Adverse Selection and Financing of Innovation: Is There Need for R&D Subsidies*

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October 26, 2008

Abstract

We study the interaction of private and public funding of innovative projects in the presence of adverse-selection based financing constraints. Government programs allocating direct subsidies are based on ex-ante screening of the subsidy applications. This selection scheme may yield valuable information to market-based financiers. We find that under certain conditions, public R&D subsidies can reduce the financing constraints of technology-based entrepreneurial firms. First, the subsidy itself reduces the capital costs related to the innovation projects by reducing the amount of market-based capital required. Second, the observation that an entrepreneur has received a subsidy for an innovation project provides an informative signal to the market-based financiers. We also find that public screening works more efficiently if it is accompanied with subsidy allocation.

JEL classification: D82, G28, H20, O30, O38

Keywords: adverse selection, innovation finance, financial constraints, R&D subsidies, certification

*We thank four anonymous referees for extensive comments. We also thank Ari Hyytinen, Saul Lach, Mikko Leppämäki, Pere Ortín Ángel, Petri Rouvinen, Javier Suarez, Otto Toivanen, John Van Reenen, Timo Vesala, Juuso Välimäki and seminar audiences at the University of Jyväskylä, conference on the Dynamics of SBEFs in Sestri Levante, the 34th EARIE conference in Sevilla, Bank of Finland and Helsinki School of Economics for comments. We gratefully acknowledge financial support from the Finnish Funding Agency for Technology and Innovation (TEKES). Tanayama also thankfully acknowledges funding from the Foundation of Finnish Cooperative Banks.

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1 Introduction

Previous research suggests asymmetric information about the quality of an innovation project between an entrepreneur and an financier leads to a higher cost of external than internal capital, creating a funding gap. This funding gap may prevent especially small and new technology-based entrepreneurial firms from undertaking economically viable innovation projects. This observation has provided grounds for government intervention aimed at reducing financing constraints of technology-based start-ups. One widely-used policy tools is direct subsidies to corporate R&D. However, the theoretical literature linking financing constraints and R&D subsidies is scant.[1] We develop a theoretical model to analyze how a governmental R&D subsidy program works in the presence of financial constraints created by asymmetric information.

Since Akerlof (1970), huge literature singles out adverse selection stemming out from informational asymmetries between entrepreneurs and financiers as a major source of financing constraints. These informational problems are acknowledged to be particularly severe in financing of R&D projects (Alam and Walton 1995, and Hubbard 1998). R&D activities typically involve soft information that is hard to verify. Hence, if adverse selection related financing constraints exist, they should be especially relevant to science and technology-based start-ups whose main assets are founders' human capital and intellectual property. Moreover, the standard solutions provided to the adverse-selection problem - signaling, reputation and financial intermediation - are more likely to fail in the case of science and technology-based start-ups.[2] Such firms cannot have acquired reputation nor assets that can be offered as collateral and credit worthiness of these firm is difficult to assess. Even venture capital and related organizations that are often regarded as the solution to innovation financing may fail to provide an adequate solution to the financing of science and technology-based start-ups (see, e.g., Hall 2002, and Lerner 1998, 2002).[3] There is indeed

[1] The majority of earlier studies are based on the view that government intervention in R&D is needed because social benefits of R&D are higher than their private returns. Subsidies and their allocation are taken as given and the focus is on analyzing how R&D subsidies affect firm behavior (e.g., Stenbacka and Tombak 1998, and Maurer and Scotchmer 2004).

[2] On signaling see Leland and Pyle (1977) and Bester (1985), on reputation see Diamond (1989), and on financial intermediation see Diamond (1984) and Chan, Greenbaum and Thakor (1986).

[3] Only a modest number of firms in specific sectors receive venture capital funding each year and venture capital investments tend to be too large for the smallest firms. A well-functioning venture capital market requires a well-functioning small and new firm stock market enabling viable exits from venture capital investments. Such exit opportunities for venture capital investors are limited in most countries. The threat of expropriation may also undermine

abundant empirical evidence that R&D investment are sensitive to cash flow, at least in the case of newly established, small, technology-based firms (e.g. Hall 1992, Hao and Jaffe 1993 , Himmelberg and Petersen 1994, Bond, Harhoff and Van Reenen 2003, and Bougheas, Görg and Strobl 2001).[4]

A major objective of the governmental R&D subsidy programs is to reduce these constraints on financing of innovation. In contrast to some other innovation policy tools such as R&D tax credits, government programs allocating direct subsidies are based on ex-ante screening of the applications. Despite the wide use of R&D subsidy programs the functioning of these programs and the related screening process has been little explored in the theoretical literature.

We model a situation in which capital constrained entrepreneurs can try to tap a public agency for funding in addition to private funding sources and analyze whether R&D subsidy policies can reduce adverse-selection based financing constraints. Our aim is thus to provide a positive analysis of application and allocation of R&D subsidies rather than normative welfare analysis of R&D subsidies. More specifically we address two questions: i) When is it worthwhile for the government to invest in ex ante screening of subsidy applications? ii) Could a subsidy provided by a public agency act as a certification for an unknown entrepreneur and ease her possibilities to secure funding from market-based financiers. While the idea of certification by a trusted financial intermediary is pervasive in the corporate finance literature, to the best of our knowledge, it has not been previously applied to the public funding of corporate R&D (but see Lerner 2002 for an informal discussion). Certification hypothesis emphasizes the role of government screening activities that are inherent in R&D subsidy programs but overlooked by the literature.

The main results are summarized as follows. First, government screening activities are more valuable if the proportion of entrepreneurs with economically non-viable projects is non-negligible and the screening costs are low enough. The former condition is needed to guarantee the existence of adverse-selection based financing constraints, while the latter prevents unsustainable screening activities. Second, the government's incentives to screen are increasing in the subsidy amount. As entrepreneurs anticipate that screening increases with the

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screening activities (Bhattacharya and Ritter 1983, and Ueda 2004). In addition, even venture capital organizations are likely to favor firms with some track records over pure start-ups (Amit, Brander and Zott 1998)

[4]As usually, there is also some contradictory evidence. For example, Blass and Yosha (2003) do not find indication of financing constraints when studying publicly traded R&D-intensive manufacturing firms in Israel. However, publicly traded firms can be considered as relatively large and well-established, which are less likely to suffer from financing constraints.

subsidy amount, larger subsidies can *deter* the entrepreneurs with low quality projects from applying. In other words, government project screening is more credible if it is accompanied with subsidy allocation. Third, it turns out that the provision of R&D subsidies and the related screening may help financially constrained entrepreneurs to finance their projects. The effect comes through two channels. First, the subsidy itself reduces the capital costs related to the innovation projects by reducing the amount of market-based funding needed. Second, the observation that an entrepreneur has received a subsidy for an innovation project provides an informative signal to the market-based financier. Finally, the findings suggest that under certain conditions R&D subsidy policy may be welfare improving.

Our modeling framework builds on Holmström and Tirole (1997), which has subsequently been used to study entrepreneurial finance, e.g., by Repullo and Suarez (2000) and Da Rin, Nicodano and Sembanelli (2005). These papers highlight the role of interim monitoring by informed financiers (banks or venture capital organizations) in mitigating moral hazard problem and in bringing along less well-informed investors. Instead of moral hazard, we focus on adverse selection created by ex-ante informational asymmetries, and the role of screening and signaling by a public funding agency in reducing financing constraints. Our starting point is that banks are not informed enough and venture capital markets do not function well enough to eliminate financing constraints of small, innovative firms. We analyze under which circumstances R&D subsidies allocated by a public agency could improve the situation.

While the theoretical literature linking R&D subsidy programs and financial constraints is limited, much more work has been done on the need to subsidize entrepreneurs or their finance in the presence of asymmetric information arising from the influential contributions by Stiglitz and Weiss (1981) and de Meza and Webb (1987). As summarized by Boadway and Keen (2005), the results depend on what are assumed about the project return distributions. In particular, adverse selection may generate too much lending to entrepreneurs rather than financing constraints. In our model, too, the beneficial effects of subsidies are more limited if the problem caused by adverse selection is overinvestment rather than financing constraints. This literature, however, abstracts from signaling role of subsidies as well as from social benefits of R&D.

