Selection Advantage of Corporate Venture Capitalists and Its Welfare Effects

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Abstract

We develop a theoretical framework for corporate ventures where corporations' *know-how* gives them an advantage over regular financiers in identifying profitable projects. Corporations and venture capitalists compete to fund entrepreneurs in an environment featuring risk, ad-verse selection, and limited liability. The expected surplus of each project is independent of the financier and the efficient scale of each project differs among entrepreneurs. We characterize the optimal financial contracts arising in equilibrium and use this characterization to explore the effect corporations' knowledge has in this environment. We show that the presence of corporations in the financial market could be detrimental to welfare when corporations' selection advantage is small. When large, corporate venture capitalists' knowledge reduces the extensive margin inefficiency arising from adverse selection, meaning less socially inefficient projects are enacted. We also show that increasing the depth or breadth of corporations knowledge leads to higher aggregate gains.[1]

JEL classifications: D86, O32, O36, G39, L24

Keywords: Adverse selection, Entrepreneurial finance, Corporate venture capital

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1 Introduction

In the Open Innovation paradigm, coined by Chesbrough (2003), knowledge flows across firm borders, generating new opportunities. Corporate venture capital (CVC) initiatives aim to leverage corporations' *know-how* and synergies to finance innovative enterprises, distinguishing themselves from standard private venture capitalists (PVCs).

Gompers and Lerner (2000) and Chemmanur et al. (2014), among others in the empirical literature on CVC, have identified two main drivers of corporations' advantage over regular financiers: corporations enhance the productivity of their funded start-ups (treatment effect), and corporations are better at identifying promising start-ups (selection effect). However, there is little understanding of the aggregate effects of CVC's introduction into the broader start-up innovation ecosystem.

Expanding our understanding of this topic is crucial. Policymakers have recently pushed to promote corporate venture initiatives, supported by the advantages identified by the empirical literature. But the rationale for such intervention depends critically on the market environment (agents and frictions) in which those CVCs advantages interact and shape economic aggregates and welfare.

To begin with, the mere introduction of new lenders without any advantage can increase welfare by increasing market competition. The seminal paper on R&D financing of Aghion and Tirole (1994) stresses that giving more bargaining power to researchers vis-a-vis investors leads to more efficient outcomes.

Akcigit et al. (2019) find and cite evidence of the treatment effect and use it to inform an endogenous growth model, obtaining significant welfare gains from the presence of venture capitalists (VCs). Their result is not surprising, as VCs' involvement in financing start-ups increases surplus per start-up, thus enhancing utilitarian welfare.

On the other hand, if corporations' advantage comes solely from the selection effect, the welfare effects of CVCs' entering the market are not straightforward. Corporations may just cream-skim the market, funding start-ups that would have been financed by PVCs in their absence and likely driving PVCs into less profitable and less socially valuable projects. In fact, Lester et al. (2015) find that reducing adverse selection with a signal may be detrimental to welfare in highly competitive environments.

We focus on the case where corporations' advantage comes solely from their being better at identifying profitable start-ups and where competition among financiers is of the Bertrand type, leaving all bargaining power to entrepreneurs.

While those may seem very harsh assumptions against the potential benefits of CVCs, we argue that they are not far from reality. Since the 2000s, and particularly in the last decade, competition in the venture capital market has increased significantly, with multiple actors like angel investors and private equity firms joining the traditional PVCs in financing early-stage entrepreneurship. Lerner and Nanda (2020) pointed out how the *spray-and-pray* approach, in which PVCs finance a large number of start-ups knowing that only a few would be profitable, took over in the last few decades. More financiers willing to fund a higher number of younger start-ups gave additional relevance to competition and information frictions.

On the other hand, the hidden qualities of an entrepreneur(ship) not only create the pervasive adverse selection problem in the start-up financing market, but they also pose a challenge for the treatment-vs.-selection effect empirical identification. Every variable of a start-up before funding that is observable to the researcher, was also observable to the VC, hence the selection process is very endogenous. Crucially, there are many *soft-skills* perceivable for a VC during in-person interactions with the start-up founders and team that could be correlated with future outcomes and thus with selection. Work using advanced econometric techniques has been able to overcome this hurdle for PVCs; see Rin et al. (2013) for a discussion. However, the challenge for CVCs is compounded by the fact that profits accrue to the corporate not only from the financial outcomes the start-up but also from a direct effect on the corporation's balance sheet (synergies), and by the necessity of identifying an advantage of CVCs over PVCs.

We follow the environment described in a companion paper, Hernandez and Wills (2019), where we set up an environment featuring risk, adverse selection, and limited liability in which VCs compete to lend entrepreneurs. That paper characterizes the unique non-linear optimal contracting equilibrium and identifies an extensive margin inefficiency that leaves room for potential welfare gains from interventions. In this paper, we add CVCs into that environment and explore the effect corporations' knowledge has there.

We show that the presence of corporations in the financial market could be detrimental to welfare when their selection advantage is small, and high-quality start-ups are scarce. However, when the CVC's selection advantage is large, their knowledge reduces the extensive margin inefficiency arising from adverse selection, meaning less socially inefficient projects are undertaken.

In what follows, we first describe Hernandez and Wills (2019)'s basic environment. Entrepreneurs are endowed with an idea of quality $\theta \in [0, 1]$ (ability), but they do not have any wealth. The value of θ is private information, drawn from a known distribution $G(\theta)$. If entrepreneurs decide to realize their idea, the probability of success depends jointly on its quality and the amount of capital invested, which needs to be provided by a financial intermediary. The entrepreneur can always discard the idea and take its outside option, which provides benefits w with certainty. Two types of financial intermediaries, private venture capitalists and corporations, compete for the projects by offering contracts. The contracts stipulate the amount to be invested, and repayments in case of success and failure. In the latter case, the venture produces zero output and a limited liability restriction prevents the contracts from demanding any payment from the entrepreneurs to the financiers, but not from the latter to the former.

In this environment, financiers will compete fiercely for the best entrepreneurs. In equilibrium, this results in zero aggregate profits for the intermediaries, but the steepness of incentives is bounded below by the limited liability constraint. The expected surplus of each project is independent of the financier and, in equilibrium, all realized projects are funded at their efficient scale. As it turns out, these two observations imply that the expected surplus per project must grow faster than entrepreneurs' expected utility whenever the financiers expect to make non-negative profits with a particular start-up. As a result, there must be cross-subsidization from higher-quality projects to lower-quality realized projects in any equilibrium. It also yields that socially inefficient projects, those whose expected surplus is below the outside option, must be realized because the lowest type that accepts a contract has an expected utility exactly equal to the outside option, and financiers must be losing money with that project.

To that setup, we introduce selection advantage for corporations as a private signal (m), that PVC do not receive. For simplicity, m can take two possible values for each entrepreneur: high and low. The distribution of types conditional on a high signal $G(\theta|m = high)$ dominates (in the Monotone Likelihood Ratio sense) the one conditional on a low signal $G(\theta|m = low)$, and this is public knowledge. The above implies that, as quality increases, the likelihood of receiving a good signal increases as well.

Once we introduce CVCs, the market splits into two. The high-signal market will be serviced only by CVCs because, not knowing the value of the signal, PVCs cannot compete without attracting too many bad-quality entrepreneurs. The low-signal market will be serviced by PVCs and CVCs acting as equals, as PVCs correctly infer they are facing start-ups who received a low signal. In equilibrium, obtaining funds from a CVC is a *stamp-of-approval* indicating ventures are more likely to succeed. This is consistent with findings in the literature, like those of Gompers and Lerner (2000) and Chemmanur et al. (2014).

In this environment, and because there are no intensive margin inefficiencies, utilitarian welfare depends on i) the quality of the lowest entrepreneurship financed, which is always below the one of the lowest socially efficient project, and ii) the relative scarcity of socially efficient projects. We find that corporate venturing initiatives could be detrimental for welfare when the selection advantage of CVCs is small and high-quality entrepreneurs are scarce.

In contrast, when selection advantage is large enough, the knowledge of corporate venture capitalists reduces the extensive margin inefficiency, meaning that less socially inefficient projects are enacted in equilibrium. Numerical simulations show that increasing the depth or breadth of corporations knowledge leads to higher aggregate gains.

The rest of the paper is organized as follows. We finish this introduction with a brief review of the related literature. In Section 2, we describe the economic environment in detail. Then, Section 3 characterizes the equilibrium, and we perform welfare analysis in Section 4. Section 5 presents results on increasing the depth and breadth of the corporate selection advantage. Finally, Section 6 concludes and discusses potential avenues for further research.

Related Literature

This paper relates to the extensive body of literature studying asymmetric information in financial markets, going back to the seminal paper of Stiglitz and Weiss (1981). In their framework the market unravels, the interest rate cannot clear the credit market because of a standard "lemons" problem, and there is credit rationing. Subsequent papers allow the financial intermediaries to use other tools to screen borrowers' types.

In particular, we relate to a strand of papers that has departed from the Stiglitz and

Weiss (1981) result by allowing intermediaries to screen borrowers using the size of the loan; a debt contract is then a pair of interest rate and loan size. Milde and Riley (1988) propose a setup where entrepreneurs have access to a project with risky returns. As in this paper, the expected return of a project depends on both the borrower's type and the size of the loan. The interaction between type and loan size in the project's payoff allows separating types using interest rate-loan size menus. The outcome, however, depends strongly on the specific function mapping the type and loan size to the return of the project: in some cases higher quality entrepreneurs take bigger loans accompanied by higher interest rates, but in other cases they take smaller loans and pay lower interest rates. They focus on the intensive margin: in their framework projects will not be funded to their optimal, full-information size because of a signaling distortion as in Riley (1975). Following the standard practice in the growth literature, we use a multiplicative productivity function *a-la* Cobb-Douglass, shifting the focus to the extensive margin: all projects are undertaken at their optimal scale, but some are socially inefficient.

Chari et al. (2014) develop a model where screening contracts are unrestricted. Their environment features adverse selection between informed sellers and uninformed buyers. In a subsequent paper, Lester et al. (2015) introduce imperfect information coming from search theoretic frictions. The latter feature allows them to do comparative statics on the degree of imperfect competition and how it interacts with the severity of adverse selection. As in our environment, they find that increasing the degree of competition or information may reduce welfare. However, in their framework all trading is welfare-enhancing, while in our case socially inefficient projects are available and in equilibrium some of them are undertaken.

This paper also relates to a long line of work on the financing of innovation. A first strand focuses on moral hazard issues and contracting and corporate governance structures designed to mitigate them.[2] Aghion and Tirole (1994) explain how the split of property rights between researchers and financiers affects innovation outcomes. They find that moral hazard is mitigated and efficiency is achieved when researchers have all the bargaining power. Building on their result, we assume perfect competition among financiers to give all bargaining power to entrepreneurs while abstracting from moral hazard considerations.

