between B and the expected profits this saver is earning. But then, this saver offering contracts over $\tilde{S}$ could deviate from offering

Figure 5: Suboptimal contracts: Slope

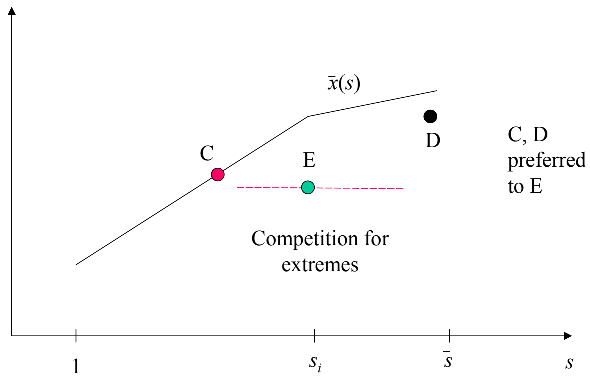


contracts over $\tilde{S}$ and offer $B - \varepsilon$ to skill type s_B, with $\varepsilon < b$ and improve his profits, contradicting the fact that schedule AB is an equilibrium in contract posting strategies. The same reasoning applies to any other nonflat schedules of contracts: savers would compete for the skill levels who were being charged the highest rents and quit posting contracts for other skill types delivering lower rents.

The equilibrium schedule $c^*(s, \Theta_2)$ is such that $-c^*(s, \Theta_2) = x^*$, for all $s \in S$ such that $\bar{x}(s) \geq x^*$. As stated in the text of the proposition, all entrepreneurs who can afford to pay x^* are granted intermediation. Suppose that were not the case. Without loss of generality, consider the candidate equilibrium schedule displayed in figure 6, the horizontal line going through point E. Here, only a strict subset of entrepreneurs who can afford to pay E is being offered insurance. It is immediate to see that the candidate schedule cannot be an equilibrium. Any saver would make a profit by posting a contract associated with point C (or D) and not posting any other contracts. Given that such a contract is not offered by other savers, entrepreneurs whose skills correspond to C (or D) would be sure to enter as they would get insurance with probability one. Clearly, C or D yield higher revenue than E, contradicting the notion that the segment going through E could be an equilibrium.

It follows from the above that the smallest skill type granted insurance in equilibrium

Figure 6: Suboptimal contracts: Extremes



is given by the intersection of the flat schedule $-c^*(s, \cdot)$ and $\bar{x}(s, \cdot)$; further, the highest skilled entrepreneur granted insurance will be the one with the highest endowment in the economy, $\bar{s}$.

Other results. We next address the computation of x^*, which corresponds to the level of the schedule $-c^*(s, \Theta_2)$. We begin by showing that the equilibrium probability of getting a client, for a saver, must be unity. Suppose not. Then, given the above, in equilibrium, we would have a flat schedule x^* charged to entrepreneurs, but for at least some savers, the probability of getting a client would be smaller than unity. Then, a profit could be made by offering a contract charging a rent $\tilde{x} < x^*$ to one of the skill types for whom one of the savers is not certain of getting a client, contradicting the fact that this would be an equilibrium. [Heuristically, this result shows that the value of x^* cannot be too high.]

Conversely, we show that, in equilibrium, it cannot be the case that savers post contracts over a subset $\tilde{S}$ of S and get a strict subset of $\tilde{S}$ as adopting entrepreneurs (clients). Suppose this were the case. The optimal contract would then be a flat schedule at some value x^*. But only a subset of skill types granted intermediation would actually adopt. This would be the outcome of the mass of savers offering contracts being smaller than the mass of entrepreneurs whose skill types are offered insurance contracts. Savers would be certain of getting a client but entrepreneurs would face too low a probability of getting access to a saver and decide not to adopt. Then a profit could be made by posting a single contract for a rent $\tilde{x} > x^*$, targeted at one skill type who is not adopting but who can afford to pay $\tilde{x}$. That is, if that skill type is s, then $\tilde{x} \leq \bar{x}(s)$ must hold. Since one saver would be targeting skill type s exclusively, one entrepreneur of this skill type would now be certain of getting insurance. He would adopt provided $\tilde{x} < \bar{x}(s)$, granting a sure benefit to the saver who posts this contract over the preceding value x^*. This contradicts the fact that the schedule x^* is an equilibrium. [Heuristically, this result shows that the value of x^* cannot be too low.]

The two previous results imply that, in equilibrium, the mass of savers will be identical to that of adopting entrepreneurs. Given the mass n_s^i of savers offering intermediation, it follows that the mass of adopting entrepreneurs must also equal n_s^i. Since interim intermediation targets the highest skilled, the lowest adopting skill-type, for technology Θ_2, $\underline{s}(\Theta_2, n_s^i)$, is found by solving:

$$\int_{\underline{s}(\Theta_2,n_s^i)}^{\bar{s}} f(s,\Theta_2)\,ds = \int_{\underline{s}(\Theta_2,n_s^i)}^{\bar{s}} g(s)\,ds = n_s^i. \tag{13}$$

It has been shown above that the least able entrepreneur will be charged his indifference rent $\bar{x}(\underline{s}(\Theta_2, n_s^i))$. It follows from the properties of the schedule $\bar{x}(\cdot,\Theta_2)$ and from equation (13) that the indifference rent $\bar{x}(\underline{s}(\Theta_2, n_s^i))$ depends negatively on the mass of savers, n_s^i: $\partial\bar{x}(\underline{s}(\Theta_2, n_s^i))/\partial n_s^i < 0$.

It has also been shown that each saver will get a client with probability one and, consequently, will collect exactly that amount with certainty. Expected profits of savers are then the expectation over different technologies Θ_2 of $\bar{x}(\underline{s}(\Theta_2, n_s^i), \Theta_2)$. Expected profits therefore equal:

$$\int_{\mathcal{G}}\int_{\mathcal{O}} \bar{x}\left(\underline{s}\left(\Theta_2, n_s^i\right), \Theta_2\right) f(z)\,dz.$$

Competition forces expected profits to be zero. Given the assumption that the equilibrium mass of insurance providing savers is interior, the continuity of $\bar{x}(s,\Theta_2)$ with respect to skill for all $\Theta_2 \in \mathcal{O}$, and the fact that $g(s) > 0$ for all $s \leq \bar{s}$, the equilibrium mass of savers is uniquely determined from:

$$\int_{\mathcal{G}}\int_{\mathcal{O}} \bar{x}\left(\underline{s}\left(\Theta_2, n_s^i\right), \Theta_2\right) f(z)\,dz = c_s^{\text{learn}}. \blacksquare$$

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