The design and the institutional setting of the R&D subsidy program modeled in this paper are inspired by the Finnish institutional environment, but the situation we describe is common in many countries where public R&D subsidy programs are in place and the markets for private start-up finance are imperfect.[5]

Section 2 describes the model. Section 3 identifies the funding gap by analyzing entrepreneurs' possibilities to fund their innovation projects in the absence of subsidies. Section 4 presents a dynamic game of incomplete information describing the subsidy application and allocation process. The section concludes with the equilibrium strategies of both the public agency and the entrepreneurs. Section 5, links public and market-based financiers to analyze the effects of subsidies on the funding gap. Section 6 concludes the paper.

2 The Model

The model has three types of risk-neutral agents: (potential) entrepreneurs, market-based financiers, and a public financier. As will be specified below, entrepreneurs have some initial wealth but are nonetheless capital constrained and need to seek funding from external financiers to be able to launch their projects. The entrepreneurs are heterogeneous in terms of their type ("talent"), which determines the productivity of their projects. Following the convention in the literature (see, e.g., de Meza and Webb 1987 and Boadway and Keen 2005), we assume that the entrepreneur's type is her private information but the level of her initial wealth is common knowledge (or at least verifiable). We proceed as if entrepreneurs first tried to seek public funding before turning to private sources but we could equally well assume that entrepreneurs first contacted market-based financiers who would make their funding decisions contingent on the public funding decision. We will look for Perfect Bayesian equilibria (PBE), which require that at each stage of the game, the agents' strategies are optimal given their beliefs, and the beliefs are obtained from equilibrium strategies and observed actions using Bayes' rule.

[5]In particular, the R&D subsidy program we have in mind is the one operated by the National Funding Agency for Technology and Innovation in Finland (Tekes). Georghiu et al. (2003) describe Tekes and the Finnish innovation policy, and Hyytinen and Pajarinen (2002) document the financing problems encountered by newly established technology-based firms in Finland. Some other examples of related R&D subsidy programs include the Advanced Technology Program (ATP) and the Small Business Innovation Research (SBIR) Program7 in U.S., R&D subsidy programs in Israel, R&D grants allocated by the Federal Ministry of Research and Education in Germany, and R&D subsidy program of the Institute for the Promotion of Innovation by Science and Technology in Flanders (IWT) in Belgium.

2.1 Entrepreneurs

There is a continuum of entrepreneurs who have access to an innovation project requiring an investment of size I. The projects have a two-point return distribution: A fraction of p of the entrepreneurs are high (H) types having access to a positive net-present value (NPV) project, the rest $(1-p)$ are low (L) types with a negative NPV project. Let λ_i and R_i denote the project success probability and the project return conditional on success of an entrepreneur of type i,$i \in \{H, L\}$. A failed project yields zero irrespective of the entrepreneur's type. Following Holmström and Tirole (1997), we assume that $\lambda_H > \lambda_L$, $R_L > R_H$, $\lambda_H R_H > I > \lambda_L R_L$.[6]

Entrepreneurs differ in the amount of their initial capital (cash) A, which is distributed across entrepreneurs according to a cumulative distribution function *G(A)*, and it is independent of the entrepreneur's type. No entrepreneur has more than I of initial wealth, so *G(A)* is defined on interval $[0, I]$. A project is initiated only when an entrepreneur invests all her initial capital in her own project and manages to raise the rest of the required funds $I - A$ from other sources.[7]

2.2 Public financier

One source of finance is public funding provided by a public agency which is called Government in the following. This public funding is a pure subsidy that needs not to be paid back but it needs to be applied for. To apply for the public funding, an entrepreneur needs to incur a fixed cost of c. In practice, application process involves both monetary and non-monetary costs, such as the costs of filling and filing the application form and providing the necessary supplementary data, the opportunity costs of time and effort that the application process consumes. Since allowing for both monetary and non-monetary costs would be

[6] In words, project return distributions are characterized by second-order stochastic dominance (but not mean preserving spread). The same assumption is also used e.g. in de Meza and Webb (2000). The practical interpretation of project return distributions is that low-type entrepreneurs are overly optimistic or have unrealistic projects.

[7] In accordance with the pecking-order hypothesis (Myers and Majluf 1984), in equilibrium, it is cheaper for H-type entrepreneurs to use their own funds than raise funds from outside. As a result, L-type entrepreneurs have no other option but to follow and invest all their initial capital in their own projects. Since there is no outside collateral in the model, collateral requirements cannot be used as a screening device. As well-known, if potential entrepreneurs had non-liquid (outside) wealth, collateral requirements would facilitate emergence of a separating equilibrium (see, e.g., Bester 1985).

unnecessarily complicate the analysis, we assume that c is a monetary cost.[8] This means that if the entrepreneur applies for a subsidy, the total size of the project will be $I + c$ instead of I.

For simplicity, we assume that Government can give a fixed subsidy (S) to any project to which public funding is applied for. Government's budget constraint does not bind, but the use of public funds involves an opportunity cost of $1 + g$ $(0 < g < 1)$.[9] A successful project may generate social benefit to Government beyond the private return R_i. Such social benefit covers the externalities generated by the project including, e.g., spillovers and consumer surplus. More specifically, we assume that private and social benefits are positively correlated: a successful project of a high-type entrepreneur generates a social benefit W to Government whereas a low-type entrepreneur's project generates no social benefit irrespective of its success.

As will be clear later, assuming that only successful high-type projects generate social benefits is not crucial for any of the main qualitative results of the paper. For example, by letting $W = 0$ our results immediately generalize to the usual case analyzed in the literature of entrepreneurial finance where no project yields social benefits beyond private returns. We could also equally well assume that a low-type entrepreneur's project generates social benefits in so far the net welfare of the low-type's project remains negative. Similarly, we could assume that failed projects generate societal benefits in so far such benefits are small enough. While we think that positive correlation between private and social returns is both realistic and theoretically sound, this assumption could also be relaxed. Such a change or assuming a positive net welfare of the low-type entrepreneur's project would modify the welfare implications of the model but not its basic structure.

Government does not observe the types of entrepreneurs but has an access to a screening technology. If Government receives an application for a subsidy from an entrepreneur, Government can learn the type of the entrepreneur by screening the application. For simplicity, we assume that screening is costly but perfect:

[8]This is without loss of generality. Note, however, that opportunity costs, too, show up in a balance sheet to the extent the application process requires hiring of specific personnel or outsourcing.

[9]While the assumptions of a fixed subsidy and the absence of Government's budget constraint are used elsewhere in the literature (see, e.g., Maurer and Scotchmer 2004), they should clearly be relaxed in future research. However, the assumptions are perhaps not so strong as they may sound from the outset. For example, in practice subsidy per entrepreneur is often capped to a certain limit and such capping can be optimal in the presence of adverse selection (Fuest and Tillessen 2005).

by incurring a screening cost σ, Government can verify the entrepreneur's true type. A major task of the personnel in the public funding agencies is to evaluate project proposals and they are classified in many dimensions. Such screening is obviously costly. While the cost of screening per application is fixed in our model, in equilibrium Government will screen an application with some positive probability and this probability measures the intensity of screening.[10]

2.3 Market-based financier

Entrepreneurs can also try to tap private sources for funding. Private funding involves no application costs but entrepreneurs need to pay the market rate for such funding. Private sector financiers have access to unlimited supply of financial capital. They are competitive and the required expected rate of return on investor capital is exogenous and normalized to unity.

The market-based financiers posses no screening technology and only know the share of high-type entrepreneurs in the population. When contemplating whether to extend funding to an entrepreneur or not, market-based financiers observe whether the entrepreneur has received a subsidy from Government or not, and they know Government's objective function. If the entrepreneur applied for the subsidy, the market-based financiers do not observe whether Government screened the entrepreneur or not. Nor do they observe whether an entrepreneur without a subsidy actually applied for the subsidy but in equilibrium this is immaterial.

Our assumption that project screening is optimal for Government but not for external financiers is of course strong, but it is not essential for our results. We only need to assume that Government's subsidy decisions are not completely random so that the subsidy decision contains some valuable information to the market.[11] If one wants to take the assumption literally, it could be motivated by a benevolent public financier's interest in the aggregate welfare generated by the project. That is, the public financier's objective function should also

[10] In other words, we assume imperfect commitment to screen but perfect screening technology. Assuming perfect commitment but imperfect technology would yield identical results. From a more practical point of view, the assumption of perfect screening technology only means that Government can identify the prospects of projects according to its own predetermined criteria. Such criteria of the public R&D funding policies are generally related to expected social and private returns of the innovation projects.