As mentioned above, this paper also contributes to the literature on venture capital, see Rin et al. (2013) for a complete survey on venture capital theory, and in particular, relates to the strand on the selection and treatment effects that make VC-funded firms superior. Akcigit et al. (2019) empirically find advantages of VC over standard bank financing for highly innovative firms, and find substantial welfare gains from the existence of VCs, in the context of an endogenous growth model where entrepreneurial finance is required for technological progress.

The literature on corporate venture capital (CVC) has stressed the corporation's knowledge and its complementarities with start-ups as the main drivers of CVC success. Both Gompers

[2]See Grossman and Hart (JPE 1986) for a first take on the issue and Shleifer and Vishny (JFE 1997) for a wide survey.

and Lerner (2000) and Chemmanur et al. (2014) find treatment and selection effect advantages of CVC over regular financiers.

Finally, this paper relates to the effects of information frictions and signalling on start-up outcomes. Bernstein et al. (2017) show how investors pay a lot of attention to any signal about entrepreneur quality and Cao (2020) finds empirically that, due to information frictions, early signals can lead to persistent effects on firm funding. Our modeling of signals provides a theory consistent their results, even when signal quality is very low. Beyond, we delve into the efficiency gains from relying on such signals.

2 A Model of Open Innovation

The model here follows Hernandez and Wills (2019) closely. Entrepreneurs and financiers (venture capitalists and corporations) will interact to undertake risky projects in a competitive environment with adverse selection and limited liability.

2.1 Environment

The economy is populated by a continuum of entrepreneurs (or startups) indexed by their heterogeneous ability or quality $\theta \in [0, 1]$ and by a plurality of financial intermediaries: some venture capitalists and some large firms (corporations). Each entrepreneur can undertake a risky R&D project, whose probability of success depends jointly on her type and the amount of capital invested in the firm. We assume the entrepreneur has zero wealth: if she decides to undertake its project, it will have to borrow funds from a financial intermediary. If the entrepreneur does not undertake the project, she gets benefits w with certainty; w is then the opportunity cost of R&D, including forgone revenue from other endeavors or forgone wages the entrepreneur could earn somewhere else, as well as non-monetary costs.

The ability of each entrepreneur, θ, is drawn from a distribution with c.d.f. $G(\theta)$, known to all agents. This ability will affect the probability that the project succeeds. If the entrepreneur decides to start the project and invests an amount k of capital in the startup, it will be successful with probability $\theta \cdot f(k)$ where $f(\cdot)$ is increasing and strictly concave, and $f(0) = 0$. Hence, the surplus maximizing investment will be increasing in the startup quality. In line with the endogenous growth literature, we interpret a successful project as the arrival of an innovation, which allows the small firm to create or "steal" some market. We denote π the payoff of a successful project, while in case of failure the payoff is zero.

The financial intermediaries have access to capital at the (gross) risk-free rate R and face a loan demand from startups. The financing market entails two frictions. First, if a project fails, the intermediary cannot exert any claims on the researchers because limited liability clauses protect the later. Second, financial intermediaries cannot observe researchers' ability, introducing adverse selection.

While neither type of financial intermediaries do observe the startup type θ, corporations receive a signal about each entrepreneur. With probability ω this signal is high, and low otherwise. The distribution of types conditional on a high signal $G(\theta|m = high)$ dominates (in the Monotone Likelihood Ratio sense) the one conditional on a low signal $G(\theta|m = low)$, implying that as quality increases, so does the likelihood of receiving a good signal. The signal is commonly available to all corporations. While venture capitalists do not see the value of m, they know both $G(\theta|m)$ and ω.

The nature of the signal can encompass multiple features identified in the open innovation literature. The signal could capture the ability of the corporation to identify marketing potential, which may include knowledge sharing and co-development efforts. It will turn to be that financing from a corporation is a *stamp-of-approval* and that those ventures are more likely to succeed. This can be related with Gompers and Lerner (2000) and Chemmanur et al. (2014) who find that, as corporations can get better information from startups about their innovative potential, they can "nurture" this innovation more and in a better way in comparison to what Venture Capitalists do to their funded enterprises.

Both types of financial intermediaries offer sets of unrestricted contracts. In this setting, a contract must specify the size of the loan k, the repayment in case of success x_1, and the repayment if the project fails x_0. Corporations will offer different contract menus depending on the signal: a set for high-signal startups and another set for low-signal startups. Venture capitalists only extend a single-contract menu.

We make an innocuous linear transformation of the contract that will allow a more straightforward parallel with the mechanism design literature focused on payments to the entrepreneur (agent). Set $x = -x_0$ and $z = \pi - (x_1 - x_0)$, then a contract will be characterized by a triple (k, x, z) that prescribes a fixed pay for agent x, an additional payment contingent on success z and an investment amount k that determines the probability of the contingent payment happening. The conditions $x \geq 0$ and $x + z \geq 0$ ensure that limited liability is satisfied: if the project fails, the entrepreneur cannot make any payment to the intermediary, but the latter could potentially make a transfer to the former.

2.1.1 Generic Mechanisms

In principle, startups and financial intermediaries could interact in many possible ways. Each intermediary could devise its own signaling game, selecting a mechanism that receives messages and assigns contracts to each message. Startups would decide which message to send to each lender and choose the most favorable among the assigned contracts and the outside option (which we write as $(0, w, 0)$).

The message space available to the startups could be arbitrarily large, comprising the firm's type, details on the other financing mechanism, cheap talk, or any other unverifiable claim even if it is orthogonal to the project's outcome. Fortunately, Martimort and Stole (2002) developed a version of the revelation and delegation principles for common agency games like this one. They showed that any of those potential interactions could be reduced to games in which each intermediary offers a set of contracts, and the startup chooses a contract inside the available menus, like the one developed here. In that sense, our mechanism and results are generic. We describe these menu games in the following section.

2.2 Menu Games

In this subsection, we specify the contract menus game. For simplicity we assume there are only four financial intermediaries, indexed by $i \in \{1, 2, 3, 4\}$, competing *a la Bertrand* for entrepreneurs.[3] There are two types of intermediaries: 2 private venture capitalists($i \in \{1, 2\}$), and 2 corporate venture capitalists ($i \in \{3, 4\}$). Within types, intermediaries are identical. There is a continuum of entrepreneurs indexed by their private type θ drawn from a distribution $G(\theta)$ known to intermediaries. Total mass of entrepreneurs is 1.

Timing: First, corporations observe the signal from researchers. Then, all financial intermediaries move simultaneously, posting unrestricted menus (sets) of contracts. After that, entrepreneurs choose among the available menus and the outside option. Once a menu is chosen each startup picks a contract inside that set, or the outside option.

Strategies: For intermediaries the contract menu *space* contains any compact[4] subset of triples (k, x, z). That is, the power set of $\mathbb{R}^+ \times \mathbb{R}^+ \times \mathbb{R}$ denoted $\mathcal{P}(\mathbb{R}^+ \times \mathbb{R}^+ \times \mathbb{R}) = \boldsymbol{\Xi}$. Private Venture Capitalists post a single contract set $\mathcal{C}_i \in \boldsymbol{\Xi}$. Corporations offer two menus: $\mathcal{C}_i^l$, $\mathcal{C}_i^h$ for $i \in \{3, 4\}$, each conditional on the observed signal. Hence their strategy space is $\boldsymbol{\Xi}^2$.

We call the outside option as intermediary $i = 0$ and define the outside option menu as $\mathcal{C}_0 = \{(0, \omega, 0)\}$. For notational simplicity we set $\mathcal{C}_i^h = \mathcal{C}_i^l = \mathcal{C}_i$ for $i \in \{0, 1, 2\}$, that is for PVCs and the outside option. Then we can define the available set of contract menus available to an entrepreneur with signal m as $\mathcal{C}^m = \big(\mathcal{C}_0^m, \mathcal{C}_1^m, \mathcal{C}_2^m, \mathcal{C}_3^m, \mathcal{C}_4^m\big)$. After observing her private type θ and $\mathcal{C}^m$, the entrepreneur chooses her preferred contract menu, say $\mathcal{C}_j^m$, determining her financier, in that case j, and then a contract inside that menu.

Payoffs: All players are risk-neutral and care only about the expected payoff. For a entrepreneur of type θ the expected payoff of signing a contract (k, x, z) is:

$$u\big(\theta, (k, x, z)\big) = \theta f(k) z + x. \tag{1}$$

In particular, if the researcher takes her outside option, her payoff is $u\big(\theta, (0, w, 0)\big) = w$. Conditional on an entrepreneur of type θ signing a contract (k, x, z) with a venture capitalist or corporation i, the financier's expected payoff is:

$$v\big(\theta, (k, x, z)\big) := \theta f(k) \cdot (\pi - z) - x - Rk. \tag{2}$$

Adding equations (1) and (2) yields the expected gross surplus of the startup. Hence, among a set of contracts delivering the same expected utility to the entrepreneur a financier strictly

[3]As long as the entrepreneurs observe all offered contracts, the outcome will be the same with more intermediaries, although the optimal strategies of each one may differ. Hence this is just a notational simplification for free entry in the intermediaries sector.

[4]Boundedness is without loss of generality since posting unbounded contract menus implies negative expected profits in equilibrium. Closure is slightly restrictive but necessary for the expected payoffs to both type of players to exist in equilibrium

prefers the one maximizing gross surplus. Given our assumption on entrepreneurs choosing the financier's preferred contract when indifferent, we can collapse the entrepreneur's strategies into choosing exactly one contract per financier because they are payoff equivalent. However, entrepreneurs could still randomize among financiers when indifferent.

2.3 Technical Definition of Strategy Space and Equilibrium

In this subsection we carefully define the strategy space, generalized payoff functions and the equilibrium definition, including mixed strategies. In equilibrium, the only randomization will be entrepreneurs choosing between two intermediaries offering the same expected utility. The reader may skip and go directly to equilibrium characterization.

Strategy Space and Payoffs: As stated before, the strategy space for private venture capitalists (PVCs) is the power set of $\mathbb{R}^+ \times \mathbb{R}^+ \times \mathbb{R}$ denoted $\boldsymbol{\Xi}$. For corporate venture capitalists (CVCs) the strategy space is Ξ^2 as they offer one contract set for each signal. For the entrepreneur of type θ and signal m a strategy is a function s_θ^m that assigns to each set of available contract menus $\mathcal{C}^m$ a probability distribution over financiers or the outside option and probability distribution for each contract menu:

$$s_\theta^m : \boldsymbol{\Xi}^5 \to \Delta\big(\{0,1,2,3,4\}\big) \times \Delta(\mathbb{R}^3)^5, \quad s.t. \quad Supp\{s_\theta^m(\mathcal{C}^m)_{i+2}\} \subseteq \mathcal{C}_i^m, \quad \forall i \in \{0,\ldots,4\} \tag{3}$$

where $\Delta(\mathbb{X})$ is the set of probability measures over $\mathbb{X}$ and $Supp\{\cdot\}$ denotes the support.