[11] In other words, we could assume that market-based financiers have a better screening technology than Government or that receiving a subsidy from Government offers a negative signal of the entrepreneur's type. The assumptions we have done now are the simplest that allow Government's screening to provide valuable information to the market.

include the externalities generated by the project besides the financial return. In contrast, market-based financiers only care about the financial return. This is what we assume: a successful high-type projects generates a social benefit W to Government beyond the beyond the private return R_i. Therefore the assumption that the public financier is better motivated to screen projects than private financiers is line with our model.

Moreover, there are several factors that may dilute the incentives of market-based financiers to engage in screening activities, especially in the case of a small country like Finland. First, the public financier is often granting project specific funding, whereas private financiers, especially those using debt finance, typically operate at the firm level. Second, since screening is a public good, private financiers can suffer from a free-riding problem. A public screening agency can offer a solution to the free-riding problem, but at the same time reduce the incentives of the private sector to engage in screening. Third, a subsidy in itself should also reduce the stake the private financiers need to take in the project, which further dilutes their incentives to screen. So if a public screening and funding agency exists for some reason, it may worsen the free-riding problem by giving an additional incentive for the private financiers to economize on screening investments.[12] Fourth, in the Finnish case at least, the public financier constitutes a centralized screening device that has massive resources to screening. It receives a large amount of applications that it can compare against each other. As a result, the public financier could be expected to have quite a good overview about the state of the art in each relevant field. Fifth, according to the so called competition-stability tradeoff, competition in banking sector can reduce banks' information surplus and thereby their incentives to gather information (e.g., Keeley 1990).[13] Information reusability can also be hampered by intertemporal volatility of borrower credit risks (Chan et al. 1986). Moreover, financial innovation has enabled the intermediaries to transfer credit risk off their balance sheets, which may have undermined their incentives to screen new borrowers.

[12]The free-riding problem among investors is traditionally given as a rationale for the existence of financial intermediaries (e.g., Diamond 1984) who monitor or screen entrepreneurs on the behalf of small, dispersed investors. However, the literature has overlooked the possibility that large governmental investments in screening do not leave room for a private sector solution to emerge. We emphasize that private incentives to screen deteriorate even if the public screening is of poor quality or there is negative correlation between public and private funding objectives.

[13]The existence of competition-stability tradeoff is of course debatable but it may especially apply for project-level financing (Hauswald and Marquez 2006).

Following Myers and Majluf's (1984) pecking-order hypothesis, we assume that to the extent an entrepreneur's initial wealth and her public funding is insufficient, the entrepreneur issues debt to market-based financiers. We consider risky debt contracts that give a financier fixed payment in the case of success and zero in the case of failure. In principle this does not require all entrepreneurs to have the same repayment obligation. Since the market-based financiers are uninformative, our focus on debt financing is not entirely implausible. Moreover, such risky debt contracts are optimal when project success is verifiable but returns are not[14], and we restrict our attention to a "realistic" subspace of contracts where i) parties are protected by limited liability; ii) markets must clear[15]; and iii) the financial contract cannot specify a positive reward for an entrepreneur to refrain from investing.[16]

3 Innovation Finance without Public Funding

The case without public support of innovation reduces to a fairly standard model of entrepreneurial finance under incomplete information. In our set-up the entrepreneurs differ in the amount of initial capital they posses, and our focus is to determine how the composition of entrepreneurs receiving market-based financing depends on the amount of their initial capital.

In the absence of public funding, there are three periods beyond the initial determination of types.

[0.] Nature draws a type $i \in \{L, H\}$ for an entrepreneur. Probabilities of a high type and a low type are $p$and $1-p$, $0<p<1$.
[1.] The entrepreneur observes her type and decides whether to seek external funding.
[2.] Financiers decide whether to give funding under the terms proposed by the entrepreneur, and the funded projects are executed.
[3.] Project returns are realized, successful entrepreneurs compensate their financiers according to the contract terms.

[14]Equivalently, project returns are verifiable up to R_H as, e.g., in Bolton and Sharfstein (1990). In this case the distinction between debt and equity becomes moot. Following, e.g., de Meza and Webb (2000), we could also assume that instead of verifiable project success, only payments are verifiable and that entrepreneurs cannot hide income in case they default.

[15]Further we rule out the unrealistic possibility that entrepreneurs could publicly destroy their initial wealth.

[16]Optimal security design with full contracting opportunities in the presence of incomplete information and a public funding agency is an intriguing topic for future research.

In the last stage of the game, an entrepreneur and her financier(s) split the return from a successful project so that

$$R_i = R_i^E + R_i^F$$

where R_i^E is the share received by an entrepreneur of type i and R_i^F is her financier's share.

Since the rate of return on capital is assumed to be equal to one, the entrepreneur's participation constraint reads as

$$\lambda_i R_i^E \geq A, \tag{1}$$

which simply means that an entrepreneur is willing to launch the project if her expected profit from the project (in the left-hand side of the equation) is at least as much as the entrepreneur would get from investing the initial capital into alternative sources. When (1) binds,

$$R_i^{F\max} = R_i - R_i^E = R_i - \frac{A}{\lambda_i} \tag{2}$$

captures the i-type entrepreneur's pledgeable income, that is, the maximum amount an entrepreneur of type i could credibly promise to pay back to a financier in the case of success. Note that even if $R_L^{F\max} \geq R_H^{F\max}$ holds and a low-type entrepreneur could offer the financier a larger return, she will not do so as it is not in her interest to reveal her type.

Financiers, who are assumed to be competitive and break even, are willing to invest in a project if the expected return from investing equals the market value of funds supplied, $I - A$. They do not observe the type of the entrepreneur they are facing, but know the proportions of high and low types (p and $1-p$, respectively) in the population and, consequently, put prior probability $\bar{\lambda} = p\lambda_H + (1-p)\lambda_L$ on the success of a project by an average entrepreneur in the population. The minimum repayment F that a financier requires to invest in a project of an average quality is then given by $\bar{\lambda}F = I - A$ or, equivalently, by

$$F = \frac{I - A}{\bar{\lambda}}. \tag{3}$$

As a result, projects can get market-based funding as long as $F \leq R_H^{F\max}$ where $R_H^{F\max}$ is the maximum repayment that a high-type entrepreneur, and by implication, a low-type entrepreneur, are willing to offer to the financier. Using (2) and (3) we can write the inequality as

$$\frac{I-A}{\bar{\lambda}} \leq R_H - \frac{A}{\lambda_H}. \tag{4}$$

Equation (4) is the financier's participation constraint when all entrepreneurs apply for funding. Solving (4) for A gives

$$A \geq \bar{A} \equiv \frac{\lambda_H \left(I - \bar{\lambda} R_H\right)}{\lambda_H - \bar{\lambda}} \tag{5}$$

In (5), $\bar{A}$ gives the threshold value of initial capital needed to get financing, when the financier anticipates all the entrepreneurs to seek financing.

Another important threshold value of initial capital comes from the condition $R_L^{F\max} \geq R_H^{F\max}$. Using (2) to solve this inequality for A gives

$$A \leq \hat{A} \equiv \frac{\lambda_L \lambda_H \left(R_L - R_H\right)}{\lambda_H - \lambda_L}. \tag{6}$$

When (6) holds, the maximum repayment a high-type entrepreneur is willing to promise to the financier if the project succeeds is never higher than what a low-type entrepreneur could promise. This means that when (6) holds, a high-type entrepreneur has no means to truthfully signal her quality even if she had an incentive to do so. We are ready to state our first result (all the proofs of the results of this paper are relegated to the Appendix).

Proposition 1 *High-type entrepreneurs with* $A < min\left\{\hat{A}, \bar{A}\right\}$ *where* $\bar{A} \geq 0$ when $p \leq \frac{I-\lambda_L R_H}{(\lambda_H - \lambda_L) R_H}$ *suffer from the funding gap that prevents them from undertaking economically viable innovation projects.*

Proposition 1 shows that no entrepreneur with $A < min\left\{\hat{A}, \bar{A}\right\}$ receives funding. In other words, there is a funding gap. As the low-type entrepreneurs' projects have a negative NPV, we are only interested in the financing difficulties encountered by high types. Quite naturally, the funding gap emerges when entrepreneurs have relatively little initial wealth and an average project has a negative NPV. When (6) holds, high-type entrepreneurs cannot separate themselves from low-type entrepreneurs and (5) then determines the level of initial capital which is required to get funding when low types are pooling with high types. The latter condition is irrelevant when the share of high types in the population is high enough ($p > \frac{I-\lambda_L R_H}{(\lambda_H-\lambda_L)R_H}$) so that an average project in the population has a positive NPV.