The first component of the entrepreneur's strategy is the distribution over intermediaries: $s_\theta^m(\mathcal{C}^m)_1 = (q_0, q_1, q_2, q_3, q_4)$ where q_i is the probability assigned to intermediary i. The expected payoff for an entrepreneur given her type, signal m, strategy s_θ^m and available menus is:

$$U(\theta, s_\theta^m, \mathcal{C}^m) = \sum_{i=0}^{5} q_i \int_{(k,x,z)\in\mathcal{C}_i^m} \big(\theta f(k) z + x\big) ds_\theta^m(\mathcal{C}^m)_{i+2}[k,x,z], \tag{4}$$

where $M[k,x,z]$ denotes the cumulative density at $[k,x,z]$ of the probability distribution M.

The expected payoff to the entrepreneur in equation (4) implies an expected payoff for intermediary i:

$$v_i(\theta, s_\theta^m, \mathcal{C}^m) := s_\theta^m(\mathcal{C}^m)_{(1,i+1)} \int_{(k,x,z)\in\mathcal{C}_i^m} \big(\theta f(k)(\pi - z) - x - Rk\big) ds_\theta^m(\mathcal{C}^m)_{i+2}[k,x,z],$$

where $s_\theta^m(\mathcal{C}^m)_{(1,i+1)} = q_i$ is the prescribed probability of entrepreneur choosing financier i, that is the $(i+1)$-th component of the probability distribution over financiers and the outside option $s_\theta^m(\mathcal{C}^m)_1$.

Denote the set of all strategies chosen by entrepreneurs with signal m as $\Sigma^m = \cup_{\theta\in\Theta} s_\theta^m$.

The total expected payoff of the corporation i can be written as:

$$V_i(\Sigma^h, \Sigma^l, \mathcal{C}^h, \mathcal{C}^l) = \omega \int_{\theta\in\Theta} \big[v_i(\theta, s_\theta^h, \mathcal{C}^h)\big] dG(\theta|h) + (1-\omega) \int_{\theta\in\Theta} \big[v_i(\theta, s_\theta^l, \mathcal{C}^l)\big] dG(\theta|l), \tag{5}$$

which is just the sum of the expected profits v_i over each type θ and signal.

Equilibrium definition: The equilibrium concept applicable to this framework is the Perfect Bayes Equilibrium.

Definition A strategy profile $\{\mathcal{C}_i^{m*}, s_\theta^{m*}\}$ for all $i \in \{1,2,3,4\}$, $m \in \{l,h\}$, and $\theta \in \Theta$, is a *Perfect Bayes Equilibrium* if:

1. Entrepreneurs maximize expected utility: For all $\theta \in \Theta$ and $m \in \{l,h\}$, the strategy for entrepreneur of type θ and signal m is as defined in equation (3). If it assigns a positive probability to intermediary i, that is $s_\theta^m(\mathcal{C}^m)_{(1,i+1)} > 0$, then all of i's contracts chosen with positive probability must maximize expected utility:

$$Supp\big\{s_\theta^{m*}(\mathcal{C}^{m*})_{i+1}\big\} \subseteq \underset{(k,x,z)\in\cup_{j=0}^4 \mathcal{C}_j^{m*}}{\arg\max} \quad \theta f(k)z + x. \tag{6}$$

2. For each intermediary $i \in \{1,2,3,4\}$, given the entrepreneur's strategies $\Sigma^{m*} = \cup_{\theta\in\Theta} s_\theta^{m*}$ and the competitor's contract menus $\mathcal{C}_{-i}^{m*}$ for $m \in \{l,h\}$, her own contract menus $\mathcal{C}_i^{h*}, \mathcal{C}_i^{l*}$ maximize her expected utility defined in equation (5), that is:

$$\begin{aligned} (\mathcal{C}_i^{h*}, \mathcal{C}_i^{l*}) \in &\underset{(\mathcal{C}_i^h, \mathcal{C}_i^l)}{\arg\max} V_i(\Sigma^{h*}, \Sigma^{h*}, \mathcal{C}_i^h, \mathcal{C}_{-i}^{h*}, \mathcal{C}_i^l, \mathcal{C}_{-i}^{l*}) \\ s.t. \forall (k,x,z) \in \mathcal{C}_i^m &: k \geq 0, \quad x \geq 0, \quad x+z \geq 0 \\ \forall i &\in \{1,2\} : \mathcal{C}_i^{h*} = \mathcal{C}_i^{l*}. \end{aligned} \tag{7}$$

The conditions $x \geq 0$ and $x + z \geq 0$ ensure that limited liability is satisfied: if the project fails, the entrepreneur cannot make any payment to the intermediary, but the intermediary could potentially make a transfer to the entrepreneur. The last condition prevents PVCs from discriminating against entrepreneurs using the signal. We assume the posted menus are compact sets for the entrepreneur's optimal strategies to exist.[5]

Mixed strategies: In this environment, mixed strategies are only necessary for entrepreneurs to break ties among financiers. Intermediaries can always break indifference, preserving incentives, for almost all entrepreneurs at a negligible cost. Hence, when indifferent among several contracts inside a menu, entrepreneurs must (almost) always choose the one most favorable for the intermediary, which is the one that maximizes joint private surplus. That will imply in equilibrium (almost) all entrepreneurs will each choose a *unique* contract inside a financier's menu. Therefore, without loss of generality we can assume no randomization inside contract menus.

As is standard in the incentive compatibility literature, see Lester et al. (2015), we will restrict the entrepreneurs' randomization among intermediaries. In case of indifference between PVC and CVC menus they will always choose corporate venture capitalists, and among the same type of financier they will randomize with equal weight. Once a financier is chosen, among all contracts that attain the maximum expected utility for the entrepreneurs, she chooses the most beneficial to the financier. This would be helpful for the characterization of equilibrium payoffs. [6]

[5]Boundedness is without loss of generality since posting unbounded contract menus implies negative expected profits in equilibrium. Closure is slightly restrictive but necessary to guarantee the least upper bound of expected payoffs is attainable.

[6]See Hernandez and Wills (2019) for a careful treatment of entrepreneurs' mixed strategies where they can randomize over any subset of the offered contracts, including the outside option.

3 Equilibrium Characterization

In this section we state a sequence of claims leading to the characterization of the equilibrium contract in an environment where CVCs have an information advantage over PVC's. As will be shown, both types of intermediaries make zero profits and the startups' expected payoffs are linear in their types. Although the equilibrium is by no means unique, all equilibria are payoff equivalent. The equilibrium allocations, both with and without CVCs, are not efficient because some projects with lower expected value than the opportunity cost are undertaken. Section 4.2 shows that CVCs' involvement does *not* necessarily reduce this inefficiency, but under regular parameterizations they generally improve welfare versus an environment in which PVCs are the only financiers.

The Expected Utility of Entrepreneurs

For every nonempty contract menu $\mathcal{C}_i^m$ offered by a financial intermediary i there exists $U_i^m(\theta)$ the promised expected utility function for each type, defined as:

$$U_i^m(\theta; \mathcal{C}_i^m) = \max_{(k,z,x)\in\mathcal{C}_i^m} \theta f(k)z + x$$

Let $U^m(\theta; \mathcal{C}^m)$ be the potential payoff that a θ-type entrepreneur could get, conditional on obtaining a signal m and becoming researcher, when she faces the contract sets $\mathcal{C}^m$.

$$U^m(\theta; \mathcal{C}^m) = \max_{(k,z,x)\in\cup_{j=0}^4 \mathcal{C}_j^m} \theta f(k)z + x$$

In what follows, and to simplify notation, we drop the dependency of U^m, U_i^m on $\mathcal{C}^m, \mathcal{C}_i^m$. The equilibrium payoff of a θ-type agent is $U^m(\theta)$.

3.1 Fighting for the Best, Losing with the Rest

In Hernandez and Wills (2019), we describe the nature of the equilibrium in the generic environment with competition, adverse selection and limited liability, but only one type of financier. Here, we leverage on those results to describe the Open Innovation Equilibrium (OIE), that is, we allow for the coexistence of PVCs and CVCs to coexist. But first, in this section we describe the equilibrium where all financiers are equal and there are no signals about the entrepreneur's ability.

Define $k^F(\theta)$ as the full information optimal investment in a project of type θ.

$$k^F(\theta) = \arg\max_k \{\theta f(k)\pi - Rk\} \tag{8}$$

And let $S(\theta)$ be maximum gross surplus generated by a researcher of type θ,

$$\begin{aligned} S(\theta) &= \max_k \{\theta f(k)\pi - Rk\} \\ &= \theta f\big(k^F(\theta)\big)\pi - R \cdot k^F(\theta). \end{aligned} \tag{9}$$

$S(\theta)$ is a gross surplus because it does not include the opportunity cost of forgoing the outside option w. Note that under the assumptions for $f(k)$ stated above, the optimal project size $k^F(\theta)$ is continuous and strictly increasing in θ.

Proposition 1 (Hernandez and Wills (2019))**.** *In equilibrium, all intermediaries offer the same the contract menu* $\mathcal{C}_i^* = \Big\{ \big(k^*(\theta), z^*(\theta), x^*(\theta)\big) : \theta \in \Theta \Big\}$ *defined by:*

$$k^*(\theta) = k^F(\theta) = \arg\max_k \{\theta f(k)\pi - Rk\}, \qquad z^*(\theta) = \frac{w}{\bar{\theta}_L f\big(k^F(\theta)\big)}, \qquad x^*(\theta) = 0.$$

Entrepreneurs randomize with equal weight between intermediaries, signing the contract indexed with their own type $\big(k^*(\theta), z^*(\theta), x^*(\theta)\big)$*.* θ_L *is the lowest type who accepts a contract, determined such that the intermediaries make zero profits, that is:*

$$0 = V_i(\Sigma, \mathcal{C}^*) = \int_{\theta_L}^{1} \Big[S(\theta) - U_i(\theta, \mathcal{C}^*) \big) \Big] dG(\theta).$$

The equilibrium in Hernandez and Wills (2019) shows that all projects financed are undertaken at their efficient level, that there is no fixed or insurance payment to the startup and that small firms that become research firms are those whose quality is above some threshold.