We next describe what will happen when entrepreneurs are wealthier, i.e., when $A \geq min\left\{\hat{A}, \bar{A}\right\}$. From the above analysis we know that all entrepreneurs receive funding when $A \in [\bar{A}, \hat{A}]$. However, for some parameter values all entrepreneurs will continue to be funded even when $A > \hat{A}$. To see this note that when $A > \hat{A}$, $R_H^{F\max} > R_L^{F\max}$, a high-type entrepreneur could truthfully signal her quality, but it is not necessarily in her interest to do so. Given the assumption of competitive financial markets, a financier continues to require F as given by (3) to invest in a project of unknown entrepreneurial quality, as long as also low-type entrepreneurs can afford offering that amount to the financier. This happens when $R_L^{F\max} \geq F$ or, equivalently, when

$$\frac{(I-A)}{\bar{\lambda}} \leq R_L - \frac{A}{\lambda_L}. \tag{7}$$

The left-hand side of (7) is the minimum repayment the financier requires to invest in a project in a pooling equilibrium and the right-hand side is the maximum repayment a low-type entrepreneur is willing to promise to the financier. Solving (7) for A gives us

$$A \leq \dot{A} \equiv \frac{\lambda_L(\bar{\lambda}R_L - I)}{p\,(\lambda_H - \lambda_L)}. \tag{8}$$

A high-type entrepreneur has no incentive to separate herself from a low-type: she should offer at least $R_L^{F\max}$ to a financier to credibly signal her type, but only F is needed to ensure funding.

When $A > \dot{A}$, a low-type entrepreneur can no longer offer F to a financier and will drop out with this interest rate. However, if the financier knew that the entrepreneur seeking funding is of a high-type, $\frac{I-A}{\lambda_H}$ would be a large enough repayment for the financier to be willing to invest in her project. But because $\lambda_H > \bar{\lambda}$, a low-type entrepreneur can offer the financier $\frac{I-A}{\lambda_H}$ for some values of A greater than $\dot{A}$. Solving the inequality $\frac{I-A}{\lambda_H} \leq R_L - \frac{A}{\lambda_L}$ for A gives

$$A \leq \frac{\lambda_L(\lambda_H R_L - I)}{\lambda_H - \lambda_L} \equiv \ddot{A}, \tag{9}$$

Only when $A > \ddot{A}$, the financier knows that only high-type entrepreneurs remain in the pool of loan applicants and are willing to accept $\frac{I-A}{\lambda_H}$. If $\dot{A} < A \leq \ddot{A}$, a low-type entrepreneur can pretend to be of high-type by offering $\frac{I-A}{\lambda_H}$ to the financier. Therefore, when $\dot{A} < A \leq \ddot{A}$, there is a semi-separating equilibrium in which all the high-type entrepreneurs and a share of low-type entrepreneurs are funded.

Figure 1 summarizes different funding regions for various values of initial capital. Given that $\bar{A}$ and $\dot{A}$ depend on the share of high-type entrepreneurs in the population (p), the different regions are presented with coordinates (p, A), $p \in [0, 1]$, $A \in [0, I]$. Note from (6), (5) and (8) that $\hat{A}$ is independent of p whereas $\bar{A}$ is decreasing and $\dot{A}$ is increasing in p, and that the three lines cross each others when $p = \frac{I-\lambda_L R_L}{\lambda_H R_H - \lambda_L R_L}$. When $A < \min\left\{\hat{A}, \bar{A}\right\}$, market-based financiers are willing to fund no projects, as shown in Proposition 1. When $A \in [\bar{A}, \dot{A}]$ all entrepreneurs are funded. When $A \in]\max\left\{\hat{A}, \dot{A}\right\}, \ddot{A}]$, all the high-type entrepreneurs and a share of low-type entrepreneurs are funded. When $A > \ddot{A}$, only high-type entrepreneurs are funded.

Let us compare the outcome in each region of Figure 1 to the outcome under complete information. With complete information, a high-type entrepreneur will receive funding by offering $\frac{I-A}{\lambda_H}$ to the financier, since the rate of return required by the financier is normalized to unity and the NPV of the project is positive. In contrast, the low-type entrepreneurs' projects have a negative NPV, which raises the cost of external funding for low types so high that no low type is willing to launch her project. Because all projects by high-type entrepreneurs but no projects by low types will be executed, the market for entrepreneurial finance is efficient, and there is no need for Government intervention.

The region 4 in Figure 1 where $A > \ddot{A}$ corresponds to the complete information outcome. Only high-type entrepreneurs are financed, and the financier gets $\frac{I-A}{\lambda_H}$, if the project succeeds.

In region 2 where $A \in [\bar{A}, \dot{A}]$ and in region 3 where $A \in]\max\left\{\hat{A}, \dot{A}\right\}, \ddot{A}]$, all the high-type entrepreneurs are financed so there is no social inefficiency related to the financing of high-type entrepreneurs. But also at least some low-type entrepreneurs are financed, which creates a social loss compared with the complete information case where no low types are financed. In other words, under incomplete information there is excessive financing in regions 2 and 3, as in de Meza and Webb (1987). In equilibrium high-type entrepreneurs also cross-subsidize low types and receive lower share from a successful project than what they would get under complete information.

In region 1 ($A < min\left\{\hat{A}, \bar{A}\right\}$) no entrepreneur is financed as shown by

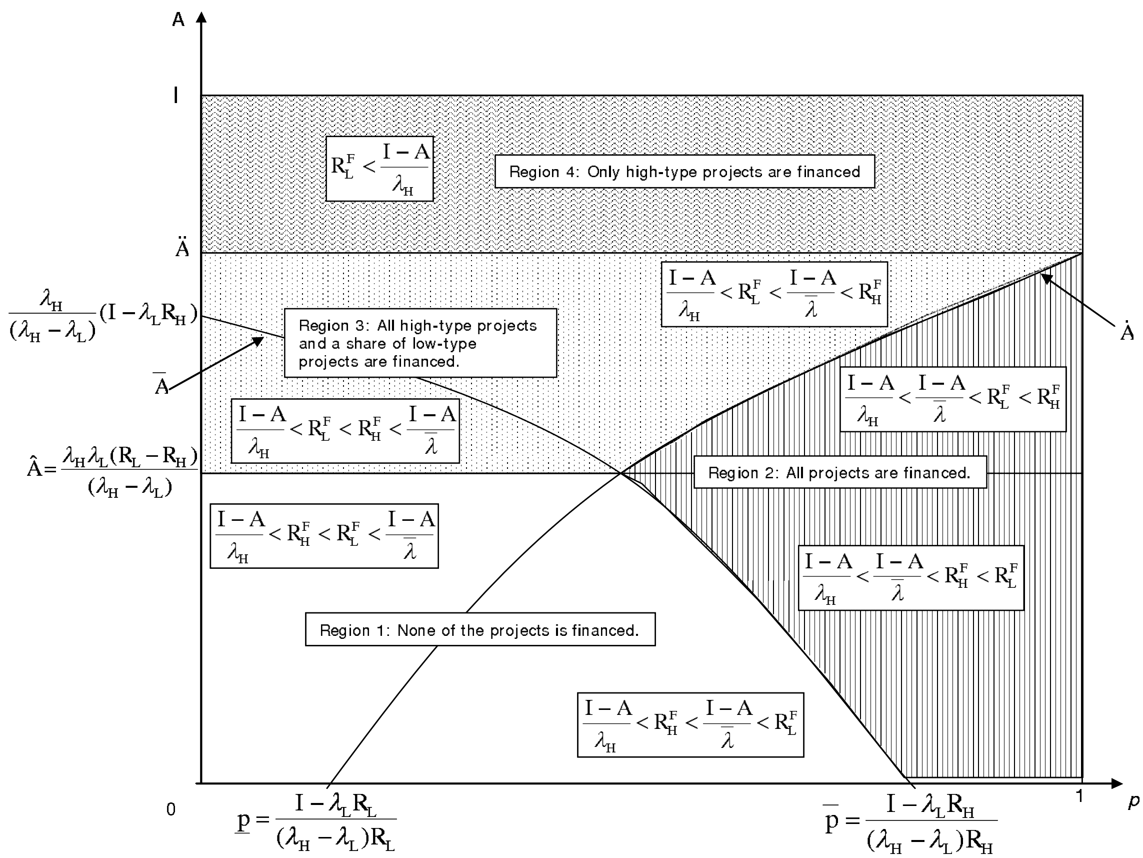

Figure 1: Market-based financing with different values of initial capital.

Proposition 1. From the social point of view it is efficient that low-type entrepreneurs do not get financing. High types should, however, obtain funding as in the complete information case. Financial constraints that prevent high-type entrepreneurs with $A < min\left\{\hat{A}, \bar{A}\right\}$ from undertaking economically viable innovation projects create a social loss. Since this paper is about financing constraints, we in what follows focus on region 1 where the funding gap exists.

4 R&D Subsidy Application and Allocation

In this section we solve the subgame where entrepreneurs contemplate applying for subsidies and Government decides on screening and awarding a subsidy, abstracting from the funding decisions of the market-based financiers. We will proceed under the assumption that receiving a subsidy is both a necessary and sufficient condition to secure the additional external funding from private sources.[17] In other words, we assume that with the subsidy an entrepreneur can launch an innovation project that she could not undertake otherwise. In the next section we verify the parameter values when this constitutes an equilibrium of the full game where the funding decisions of the market-based financiers are explicitly taken into account.

Because the subgame considered in this section is more complicated than the standard adverse selection model outlined in the previous section, it is useful to specify the timing of actions and agents' strategies.

[0.] Nature draws a type $i \in \{H, L\}$. Probabilities of a high type and a low type are p and $1-p$, $0 < p < 1$.
[1.] The entrepreneur observes her type and then chooses an action $a^E \in A^E =$ {apply for a subsidy (AP), do not apply (NAP)} where A^E is the action space of the entrepreneur.
[2.] Government receives the application, but does not observe the type of the entrepreneur. Government chooses an action $a_1^G \in A_1^G$={screen the application (SC), do not screen (NSC)} where A_1^G is the Government's action space at this stage.
[3.] Government chooses an action $a_2^G \in A_2^G$= {give a subsidy (S), do not give (NS)} where A_2^G is the Government's action space at this stage.
[4.] The entrepreneurs with the subsidy execute their projects, and payoffs are realized as shown below.

[17] This assumption is qualitatively in line with reality, since in practice R&D subsidies are paid against incurred costs. If a project does not get market-based financing, the project cannot be launched and the subsidy will not be paid.

Since the entrepreneur's action in the last stage of the game is straightforward, the entrepreneur's only strategic decision is to whether to apply for a subsidy or not in stage 1. Hence we can write that the entrepreneur chooses a pure strategy s^E from her pure-strategy space $\Sigma^E = A^E = \{AP, NAP\}$. If Government screens and finds out the true type of the entrepreneur in stage 2, it gives a subsidy to a high-type entrepreneur but not to a low-type entrepreneur in stage 3. Government's pure-strategy space is hence

$$\Sigma^G = \{SC,\ S \text{ if } i = H,\ NS \text{ if } i = L), (NSC,\ S),(NSC,\ NS)\}$$

In the following we refer to the first strategy as SC so

$$\Sigma^G = \{SC, (NSC,\ S),(NSC,\ NS)\}\,.$$

As we focus on Perfect Bayesian equilibria, Government's updated belief θ about the entrepreneur's type in the non-singleton information sets is determined by Bayes' Rule using the prior probabilities and the equilibrium strategies. Figure 2 shows the extensive-form representation of the subgame.

Let $\Pi^{G,i}_{s^G}$ refer to Government's payoff from choosing a pure-strategy $s^G \in \Sigma^G$ when the entrepreneur applies for a subsidy and the type of the entrepreneur is $i \in \{H, L\}$. When Government decides to screen ($s^G = SC$) and the entrepreneur is of a high-type ($i = H$), Government's payoff is given by

$$\Pi^{G,H}_{SC} = \lambda_H(R_H + W) - I - gS - c - \sigma. \tag{10}$$

Upon finding out that the entrepreneur is of a high-type, Government grants a subsidy S to the entrepreneur who can then secure the rest of the required funds, $I + c - A - S$, from the private sector financiers and is able to launch her project. Recall that the total size of the project is $I + c$ after the monetary cost of applying for the subsidy (c) is taken into account. The entrepreneur's and her private financiers' joint expected payoff is then $\lambda_H R_H - I - c + S$. Since Government's objective function includes the private sector agents' payoffs as arguments, the net cost of the subsidy to Government consists of the shadow cost of public funds gS. In (10) σ is the screening cost and W is the social externality generated by a successful project of a high-type entrepreneur.

Similarly, if Government decides to economize on screening costs, but nonetheless grants a subsidy and the applicant is of a high-type, the Government's payoff

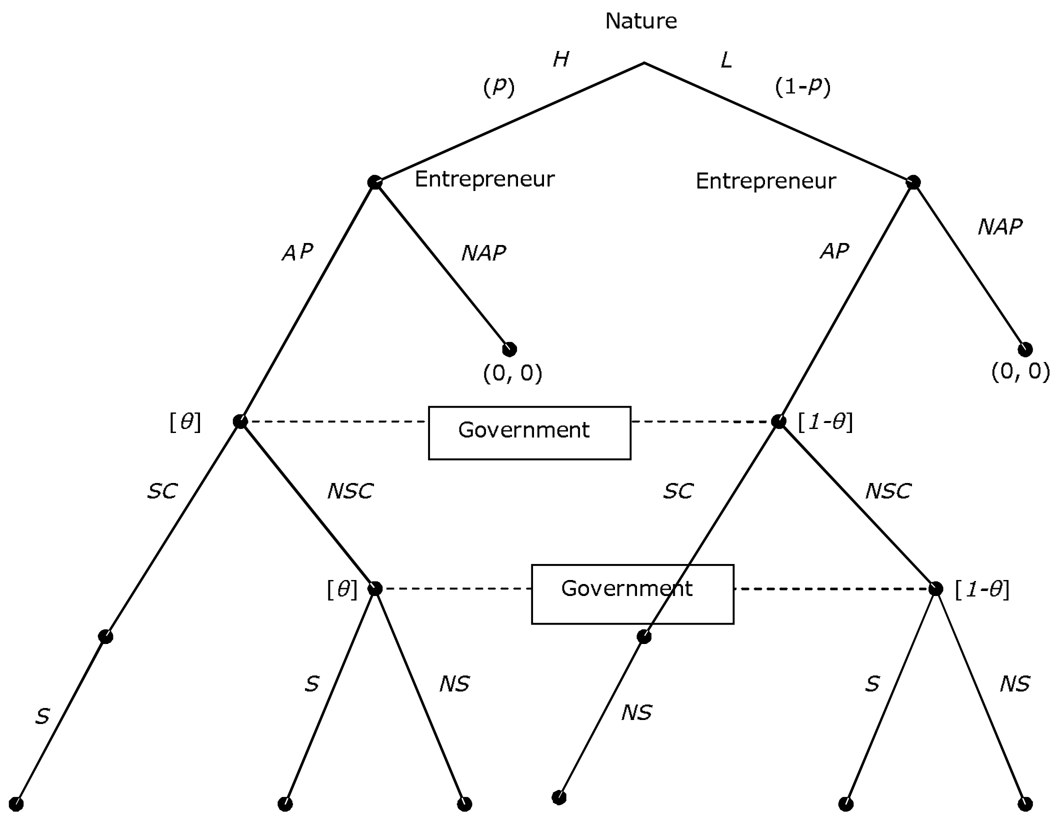

Figure 2: Extensive-form representation of the application process with perfect screening.

is

$$\Pi^{G,H}_{NSC,S} = \lambda_H (R_H + W) - I - gS - c, \tag{11}$$

which is identical to (10) save the cost of screening σ. Government's payoff from the same strategy $s^G = (NSC, S)$ when the applicant is of a low type is given by

$$\Pi^{G,L}_{NSC,S} = \lambda_L R_L - I - gS - c. \tag{12}$$

In this case, there are no societal benefits associated to the low-type entrepreneur's project even if it succeeds.

When the applicant is of a low type, the Government's payoff to screening is

$$\Pi^{G,L}_{SC} = -c - \sigma. \tag{13}$$

After screening and realizing that the entrepreneur is of a low type, the Government does not give a subsidy. Hence, under our assumptions, the entrepreneur cannot execute her project. For the same reason, the Government's payoff in case Government does not screen and does not give a subsidy is simply

$$\Pi^{G,i}_{NSC,NS} = -c \tag{14}$$

irrespective of the entrepreneur's type.