In equilibrium, when a project fails, financiers won't pay anything to researchers: $x^*(\theta) = 0$. If that were not the case, a savvy intermediary s could "cream-skim" the market. That is, firm i could deviate to a contract serving all the profitable types, and leave all the unprofitable types to the competitors. Given this equilibrium, the expected utility for the startup is:

$$U(\theta; \mathcal{C}^*) = \max_{s \in \Theta} \theta f\big(k^*(s)\big) z^*(s) + x^*(s) = \max_{s \in \Theta} \theta \frac{w}{\theta_L} = \theta \frac{w}{\theta_L},$$

as $f\big(k^*(s)\big) z^*(s)$ is constant. Hence the *equilibrium* expected utility for the entrepreneur is linear on θ.

Since projects are enacted at their efficient level $k^*(\theta)$ the expected payoff for intermediaries of signing a contract with an entrepreneur of type θ becomes:

$$v_i\big(\theta, s_\theta(\mathcal{C}^*)\big) = S(\theta) - U(\theta, \mathcal{C}^*).$$

Intermediaries make zero *aggregate* profits. As a result, startups have all the bargaining power and one could suspect that intermediaries will make zero profits type by type and each entrepreneur would receive all the economic surplus it produces, as in Rothschild and Stiglitz (1992). This would also be consistent with Aghion and Tirole (1994), where the intermediaries behave as the "consumers" of innovation derived from the entrepreneurs. That intuition would be correct in a similar framework without limited liability, or without asymmetric information. However, the interaction between the two frictions does not allow for the former result to hold in our economy. On the contrary, the expected surplus of the project grows faster than incentives (expected utility) can be provided: whenever expected profits are positive, locally expected revenues increase faster than expected costs. In a nutshell, intermediaries want to attract more able types (fight for the best) but cannot increase local rewards too fast, hence they have to offer better terms to all startups (lose with the rest).

The cross-subsidization result would not hold absent limited liability. In that case, the optimal mechanism specifies startups that get all the profits from the project and pay $Rk^*(\theta)$ in both success and failure, making intermediaries earn zero profits per each contract.

3.2 Open Innovation Equilibrium

In this section, we describe the equilibrium in the environment with both PVCs and CVCs. There will be a market for high-signal startups and a market for low-signal startups. High-signal startups will only obtain financing from corporations, as venture capitalists cannot compete in that submarket without attracting too many low-signal types, which would lead to losses. Realizing this, venture capitalists tailor their contract menus to face only low-signal types. Corporations, moreover, offer the exact same menu to low-signal types. There will be zero profit by submarket, but intra-market cross-subsidization.

3.2.1 High-Signal Equilibrium

From Hernandez and Wills (2019), it follows that competition among the two corporations will result in an equilibrium contract menu of the following form:

Claim 1. *In equilibrium, startups with high signal contract only with corporations, and the equilibrium menu $\mathcal{C}_h^*$ is characterized by:*

$$k_h^*(\theta) = k^F(\theta) = \arg\max_k \{\theta f(k)\pi - Rk\}, \qquad z_h^*(\theta) = \frac{w}{\theta_L^h f\big(k^F(\theta)\big)}, \qquad x_h^*(\theta) = 0.$$

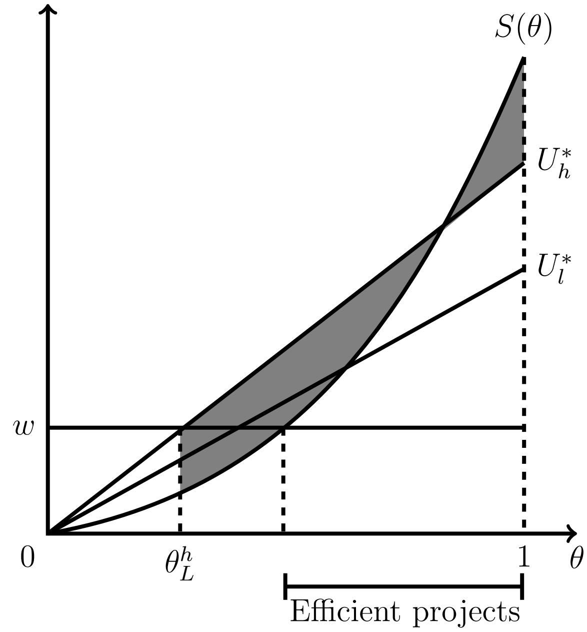
where θ_L^h, the lowest type who accepts a contract, is such that the **corporations** *make zero profits in the* **high signal submarket***, that is:*

$$0 = V_i^h(\Sigma, \mathcal{C}_h^*) = \int_{\theta_L^h}^1 \big[S(\theta) - U_h^*(\theta, \mathcal{C}_h^*)\big]\, dG(\theta|h) \tag{10}$$

Notice that in equation(10), the integral uses the distribution conditional on a high signal. From proposition 1, competition for the best startups among corporations will lead to zero profits for them. If venture capitalist tried to offer similar or better contracts, they would attract not only high but also low-signal types, the unconditional distribution. The only thing left to prove is that when offering the same contract menu $\mathcal{C}_h^*$ the private venture capitalists incur losses, which is a direct consequence of the Monotone Likelihood Ratio Property (see proof in the Appendix).

Figure 1 shows the equilibrium in the high signal market. The shaded regions represent the difference between the surplus $S(\theta)$ and the expected payment to the startup U_h^*. *Weighted* by the density of types θ conditional on the signal $g(\theta|h) = dG(\theta|h)$, both areas must be equal (zero profit).

Figure 1: Equilibrium Contract and Zero Profits with High Signal



3.2.2 Low signal equilibrium

Due to the previous claim, PVCs know they are going to face only low-signal type entrepreneurs. In this case, the low-signal equilibrium is akin to the Hernandez and Wills (2019) equilibrium with 4 intermediaries, since all market participants know the distribution of types in this submarket is $G(\theta|l)$. The next claim characterizes the equilibrium:

Claim 2. *In equilibrium, startups with low signal face the same contract schedule from corporations and venture capitalists $\mathcal{C}_l^*$ is characterized by:*

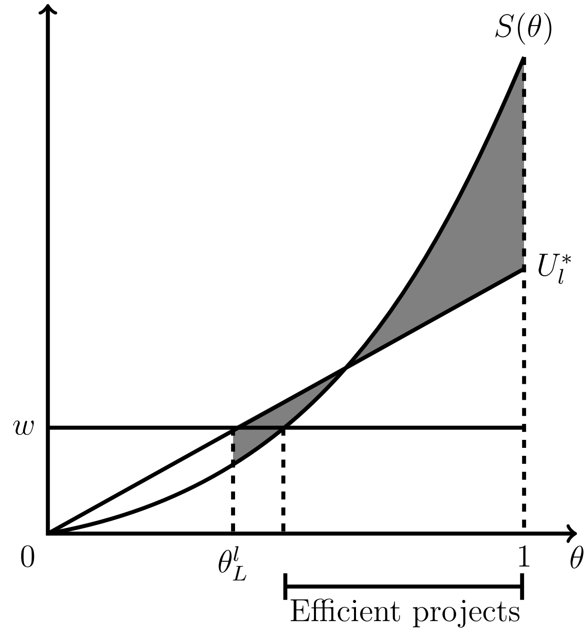
$$k_l^*(\theta) = k^F(\theta) = \arg\max_k\{\theta f(k)\pi - Rk\}, \qquad z_l^*(\theta) = \frac{w}{\theta_L^l f\big(k^F(\theta)\big)}, \qquad x_l^*(\theta) = 0.$$

where θ_L^l, the lowest type who accepts a contract, is such that the **venture capitalists and corporations** *make zero profits in the* **low signal submarket***, that is:*

$$0 = V_i^l(\Sigma, \mathcal{C}_l^*) = \int_{\theta_L^l}^1 \big[S(\theta) - U_l^*(\theta, \mathcal{C}_l^*)\big] dG(\theta|l) \tag{11}$$

This claim follows verbatim from Hernandez and Wills (2019). The proof of claim 1 implies that $\theta_L^h < \theta_L^l$ and that $U_h^*(\theta) > U_l^*(\theta)$ for all θ, as seen in Figure 1. Figure 2 illustrates the equilibrium for the researcher with "low" signal. The contract menu offered by venture capitalists is the same as the one offered by corporations $\mathcal{C}_l^*$, generating the same curve U_l^*. Therefore, the gray area, weighted by the density $g(\theta|\mathbf{l})$, represents the profits of both types of intermediaries in this sub-market. At first glance the area of positive expected profits, the part where $S(\theta) > U_l^*(\theta)$ seems to be larger than the area of negative expected profit, the part where $U_l^*(\theta) > S(\theta)$ however, when the signal is low startups types are more likely to be concentrated in the negative expected profit zone.

Figure 2: Equilibrium Contract and Zero Profits for Low Signal



3.2.3 The Open Innovation Equilibrium

To sum up, we define the Open Innovation Equilibrium, as the whole set of submarkets and contract menus offered.

Proposition 2. *In the Open Innovation Equilibrium OIE, there are two contract menus: $\mathcal{C}_h^*$ posted only by the corporations and only available to high signal startups and $\mathcal{C}_l^*$ posted by the venture capitalists and available to all startups. High signal startups will contract with corporations only. The contract menus are characterized by:*

$$k^*(\theta) = k^F(\theta) = \arg\max_k\{\theta f(k)\pi - Rk\}, \qquad z_l^*(\theta) = \frac{w}{\theta_L^l f\big(k^F(\theta)\big)},$$

$$x_m^*(\theta) = 0, \forall m \in \{l, h\} \qquad z_h^*(\theta) = \frac{w}{\theta_L^h f\big(k^F(\theta)\big)},$$

where θ_L^m, the lowest type who accepts the contract conditional on obtaining the signal m, is such that the intermediaries make zero profits in the respective sub-market.

$$0 = V_i^l(\Sigma^l, \mathcal{C}_l^*) = \int_{\theta_L^l}^1 \Big[S(\theta) - \frac{\theta}{\theta_L^l} w\Big] dG(\theta|\mathbf{l}),$$

$$0 = V_i^h(\Sigma^h, \mathcal{C}_h^*) = \int_{\theta_L^h}^1 \Big[S(\theta) - \frac{\theta}{\theta_L^h} w\Big] dG(\theta|\mathbf{h}).$$

It is important to stress that financial intermediaries' market shares are undetermined in this equilibrium. We will assume that corporations will abstain from financing startups where they cannot outdo venture capitalists, which is consistent with the observations. This can be explained by the reluctance of the corporation board of directors to authorize financing of businesses with no connection with the corporation's activity or know-how.