Let us next consider the entrepreneurs' payoffs from applying for a subsidy to any given Government's pure strategy $s^G \in \Sigma^G$. A high-type entrepreneur gets a subsidy if Government follows the strategy s^G =*SC* or s^G =*(NSC,S)* but does not get subsidy if Government follows the strategy s^G =*(NSC, NS)*. Similarly, if Government follows the strategy s^G =*SC* or s^G =*(NSC,NS)*, a low-type entrepreneur does not get a subsidy, but if s^G =*(NSC,S)*, she gets a subsidy. Since from the entrepreneur's point of view the only payoff-relevant decision of the Government is whether it gives a subsidy or not, we will use $\Pi^{E,i}_{a_2^G}$ to denote the payoff of an entrepreneur of type $i \in \{H, L\}$ to the Government's second action $a_2^G \in A_2^G$. As a result, the entrepreneur's payoff to an accepted subsidy application $\left(a_2^G = S\right)$ is given by

$$\Pi^{E,i}_{S} = \lambda_i \left(R_i - F^S\right) - A, \tag{15}$$

and to a rejected application $\left(a_2^G = NS\right)$ by

$$\Pi^{E,i}_{NS} = -c. \tag{16}$$

In (15), F^S is the entrepreneur's repayment obligation to the market-based financier if the entrepreneur has received a subsidy and her project succeeds. For the moment we take it given and assume that it is small enough to render $\Pi_S^{E,i} > 0$ and the problem interesting. F^S will be determined as part of equilibrium in section 5.

.

4.1 Equilibria

Since a pure-strategy equilibrium is an equilibrium in degenerate mixed strategies, we focus on mixed strategies. As we are interested in Government's screening activities, we seek PBE where screening is a viable strategy choice for a Government, a high-type entrepreneur always applies, and a low-type entrepreneur chooses a mixed strategy $\mu_{s^E} \in \Delta\Sigma^E$ where $\Delta\Sigma^E$ denotes the set of probability distributions over pure strategies and μ_{s^E} is the probability assigned to a pure strategy $s^E \in \Sigma^E = \{AP, NAP\}$.[18] Similarly, Government chooses a mixed strategy $\alpha_{s^G} \in \Delta\Sigma^G$ over pure strategies $s^G \in \Sigma^G = \{SC, (NSC, S), (NSC, NS)\}$. As μ_{s^E} and α_{s^G} are probability distributions we will write that $\mu_{AP} = \mu$, $\mu_{NAP} = 1 - \mu$, and $\alpha_{NSC,NS} = 1 - \alpha_{SC} - \alpha_{NSC,S}$ ($\mu, \alpha_{SC}, \alpha_{NSC,S} \geq 0$), meaning that a low-type entrepreneur applies with probability μ and Government randomizes between strategies *SC*, (*NSC, S*) and (*NSC, NS*) with probabilities α_{SC}, $\alpha_{NSC,S}$ and $1 - \alpha_{SC} - \alpha_{NSC,S}$.

We first consider the entrepreneurs' optimal strategies. Given Government's mixed strategy α_{s^G}, the expected payoff of a high-type entrepreneur from applying is

$$E(\Pi_{AP}^{E,H}) = (\alpha_{SC} + \alpha_{NSC,S})\Pi_S^{E,H} + (1 - \alpha_{SC} - \alpha_{NSC,S})\Pi_{NS}^{E,H}. \tag{17}$$

and the low-type entrepreneur's expected payoff from applying is

$$E(\Pi_{AP}^{E,L,}) = (1 - \alpha_{NSC,S})\Pi_{NS}^{E,L} + \alpha_{NSC,S}\Pi_S^{E,L}. \tag{18}$$

In (17) and (18), $\Pi_S^{E,i}$ and $\Pi_{NS}^{E,i}$, $i \in \{H, L\}$, are specified by (15) and (16). The entrepreneurs who do not apply for a subsidy obtain zero payoff.

[18]It can be shown that with the exception of the trivial equilibrium where no-one applies and Government does not grant subsidies, high types always apply in the parameter region we focus on. Intuitively, in this region the market-based financiers interpret all entrepreneurs without subsidies as low types and do not give them the additional funding required to implement the project.

Lemma 1

- If $\alpha_{SC} + \alpha_{NSC,S} > \frac{c}{\lambda_H(R_H - F^S) - A + c}$, the best strategy for a high-type entrepreneur is to apply.
- If $\alpha_{NSC,S} > \frac{c}{\lambda_L(R_L - F^S) - A + c}$, the best strategy for a low-type entrepreneur is to apply (μ= 1).
- If $\alpha_{NSC,S} < \frac{c}{\lambda_L(R_L - F^S) - A + c}$, the best strategy for a low-type entrepreneur is not to apply ($\mu = 0$).
- If $\alpha_{NSC,S} = \frac{c}{\lambda_L(R_L - F^S) - A + c}$, a low-type entrepreneur randomizes between applying and not with probabilities μ and $(1 - \mu)$.

Lemma 1 describes the entrepreneurs' optimal application strategies as function of Government's screening and subsidy allocation strategies. High types get a subsidy unless Government picks strategy (NSC, NS) according to which it does not screen nor give subsidies. Low types care in turn only whether Government is using strategy (NSC, S) as this is their only chance to obtain subsidies, given our assumption of perfect screening.

Let us next turn to the Government's strategy choices. Since a low-type entrepreneur is using a mixed strategy $(\mu, 1 - \mu)$,Government's belief θ that an applicant is of a high type is given by Bayes' Rule as

$$\theta = \frac{p}{p + \mu(1 - p)}. \tag{19}$$

Government's expected payoff from choosing pure strategy screening ($\alpha_{SC} = 1$) is $E(\Pi^G_{SC}) = \theta \Pi^{G,H}_{SC} + (1 - \theta)\, \Pi^{G,L}_{SC}$ which, by using (10) and (13), can be written as

$$E(\Pi^G_{SC}) = \theta\, [\lambda_H\, (R_H + W) - I - gS] - c - \sigma. \tag{20}$$

Similarly, using (11) and (12) we see that Government's expected payoff from $\alpha_{NSC,S} = 1$ is

$$E(\Pi^G_{NSC,S}) = \theta\, [\lambda_H\, (R_H + W)] + (1 - \theta)\lambda_L R_L - I - gS - c. \tag{21}$$

Finally, from choosing pure-strategy s^G =*(NSC, NS)* $(\alpha_{SC} = \alpha_{NSC,S} = 0)$, the Government's payoff is simply given by (14) as $E(\Pi^G_{NSC,NS})$ = -*c*.

As (20) and (21) indicate, Government's strategy choice depends on the low-type entrepreneurs' application strategies (value of μ, incorporated in θ). Let us define $\underline{\mu} \equiv \left(\frac{p}{1-p}\right)\left(\frac{\sigma}{I+gS-\lambda_L R_L-\sigma}\right)$and $\bar{\mu} \equiv \left(\frac{p}{1-p}\right)\left(\frac{\lambda_H(R_H+W)-I-gS-\sigma}{\sigma}\right)$. We proceed under the assumption that $\underline{\mu} \leq \bar{\mu}$ and verify later that it holds in the equilibria we are focusing on.

Lemma 2

- If $\mu < \underline{\mu}$, the best strategy for Government is (*NSC, S*) ($\alpha_{NSC,S} = 1$).
- If $\mu > \bar{\mu}$, the best strategy for Government is (*NSC, NS*) ($1 - \alpha_{SC} - \alpha_{NSC,S} = 1$).
- If $\underline{\mu} < \mu < \bar{\mu}$, the best strategy for Government is *SC* ($\alpha_{SC} = 1$).
- If $\mu = \bar{\mu}$, Government randomizes between *SC* and (*NSC, NS*) with probabilities α_{SC} and $1 - \alpha_{SC}$.
- If $\mu = \underline{\mu}$, Government randomizes between *SC* and (*NSC, S*) with probabilitiesα_{SC} and $\alpha_{NSC,S} = 1 - \alpha_{SC}$.