This is not restrictive, as the aggregate allocation of the economy is the same, (same projects undertaken, same payoffs for all agents). The literature has shown that, when corporations do not have a knowledge advantage over PVCs, other sources of inefficiencies will emerge. As has been shown by Yang and Wang (2016), the effectiveness of R&D requires the effective allocation of innovation elements as manpower, funds, information, management, etc., as well as R&D institutions and training teams. Therefore, following Chesbrough (2003), the market uncertainty for those who do not have experience in the specific market (corporations facing low signal entrepreneurs) is larger than for the big companies who have worked in the field before (PVCs facing the same entrepreneurs). Consequently, it is better for corporations to specialize in the market of which they have knowledge (startups with positive signal).

3.2.4 Why CVCs Do Not Hire Researchers

It is worth considering the option of the corporation wanting to pursue the innovation project on its own. Given it has the monetary resources, the key constraint is having the researcher-entrepreneur in house. It is straightforward to imagine the corporation hiring the researcher for a wage ω instead of funding her startup, but this hiring would be akin to having $x = \omega$ in our setup. Competition among corporations to poach the best employees would drive wages *plus benefits and bonuses* up, but base pay down ω. In equilibrium, a corporation offering a strictly positive base pay will be cream-skimmed by competitors offering only variable pay, leaving it with low-type researchers whose projects yield expected losses.

3.3 Private Venture Capitalist Equilibrium (PVCE)

So far, the model has shown the equilibrium in an environment populated with corporations, venture capitalists, and researchers (startups). Here we describe the economy with PVCs as the only lenders and their interaction with startups to compare it with the Open Innovation Equilibrium. In section 4, we show that the introduction of CVCs in the Open innovation Equilibrium improves market efficiency. In this context, PVCs have to deal with both market and technological uncertainty. Formally, they can not see any signal from the researchers. The welfare analysis has to acknowledge there is less information in this environment than in the one with both PVCs and CVCs.

Since there are only private venture capitalists, the equilibrium follows directly from proposition 1 in Hernandez and Wills (2019).

Claim 3. *In equilibrium, startups offer a contract schedule $\mathcal{C}^*_{PVCE}$ is characterized by:*

$$k^*_{PVCE}(\theta) = k^F(\theta), \qquad z^*_{PVCE}(\theta) = \frac{w}{\theta_L^{PVCE} f\big(k^F(\theta)\big)}, \qquad x^*_{PVCE}(\theta) = 0.$$

where θ_L^{PVCE}, the lowest type who accepts a contract, is such that the **venture capitalists** *make zero profits.*

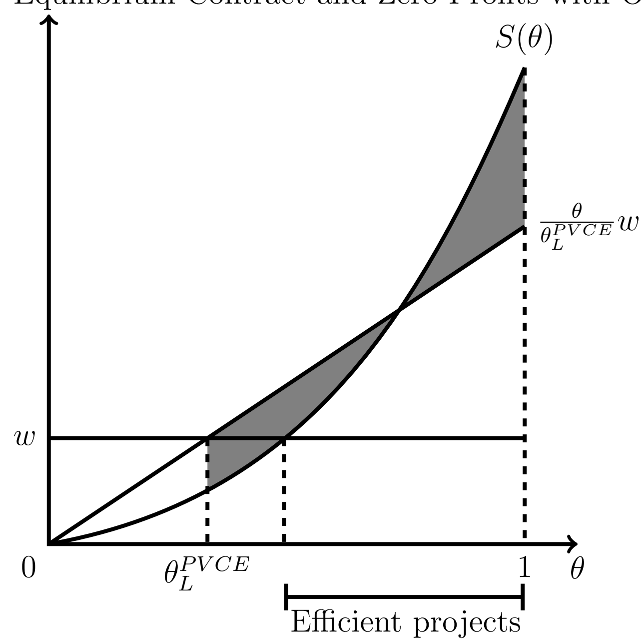
$$0 = V_i(\Sigma, \mathcal{C}^*_{PVCE}) = \int_{\theta_L^{PCVE}} \big[S(\theta) - U^*_{PVCE}(\theta, \mathcal{C}^*_{PVCE})\big] dG(\theta) \tag{12}$$

The results are equivalent to the ones stated above, and the contract offered by the VC also satisfies the ZPC. However, in the absence of funding by corporations, VCs know that they do not have competitors with more information. Therefore VCs are going face the unconditional distribution of entrepreneurs $G(\theta)$ instead of low-signal entrepeneurs $G(\theta|l)$ only. This implies that VCs are going to post more generous contracts for every θ, compared with the contracts they would have offered in the Open Innovation Equilibrium OIE described in proposition 2. In fact, the MLRP-ranking of the distributions $G(\theta|h) \succ_{MLRP} G(\theta) \succ_{MLRP} G(\theta|l)$ implies the ranking of θ_L's as $\theta_L^h < \theta_L^{PVCE} < \theta_L^l$.

Figure 3 illustrates the results. The area shaded in gray represents the profits of a PVC. From the figure, it is clear that changes in θ_L^{PVCE} change the slope of the researchers expected payoff. These changes, in turn, modify the PVCs' payoffs, and hence θ_L^{PVCE} can be adjusted so that PVCs make zero profits.

Here, we can see that the key force in this economy mentioned above remains: to provide the correct incentives, the payoff to researchers cannot grow as fast as the total surplus does. That means that PVC always make higher profits with the more able types. Since high types are more profitable, PVCs are willing to lose money with low types to offer more attractive contracts to (profitable) high types and maintain incentives.

Figure 3: Equilibrium Contract and Zero Profits with Only PVCs



4 Welfare

In all the discussed frameworks, the expected social surplus of a project is $\theta f\big(k^F(\theta)\big)\pi - Rk^F(\theta) - w$. Hence an unconstrained social planner (one that could observe agents' abilities) would set $\theta f'\big(k^F(\theta)\big)\pi = R$ as before, but only for those θ such that the expected social benefit is not negative. As the surplus is increasing in θ, by the envelope theorem, there is a lower bound θ_P, above which, projects are socially valuable. Then it is worth for the society to devote resources to all projects with $\theta \geq \theta_P$ where θ_P is defined by, $\theta_P f\big(k^F(\theta_P)\big)\pi - Rk^F(\theta_P) = w$.

By contrast, in the decentralized equilibria, the lowest-quality project undertaken θ_L^x is such that intermediaries make zero aggregate profits:

$$\int_{\theta_L^x}^1 \left\{\theta f\big(k^F(\theta)\big)\pi - Rk^F(\theta)\right\} dG(\theta|s) - \int_{\theta_L^x}^1 \theta \frac{w}{\theta_L^x} dG(\theta|s) = 0,$$

for $s \in \{l, h, \emptyset\}$ and the corresponding $x \in \{l, h, PVCE\}$

Claim 4. *In both the OIE and the PVCE, socially inefficient projects are always undertaken. That is $\theta_L^x < \theta_P$ for $x \in \{l, h, PVCE\}$. Moreover, efficiency will be restored if any of the following becomes true:*

- *No adverse selection: Types are public information*
- *No limited liability: Financial intermediaries are able to recover any contracted amount.*
- *No competition: There is only one financial intermediary or financial intermediaries collude*[7]*.*

The intuition behind the result above is as follows: if only efficient projects were financed, $\theta_L^x \geq \theta_P$, then the lowest quality project must yield profits for the intermediary, as $S(\theta_L) \geq S(\theta_P) = w = U(\theta_L^x)$. But the envelope theorem implies that if intermediaries make expected profits with a type $\hat{\theta}$, they will make expected profits with higher types $\theta > \hat{\theta}$, leading to positive aggregate profits. But then, positive profits attract new intermediaries who can "steal" the market by offering more generous contracts. More generous contracts involve some cross-subsidization and, as a result, socially inefficient projects will be active. This efficiency loss can be seen as the shaded area under the horizontal line at w.

If types are public information but all other conditions remain the same, intermediaries will break even on each type. This implies that all signed contracts are such that $U(\theta) = S(\theta)$, and only types $\theta > \theta_P$, sign contracts. Contracts will not be completely determined since many combinations of $x(\theta)$ and $z(\theta)$ yield $U(\theta) = S(\theta)$, but all projects would be undertaken at their efficient scale $k(\theta) = k^F(\theta)$. The equilibrium payoff of type θ is $U(\theta) = \max\{w, S(\theta)\}$.

If there is no limited liability but all other conditions hold, the only IC contract schedule in equilibrium is $k^*(\theta) = k^F(\theta)$, $x^*(\theta) = -R \cdot k^F(\theta)$ and $z(\theta) = \pi$, which implies $U(\theta) = S(\theta)$. This is a risk-free type of contract. As is well understood, when the researcher is risk-neutral, transferring all the risk to her solves the incentive problem.

If there is only one financial intermediary, but adverse selection and limited liability still hold, the only equilibrium is as follows: the contract that maximizes profits for the intermediary is $k^*(\theta) = k^F(\theta)$, $x^*(\theta) = w$, $z^*(\theta) = 0$ and researchers with types $\theta \geq \theta_L$ take it, all others reject. The financial intermediary will take all the surplus and her profits would be $\int_{\theta_P}^1 \big(S(\theta) - w\big) dG(\theta)$. Interestingly, in the context of our model, the first best outcome is not

[7]The proof of this proposition is in Hernandez and Wills (2019)

reached in the competitive equilibrium, but is attained under monopoly/collusion. The reason is that limited liability constrains the contract space; but while this constraint is binding under competition, it is not under collusion.

These findings imply that, in any of the described competitive equilibria, there are always social inefficiencies. Then there is room for assessing the impact of introducing corporations with more information than PVCs about the probability of success of the projects. While in general, more information lessens the adverse selection problem, there is no guarantee that in this environment the inefficiency is smaller in the OIE vs the PVCE. To illustrate this point, we follow a numerical approach.

4.1 A Welfare Measure

As a point of reference we take the Full Information Total Surplus (FITS) generated by the entrepreneurial activity. That is:

$$FITS = \int_{\theta_P}^{1} (S(\theta) - w) dG(\theta|s).$$

Notice this is the same for both the OIE and the PVCE as the signals do not change the aggregate distribution of entrepreneurial productivity. We use the FITS as a denominator to compare to the inefficiency in both equilibria.

The total inefficiency is just the net surplus destroyed by those entrepreneurs with types between θ_L and θ_P ,that is, those enacting socially inefficient projects that yielded less than the outside option w. Hence the relative inefficiency for the PVCE equilibrium is:

$$\mathcal{I}_{PVCE} = FITS^{-1} \int_{\theta_L^{PVCE}}^{\theta_P} \big(w - S(\theta)\big) dG(\theta). \tag{13}$$

The relative inefficiency for the OIE has to take into account the submarkets for the low and high signal, that is:

$$\mathcal{I}_{OIE} = \frac{\omega}{FITS} \int_{\theta_L^l}^{\theta_P} (w - S(\theta)) dG(\theta|l) + \frac{1-\omega}{FITS} \int_{\theta_L^h}^{\theta_P} \big(w - S(\theta)\big) dG(\theta|h), \tag{14}$$

where θ_L^x refers to the lowest type of entrepreneur that will accept the contract in a given submarket derived from the signal $x \in \{l, h\}$.

Given the previous definitions, the next step is to determine if the introduction of CVCs with a strong selection advantage, in the MLRP sense, is enough to guarantee an improvement in welfare. Unfortunately, that is not the case. We provide two numerical examples: a baseline parameterization where welfare increases with the introduction of CVCs and an extreme parameterization where it decreases.

4.2 Baseline Parameterization

Fundamentals

We set the researchers' outside option $w = 15$; the output of the project in case of success, $\pi = 100$; and the gross interest rate is $R = 1.02$. We set the probability that a project succeeds be $\theta f(k)$ with $f(k) = 1 - \exp(-\beta k^{\alpha})$ for $\beta > 0$ and $\alpha \in (0, 1)$. A way to interpret the above functional form is that the probability of success is the product of θ and the probability that an exponential random variable is lower than k^{α} [8]. As exponential variables are usually employed for waiting times for a *Poisson* process, it can be interpreted as the waiting time until the arrival of a new innovation (success), an amount k of capital allows the entrepreneur to run the project for k^{α} periods and hence the probability of a good idea arriving would be $f(k)$.

The Signal

We use a given particular family of densities $d\bar{G}(\theta;\kappa) = 2(1-\kappa) - 2(1-2\kappa)\theta$, parameterized by $\kappa \in [0.1]$. In this family, $\kappa_1 > \kappa_0$ implies $\bar{G}(\theta;\kappa_1) \succ \bar{G}(\theta;\kappa_0)$ in the monotone likelihood ratio sense. Conditional on a high signal $m = h$, the type distribution is $\bar{G}(\theta;\kappa = 1)$ while conditional on a low signal $m = l$, the conditional distribution is $\bar{G}(\theta;\kappa = 0)$. The share of entrepreneurs receiving a low signal is $\omega = 75\%$, while the other 25% receive a high signal. The unconditional distribution of types can be recovered from the conditional distributions following the fact that:

$$dG(\theta) = \omega dG(\theta|m = l) + (1-\omega)dG(\theta|m = h). \tag{15}$$

That yields a unconditional type distribution $\bar{G}(\theta;\kappa = 0.25)$. It follows that $G(\theta|h) \succ G(\theta) \succ G(\theta|l)$ in the MLRP sense, hence the signal is informative.

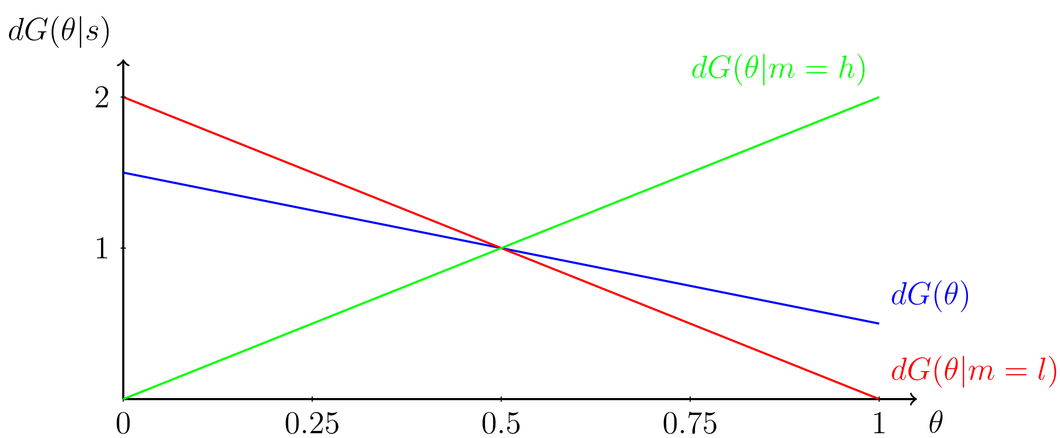


Figure 4: Conditional and unconditional type densities

Equilibrium and Welfare

Using the parameters and functional forms presented above, we solve numerically for both OIE and PVCE and compare the surplus in each case with the Full Information Total Surplus

[8]Equivalently, $f(k)$ is the probability that a Weibull random variable is smaller than k. In that case, the waiting time interpretation would be that the longer it takes for a project to succeed the less likely it will succeed in the future, Jovanovic and Szentes (2013) use a similar approach; hence our functional forms may be regarded as a reduced form of their results.

(FITS).

Table 1: Equilibirum comparison under Baseline Parametrization

	Submarket	θ_L^m	Inefficiency[1]	Surplus[1]
OIE	$m = l$	0.551	3.3%	66.9%
	$m = h$	0.500	3.9%	25.8%
	Total	-	7.3%	92.7%
PVCE		0.524	9.1%	90.9%
FITS		0.623	0%	100%

[1] % of aggregate efficient surplus.

Table 4.2 shows a summary of the results. The θ_l^m column shows, for each sub-market and equilibrium, the lowest type that accepts a contract. For the full information, that value is equal to the socially efficient $\theta_P = 0.62$. As expected $\theta_L^h < \theta_L^{PVCE} < \theta_L^l < \theta_P$. The inefficiency column shows the relative aggregate loss in terms of the full information surplus. For the PVCE is the result of equation (13), for the OIE it presents separately each of the terms on the right-hand side of equation (14) and the total sum.

In the OIE, the surplus split is roughly aligned with the 3:1 ratio given by ω (ratio of 2.6:1), but the inefficiency is generated mostly in the *high* signal submarket. This is in line with the *fighting for the best, losing with the rest* intuition: in the high signal submarket there are a many good entrepreneurs, and the fight for them attracts many bad entrepeneurs.

Comparing PVCE and OIE, the results above show that the inclusion of CVCs with selection advantage reduces the relative inefficiency, as it incorporates more information through signals. Unfortunately, even with strong signals, in the MLRP sense, a welfare increase cannot be guaranteed.

4.2.1 Extreme Parameterization

Table 2 shows a comparison of the baseline and extreme parametrizations. Changes to parameters not affecting the distributions were made for computational efficiency and are described in the Appendix. The value of the lowest socially efficient type, $\theta_P = 0.28$, is independent of the type distribution and critical for the exercise.

Table 2: Benchmark Parameters

	w	π	R	$f(k)$	α	β
Baseline	15	100	1.02	$1 - \exp(-\beta k^\alpha)$	0.7	0.1
Extreme	7.5				1	

The other main ingredient for this parameterization is a skill distribution where the amount of bad entrepreneurs grows quickly as the type moves just below θ_P. We use a family of such distributions ordered by the MLRP by one parameter $\bar{G}_x(\theta;\kappa)$. We discuss the construction of this family of distributions and its properties in the Appendix.

We set $\kappa_l = -1.0$, $\kappa_h = -0.99$ and $\kappa_0 = -0.995$. Under the extreme parameterization, the unconditional density $G(\theta) = \bar{G}_x(\theta;\kappa_0)$ is proportional to that displayed in Figure 5. This distribution is very steep, around $\theta = 0.28$, which is the threshold for socially efficient projects θ_P. That implies that many bad entrepreneurs are in the inefficiency zone relative to the few that are socially efficient.

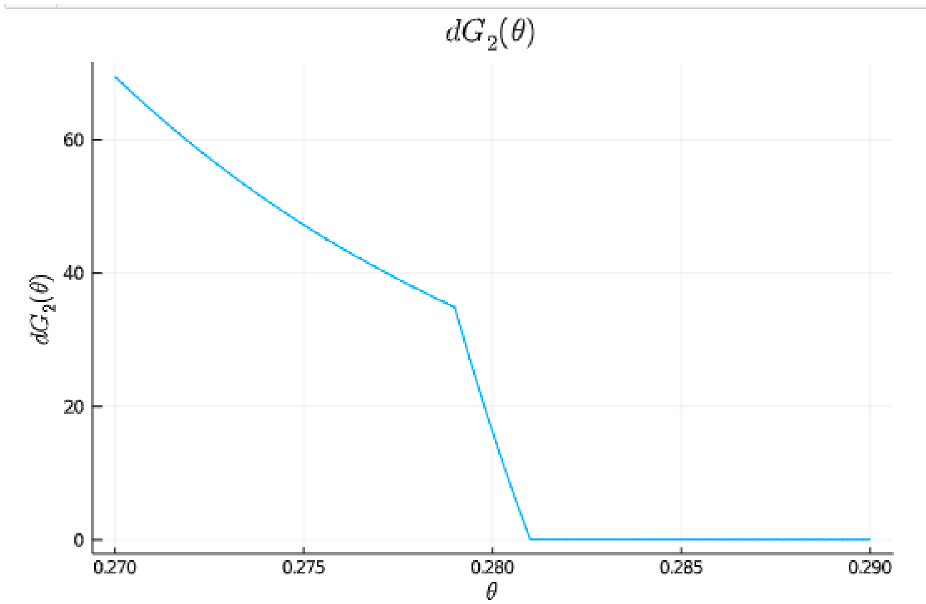


Figure 5: Unconditional Type Density for the Extreme Parameterization

We set the conditional densities $G(\theta|l) = \bar{G}_x(\theta;\kappa_l = -1.0)$ and $G(\theta|h) = \bar{G}_x(\theta;\kappa_h = -0.99)$. Keeping the parameters close makes the signal informative but very weak. The conditional distributions are very close to each other and to the unconditional one. However, this small change is enough to generate significant movement relative to the (meagre) full information social surplus. Table 3 shows the comparison of the OIE and the PVCE.

First, focusing on the PVCE, it is remarkable that the lowest type taking a contract is just below the socially efficient type, $\theta_L^{PVCE} = 0.2792$ vs $\theta_P = 0.28$. But the inefficiency destroys about one third of the surplus generated by the socially efficient entrepreneurs.

Looking at the OIE, the low-signal market almost collapses. The lowest type contracting in that market θ_L^l is very close to the lowest efficient type θ_P, but this is because there are almost no efficient types in this sub-market. The socially efficient types with low signal account for 11.2% of the socially efficient surplus, but the inefficient types destroy 2.8%.

The most striking part is the high signal sub-market. There the lowest type contracting θ_L^h is just below the one at the PVCE: 0.2790 vs 0.2792. But this small movement is enough to attract many more socially inefficient entrepreneurs given the steepness of the distribution.