Lemma 2 suggests that Government would screen applicants only with intermediate values of μ. If low types were not likely to apply (μ is small), Government would give subsidies to all applicants without screening. In contrast, if low types would apply with a high probability (μ is high), Government would not give subsidies to any one. This conclusion is, however, based on the assumption that $\bar{\mu}$ is smaller than one. If $\bar{\mu} > 1$, the strategy (*NSC, NS*) is not a plausible option for Government and Government would always screen if $\mu > \underline{\mu}$. Figure 3 summarizes the optimal strategies for Government as a function μ. The figure is drawn under the assumption that $\bar{\mu} < 1$.

As we aim at analyzing Government's screening activities, we focus on the parameter range where screening remains as a viable option for Government.

Proposition 2 *Screening is a plausible strategy for Government only if*
$\sigma \leq min\left\{\frac{(I+gS-\lambda_L R_L)(\lambda_H(R_H+W)-I-gS)}{\lambda_H(R_H+W)-\lambda_L R_L}, (1-p)(I+gS-\lambda_L R_L)\right\}$.

Proposition 2 suggests that screening is viable strategy choice for Government only if screening costs and the proportion of high-type entrepreneurs in the population are low enough. Obviously, if screening is costly enough or its benefits

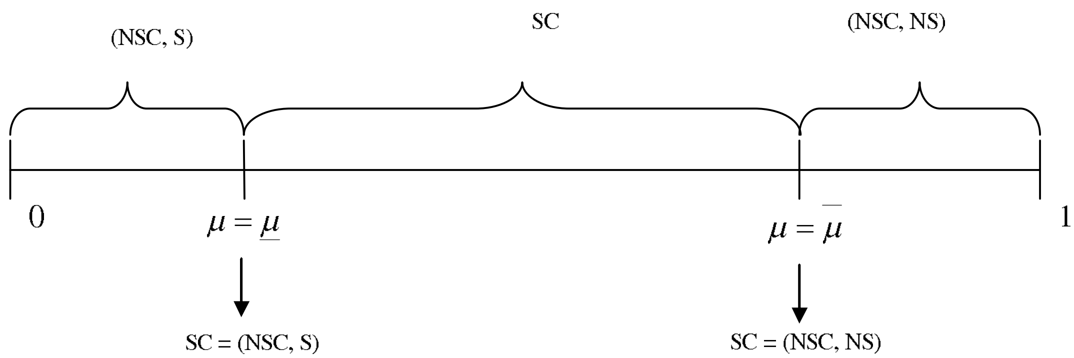

Figure 3: Optimal strategies for Government with different values of μ.

- the probability of finding a low type project - are low enough, screening is no longer profitable.

Generally, the set of sensible Government strategies depends on the values of σ and p, as shown by Figure 4.[19]

The figure displays four different regions. In regions 1 and 2, screening is a plausible strategy, whereas in regions 3 and 4 the combinations of p and σ are such that screening is never optimal. In region 3 it is always optimal for Government to grant a subsidy without screening. In other words, the screening costs are so high compared to the relatively high share of high-type entrepreneurs in the population that it is optimal for Government just to grant a subsidy to every applicant. In region 4 Government chooses between strategies *(NSC, S)* and *(NSC, NS)*. Note that the figure is restricted to the parameter space where financing constraints exists, $p \leq \frac{I-\lambda_L R_H}{(\lambda_H-\lambda_L)R_H}$ (see Proposition 1).

Propositions 1 and 2 identify the parameter region which is the focus of this paper.[20] Consequently, we consider regions 1 and 2 from Figure 4. Note that if $\bar{\mu} > 1$, the strategy (*NSC, NS*) is not a plausible option for Government and we are in region 2 of Figure 4. Since $\bar{\mu} \equiv \left(\frac{p}{1-p}\right)\left(\frac{\lambda_H(R_H+W)-I-gS-\sigma}{\sigma}\right)$, $\bar{\mu} < 1$ if $\sigma > p(\lambda_H(R_H+W) - I - gS)$. The intuition is that (*NSC, NS*) is a plausible strategy for Government only if screening costs are high relative to the share of high-type entrepreneurs in the population (region 1 of Figure 4). For p low

[19] In a working paper version (Takalo and Tanayama, 2008) we characterize what will happen when Proposition 2 does not hold and $\underline{\mu} > \bar{\mu}$.

[20] This parameter restriction also rules out the unrealistic case that if all entrepreneurs apply it is optimal for Government to just grant subsidies to all. To see this, substitute p for θ in equations (19) and (20) to get that (SC) is better than (NSC,S) if $\sigma < (1-p)(I+gS-\lambda_L R_L)$ and that (NSC, NS) is better than (NSC, S) if $p < \frac{I+gS-\lambda_L R_L}{\lambda_H(R_H+W)-\lambda_L R_L}$.

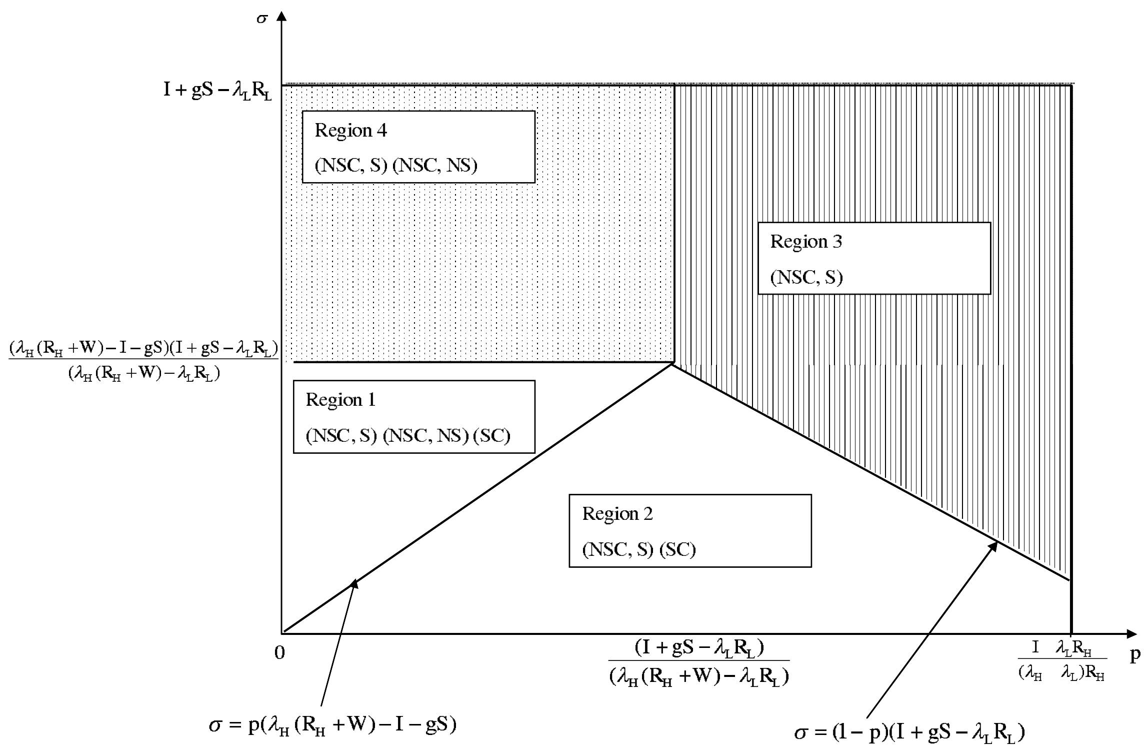

Figure 4: Plausible Government strategies with different values of screening costs (σ) and different share of high-type entrepreneurs in the economy (p).

enough it is possible that $\bar{\mu} < 1$ and Proposition 2 hold simultaneously.

We can now state the main result of this section.

Proposition 3 *In a PBE of the game*

- *A high-type entrepreneur always applies.*
- *A low-type entrepreneur applies with probability* $\mu = \underline{\mu} \equiv \left(\frac{p}{1-p}\right)\left(\frac{\sigma}{I+gS-\lambda_L R_L-\sigma}\right)$.
- *Government randomizes between (NSC, S) and SC with probabilities* $\alpha_{NSC,S} = \frac{c}{\lambda_L(R_L-F^S)-A+c}$ *and* $\alpha_{SC} = 1-\alpha_{NSC,S} = \frac{\lambda_L(R_L-F^S)-A}{\lambda_L(R_L-F^S)-A+c}$ *and*
- *Government's belief that the applicant is of a high type is determined by* $\theta = 1 - \frac{\sigma}{I+gS-\lambda_L R_L}$.