Table 3: Equilibrium Comparison under Extreme Parameterization

	Submarket	θ_L^m	Inefficiency[1]	Surplus[1]
OIE	$m=l$	0.2797	2.8%	8.4%
	$m=h$	0.2790	31.9%	56.9%
	Total	-	34.7%	65.3%
PVCE		0.2792	33.8%	66.2%
FITS		0.28	0%	100%

[1] % of aggregate efficient surplus.

Crucially, the social surplus destroyed by an entrepreneur of type $\theta = 0.2791$ is significantly higher than the one destroyed by one of a type closer to θ_P, like $\theta = 0.2976$. When added, the total surplus in the OIE is below that of the PVCE.

While theoretically important, it is important to highlight that the previous result relied on a very extreme skill distribution and a faint signal. The generic results are akin to those on the baseline exercise.

5 Quality of Selection Advantage

Coming back to the baseline parameterization where CVC inclusion was welfare improving, we will now focus on the effects of the breadth and depth of the corporation's knowledge.

5.1 Selection Advantage Depth

We relate the depth of the selection advantage as the difference between the entrepreneur skill distributions faced by CVCs and PVCs. To isolate the effect of knowledge, we fix the unconditional skill distribution as $G(\theta) = \bar{G}(\theta; \kappa = 0.25)$ form the baseline distribution family: $d\bar{G}(\theta; \kappa) = 2(1-\kappa) - 2(1-2\kappa)\theta$. We also keep constant the fraction of entrepreneurs receiving a high signal: $\omega = 25\%$.

The exercise consists of varying the parameter κ_1 for the type distribution conditional on a high signal $G(\theta|h) = \bar{G}(\theta; \kappa_1)$ from 0.25 to 1.0. For each κ_1 we find the parameter κ_0 such that by defining the type distribution conditional on a low signal as $G(\theta|l) = \bar{G}(\theta; \kappa_0)$, we recover the unconditional distribution as in equation (15). At the lower bound for κ_1, the conditional distributions are both identical to the unconditional one, while at the upper bound we reach the baseline case from the previous section.

For each κ_1 we find the OIE and calculate the relative inefficiency to the full information surplus, as in equation (14). Since the unconditional distribution is held constant, both the

FITS and the PVCE stay constant.

$$\mathcal{I}_{OIE}(\kappa_1) = \frac{0.75}{FITS}\int_{\theta_L^l}^{\theta_P} \big(w - S(\theta)\big) d\bar{G}\big(\theta; \kappa_0(\kappa_1)\big) + \frac{0.5}{FITS}\int_{\theta_L^h}^{\theta_P} \big(w - S(\theta)\big) d\bar{G}(\theta; \kappa_1)$$

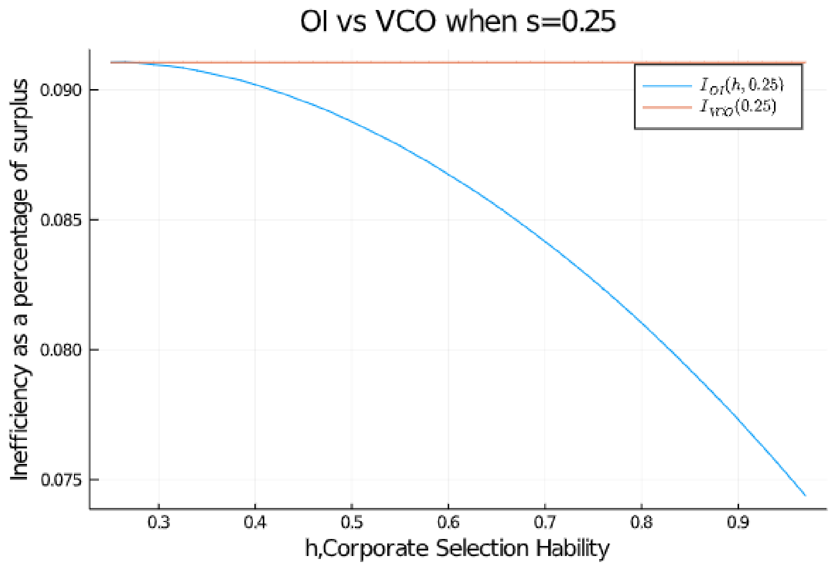


Figure 6: Relative Inefficiency for Varying Selection Advantage Depth

Figure 6 shows the relative inefficiency of the PVCE and the OIE for various levels of signal depth κ_1. As expected, the greater the differentiation among entrepreneurs, the lower the inefficiency.

5.2 Selection Advantage Breadth

We relate the breadth of the selection advantage as mass of those entrepreneurs for which the CVCs have additional knowledge. We again keep fixed the unconditional skill distribution as $G(\theta) = \bar{G}(\theta; \kappa = 0.25)$. In this case, we also fix the *high* signal depth $\kappa_1 = 1.0$ hence $G(\theta|h) = \bar{G}(\theta; \kappa_1 = 1.0)$.

The exercise consists of varying the fraction of entrepreneurs receiving the high signal $\omega_h = 1 - \omega$ from 0.0 to 0.25. For each ω_h we find the parameter κ_0 such that by defining the type distribution conditional on a low signal as $G(\theta|l) = \bar{G}(\theta; \kappa_0)$, we recover the unconditional distribution as in equation (15). As in the depth exercise, at the lower bound for ω_h, the conditional distributions are both identical to the unconditional one, while at the upper bound we reach the baseline case from the previous section.

For each ω_h we find the corresponding low signal distribution parameter $\kappa_0(\omega_h)$OIE and calculate the relative inefficiency to the full information surplus:

$$\mathcal{I}_{OIE}(\omega_h) = \frac{1-\omega_h}{FITS}\int_{\theta_L^l}^{\theta_P} \big(w - S(\theta)\big) d\bar{G}(\theta; \kappa_0(\omega_h)) + \frac{\omega_h}{FITS}\int_{\theta_L^h}^{\theta_P} \big(w - S(\theta)\big) d\bar{G}(\theta; \kappa = 1.0)$$

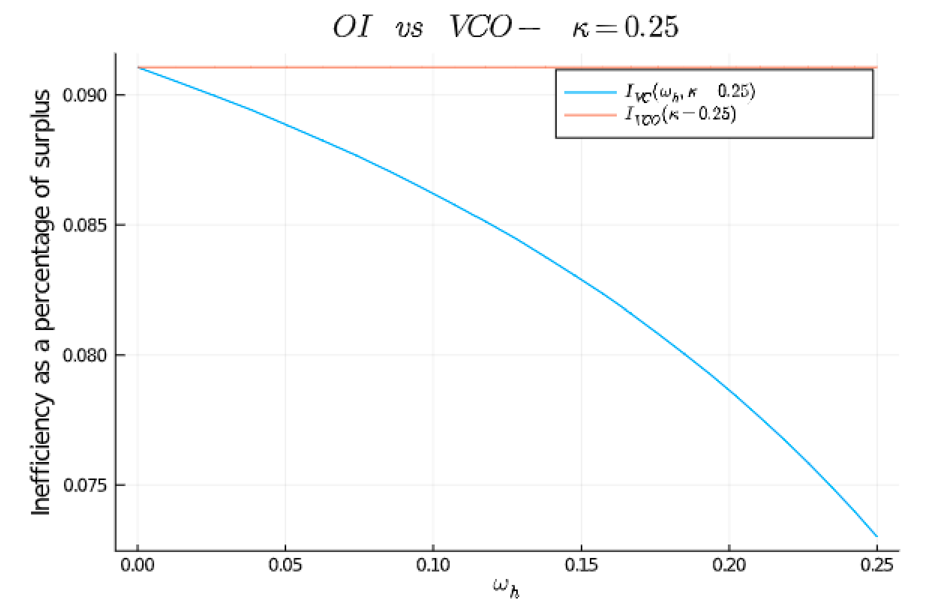


Figure 7: Relative Inefficiency for $\kappa = 0.25$ and Comparative Static for the Open Innovation Equilibrium

Figure 7 shows inefficiency is decreasing in the share of high signal entrepreneurs. As CVCs selection breadth increases, they separate more above average entrepreneurs from the rest, and this separation increases welfare.

6 Concluding Remarks

We developed a theoretical framework for corporate ventures where corporations' *know-how* gives them an advantage over regular financiers in identifying profitable projects. We characterized the financial contracting equilibrium when corporations and venture capitalists compete to fund entrepreneurs.

In our environment, risk, adverse selection, and limited liability constrained both types of financiers. The expected surplus of each project is independent of the lender, and their efficient scale differs among entrepreneurs. We name the equilibrium with both corporate and private venture capitalists as the Open Innovation Equilibrium (OIE), and compare it with the equilibrium with only Private Venture Capitalists (PVCs).

We find that, under the optimal contract in the OIE, corporations leverage on their private knowledge to fund startups that *on average* are more likely to succeed.

While both equilibria fail to achieve the full information total surplus, we find that the introduction of corporations into the financial market could be detrimental to welfare when corporations' selection advantage is small. That is, the social surplus of the OIE could be below that of the PVCE.

However the previous result hinges on a very extreme entrepreneur quality distribution and parameterization. Under a baseline, generic skill distribution, Open Innovation scenario has a higher surplus than the PVCE. Corporate venture capitalists' knowledge reduces the extensive margin inefficiency arising from adverse selection, meaning less socially inefficient projects are undertaken. A numerical approach corroborates this insight. We also show that increasing the depth or breadth of corporations knowledge leads to higher aggregate gains.

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A Extreme Parameterizaton

As mentioned above, we tweaked some parameters relative to the baseline, as described in Table 2. We set $\alpha = 1$ to have an analytical solution for $k^F(\theta)$. The outside-option wage for the entrepreneur (w) was set to have control of the location of θ_P the lowest socially efficient type, $\theta_P = 0.28$, which is always independent of the type distribution.

A.1 The Distribution Family

The type distribution is such that the amount of bad entrepreneurs grows quickly as the type moves just below θ_P. We use a family of such distributions ordered by the MLRP by one parameter $\bar{G}_x(\theta;\kappa)$.

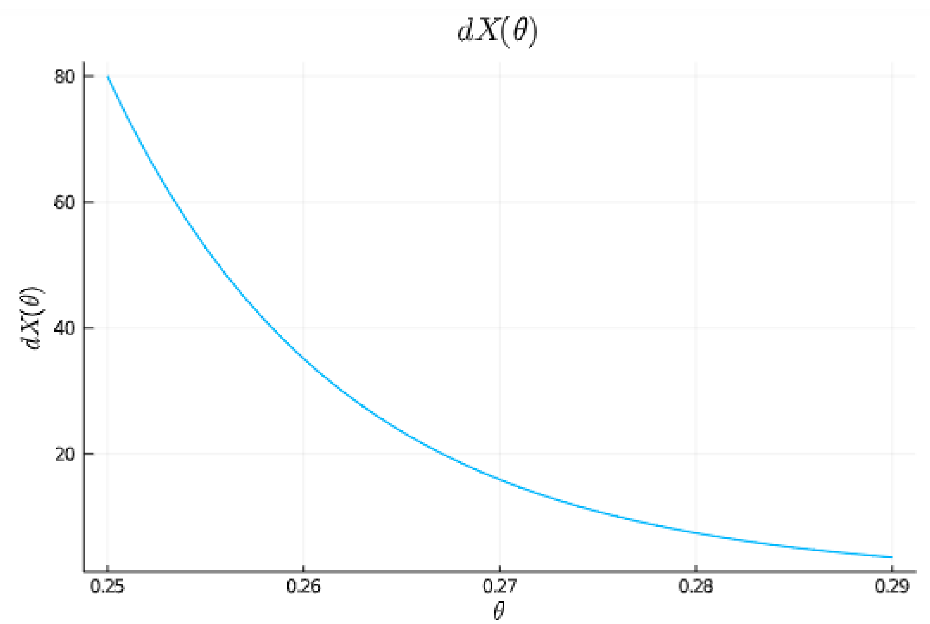

Figure 8: Truncated Pareto Distribution Density $X \sim Pareto^T(0.25, 20)$

As a basis for the family we use a truncated Pareto distribution: $X \sim Pareto^T(0.25, 20)$ with lower bound parameter $\theta = 0.25$ and shape parameter 20. Figure A.1 shows there is considerable mass below 0.28 and relatively little above. The problem with Pareto distributions is that they are not ordered in the MLRP sense by their shape parameter. Hence we take a different approach, and we will say for each type θ and distribution parameter $\kappa \in [-1, 1]$ the pdf $d\bar{G}_x(\theta;\kappa)$ is defined, up to a constant, as:

$$d\bar{G}_x(\theta;\kappa) \sim (1 + \kappa \cdot m(\theta))dX(\theta), \tag{16}$$

where $m(\theta)$ is a strictly increasing function with range contained in (-1,1). This setup serves two purposes. First, the monotonicity of the function $m(\theta)$ implies the monotonicity of the likelihood ratio for different values of κ, which is up to a constant:

$$\frac{d\bar{G}_x(\theta;\kappa)}{d\bar{G}_x(\theta;\kappa')} \sim \frac{1+\kappa\cdot m(\theta)}{1+\kappa'\cdot m(\theta)}.$$

Then, $\kappa' > \kappa$ implies $\bar{G}_x(\theta;\kappa') \succ \bar{G}_x(\theta;\kappa)$ in the MLRP sense. Second, the mixture of two distributions of the family yields another distribution of the same family. This will be useful for the definition of the signal and the selection advantage.

In this setup, $m(\theta) = \max\left\{-0.999+0.001\theta, \min\left\{0.999+0.001\theta,\ 1000(\theta-0.28)\right\}\right\}$, which is a function that varies from -1 to 1, and has a steep section around 0.28 with a slope of 1000:

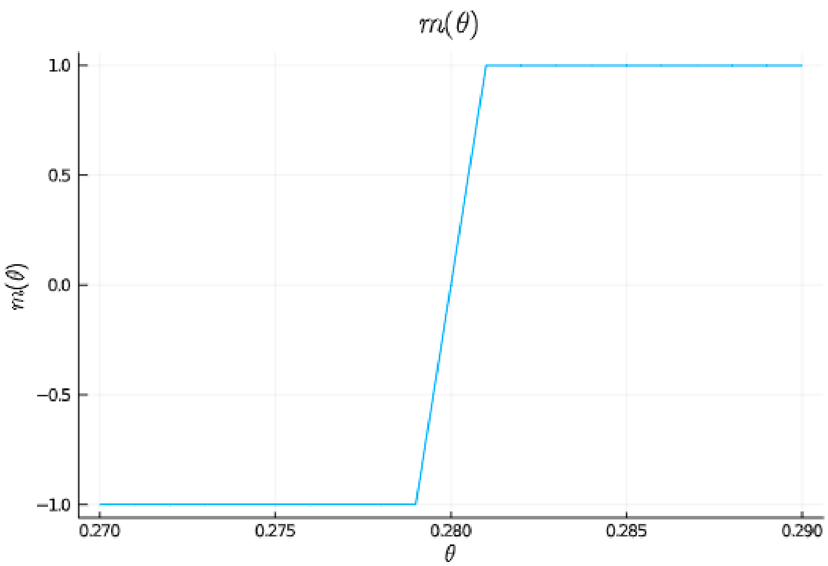

Figure 9: Function $dG_2(\theta;\kappa=-0.995)$

A.2 The Signal

We begin with an unconditional distribution $G(\theta) = \bar{G}_x(\theta;\kappa_0)$ determined by the parameter κ_0. Let κ_l and κ_h be the parameter associated with the low and high signals such that $0.5\kappa_l + 0.5\kappa_h = \kappa_0$

For each θ we define the probability of receiving a *low* signal as:

$$P(l|\theta) = 0.5\frac{1+\kappa_l\cdot m(\theta)}{1+\kappa_0\cdot m(\theta)},$$

and conversely the probability of receiving a high signal conditional on θ is:

$$P(h|\theta) = 0.5\frac{1+\kappa_h\cdot m(\theta)}{1+\kappa_0\cdot m(\theta)}.$$

Using Bayes theorem, we find the conditional distribution of types given the low signal:

$$dG(\theta|l) \sim P(l|\theta)\cdot dG(\theta) \sim \frac{1+\kappa_l\cdot m(\theta)}{1+\kappa_0\cdot m(\theta)}\cdot(1+\kappa_0\cdot m(\theta))dX(\theta) = (1+\kappa_l\cdot m(\theta))dX(\theta),$$

hence $G(\theta|l) = \bar{G}_x(\theta; \kappa_l)$ and analogously $G(\theta|h) = \bar{G}_x(\theta; \kappa_h)$. The share of types receiving the low signal ω is defined implicitly. Recall that equation (16) defines the distributions $\bar{G}_x(\theta; \kappa)$ up to a constant. Let (c_l, c_0, c_h) be those constants for $(\kappa_l, \kappa_0, \kappa_h)$, then $\omega \frac{c_l}{c_0} = 0.5$. The following equality is useful for sampling and computing the relative surplus and inefficiency.

$$\begin{aligned}
dG_2(\theta; \kappa_0) &= \omega dG_2(\theta; \kappa_l) + (1-\omega) dG_2(\theta; \kappa_h) \\
c_0(1 + \kappa_0 \cdot m(\theta))dX(\theta) &= \omega c_l(1 + \kappa_l \cdot m(\theta))dX(\theta) + (1-\omega)c_h(1 + \kappa_h \cdot m(\theta))dX(\theta) \\
(1 + \kappa_0 \cdot m(\theta))dX(\theta) &= 0.5(1 + \kappa_l \cdot m(\theta))dX(\theta) + 0.5(1 + \kappa_h \cdot m(\theta))dX(\theta).
\end{aligned}$$

We set $\kappa_l = -1.0$, $\kappa_h = -0.99$ and $\kappa_0 = -0.995$. Under the extreme parameterization, the unconditional density $G(\theta) = \bar{G}_x(\theta; \kappa_0)$ is proportional to the one displayed in Figure 5. This distribution is very steep around $\theta = 0.28$ which is the threshold for socially efficient projects θ_P. That implies a many bad entrepreneurs are in the inefficiency zone relative to the few that are socially efficient. Even at this scale, in a figure depicting the three distributions in the relevant domain $[0.27, 0.29]$ they cannot be distinguished.

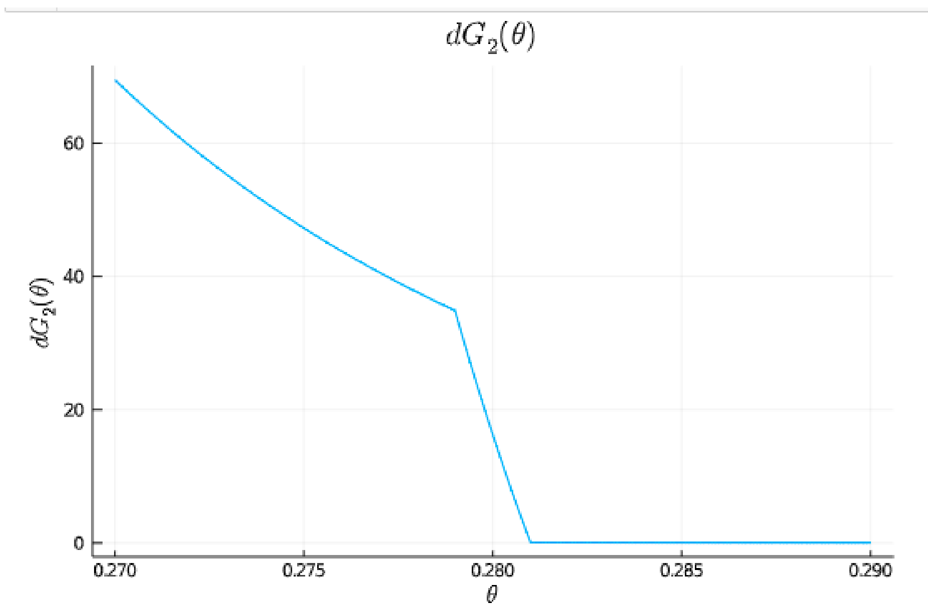

Figure 10: Unconditional Type Density for the Extreme Parameterization

B Baseline Numerical Results

All the parameters and functional forms used in the numerical example are summarized in Table 2.

B.1 Type Distribution Family

Given density family: $d\bar{G}(\theta; \kappa) = 2(1-\kappa) - 2(1-2\kappa)\theta$, we describe some of their underlying statistical properties, and how they relate to those distributions the used in the literature.

This family is ordered in Monotone Likelihood Ratio Property (MLRP) by the κ parameter. A higher κ leads to a more right-shifted density function of entrepreneurs' types. This shift in the distribution can be measured as the distribution third moment, skewness. For distributions in this family, the skewness range is $\tilde{\mu}_3(\kappa) \in [-0.55, 0.55]$ and it is decreasing in κ, $\tilde{\mu}_3(\kappa)' < 0 \quad \forall \kappa \in [0,1]$. This skewness is considerably lower to the level of 20 used by Saffie and Ates (2013), where the skewness of potential entrepreneurs is the critical parameter for their quantitative results. We can only expect our results to strengthen when introducing more convoluted and skewed densities.