In this PBE low types have an incentive to apply because Government does not screen all applications but just gives a subsidy without screening with some positive probability. In this way Government can save some screening costs that offsets the welfare loss caused by subsidies directed to low type projects.

Government's mixed strategy can be interpreted as Government deciding on the intensity of screening. The higher is the probability of screening versus automatically granting a subsidy, the higher is the screening intensity and the higher is the probability of finding out the true type of the project. Only if the probability of screening is equal to one, screening is truly perfect and Government finds out the true type of the project for sure.[21]

The PBE identified by Proposition 3 is based on the assumption that the subsidy program is in place and Government chooses whether to screen or not, i.e, the possibility to just close the program is not taken into account. If Government chooses to close the whole program, the payoff is zero to both entrepreneur and Government (ignoring the costs related to the closing of the program). If the strategy profile characterized by Proposition 3 generates a strictly positive payoff to Government then it is an equilibrium, even taking into account the possibility of closing the subsidy program. It can be shown that the above strategy profile remains an equilibrium with minor modifications to the restriction imposed on σ in Proposition 2.[22]

[21] Clearly, it would be equivalent to assume that Government can commit to screen all applications but makes mistakes in screening.

[22] Instead of $\sigma \leq \frac{(I+gS-\lambda_L R_L)(\lambda_H(R_H+W)-I-gS)}{\lambda_H(R_H+W)-\lambda_L R_L}$ we need to have $\sigma \leq \frac{(I+gS-\lambda_L R_L)(\lambda_H(R_H+W)-I-gS-c)}{\lambda_H(R_H+W)-\lambda_L R_L}$.

Comparative statistics of the Government screening probability would be straightforward if we took the entrepreneur's repayment obligation, F^S , as fixed. However, in an equilibrium of the full game, determined in the next section, the parameters of F^S will include S, c, α_{SC} and θ. As a result, in an equilibrium of the full game, the formula for α_{SC} given in Proposition 3 is in an implicit form. In the end of the Appendix we derive the partial derivatives of the screening probability with respect to σ, c, A and S when F^S is endogenous. If the parameters are such that Government is relatively confident that an application comes from a high-type entrepreneur (the equilibrium value of θ is sufficiently high, e.g. because σ is very low), the results are intuitive: the screening probability is decreasing in the screening cost, in the application cost, and in the initial wealth, and increasing in the level of the subsidy.

Fortunately, comparative statics of the low-type's optimal strategy are easier. An increase in the screening cost (σ), in the share of high types (p) in the population, or in the NPV of the low-type entrepreneurs' projects ($\lambda_L R_L - I$) increases low-type's application probability as could be expected, but an increase in the subsidy decreases the application probability. The latter outcome may seem counterintuitive, but it is explained by Government's screening incentives, which are increasing with S. If S increases, low-type entrepreneurs anticipate tighter screening and are less likely to apply. Hence, public screening works more efficiently in discouraging low-type entrepreneurship if it is accompanied with subsidy allocation.

5 Public and Private Funding of Innovations

We now analyze the full model where the entrepreneurs can first apply for an R&D subsidy from Government, and then seek market-based financing from other sources. For brevity, we assume that in the funding gap region that we are focusing on, entrepreneurs need external market-based financing besides the subsidy to be able to undertake the innovation project ($A - c + S < I$) and have enough initial wealth to apply for a subsidy ($A > c$).

As mentioned, we assume that the private financier observes whether the entrepreneur has received an R&D subsidy or not, and it knows how Government funding policy works. The subsidy observation provides additional information to the market-based financier about the type of the project. Then, if the entrepreneur has been granted a subsidy, market-based financiers' participation constraint reads as

$$I - A - S + c \leq \hat{\lambda} F^S, \tag{22}$$

where $\hat{\lambda}$ is the updated success probability when the entrepreneur has received an R&D subsidy, and it is determined by Bayes' Rule as

$$\hat{\lambda} = P(H|S)\lambda_H + [1 - P(H|S)]\lambda_L. \tag{23}$$

In (23), $P(H|S)$ is the conditional probability that the entrepreneur is of a high-type, given that she has received an R&D subsidy from Government. In equilibrium, Government randomizes between SC and (NSC, S) with probabilities α_{SC} and $1 - \alpha_{SC}$. This means that $P(H|S) = \hat{p} = \alpha_{SC} + (1 - \alpha_{SC})\theta$ where θ and α_{SC} are given by Proposition 3. Since in this equilibrium high-type entrepreneurs always apply, the financier knows for sure that an entrepreneur without a subsidy is a low type. Given that financiers must break-even, equation (22) holds with equality and the share of a successful project given to a financier is

$$F^S = \frac{I - A - S + c}{\hat{\lambda}}. \tag{24}$$

The entrepreneur's participation constraint remains $\lambda_i R_i^E \geq A$, since to receive an R&D subsidy the entrepreneur has to invest her initial wealth in the project (where now the application and investment constitute the project). The pledgeable income that can be offered to the financier is $R_i^{F\max} = R_i - R_i^E = R_i - \frac{A}{\lambda_i}$ as before. As a result, an entrepreneur with a subsidy can get market-based financing if

$$\frac{I - A - S + c}{\hat{\lambda}} \leq R_H - \frac{A}{\lambda_H}. \tag{25}$$

The right hand side of the equation (25) is the pledgeable income that a high-type entrepreneur is willing to offer to the financier, and it is the same as without a subsidy program. Solving equation (25) for A shows that if the entrepreneur has been granted an R&D subsidy, the private financiers grant funding if

$$A \geq \bar{A}^S \equiv \frac{\lambda_H}{\lambda_H - \hat{\lambda}}[I - S + c - \hat{\lambda} R_H].$$

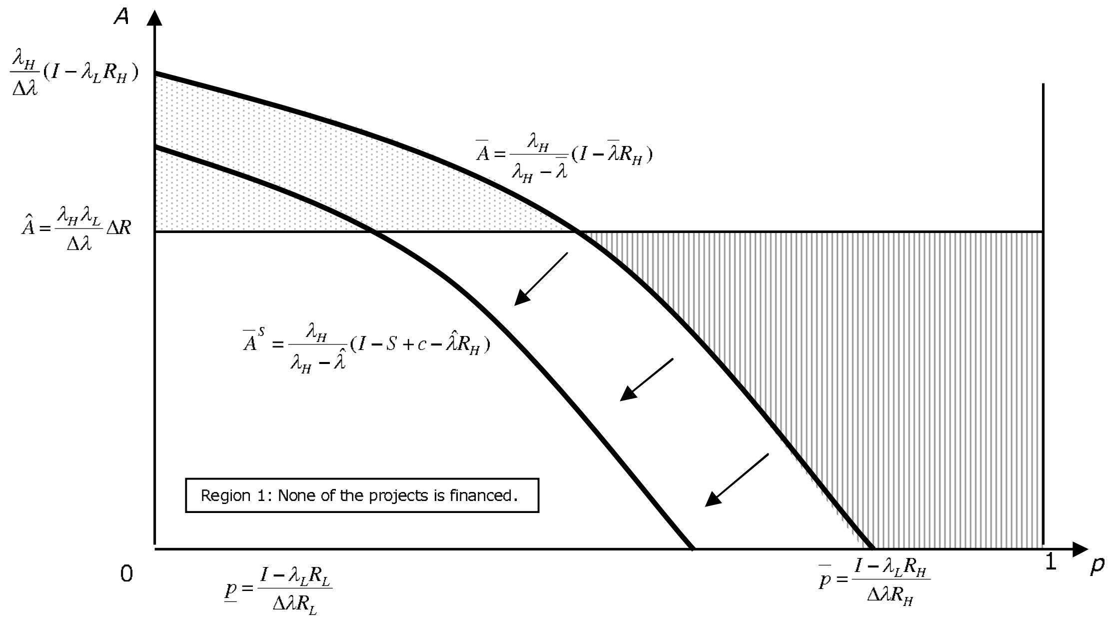

Figure 5: Change in Region 1, when a subsidy program is introduced.

Proposition 4 *i) Entrepreneurs with an R&D subsidy can get market-based financing with less initial capital, i.e.* $\bar{A} > \bar{A}^S$*, if* $\hat{\lambda} \geq \bar{\lambda}$**.** *ii) Due to Government screening, the fact that an entrepreneur has received an R&D subsidy provides an informative signal to the financier, i.e.* $\hat{\lambda} > \bar{\lambda}$*.*

Figure 5 shows how the funding gap region presented in Figure 1 changes as a result of the introduction of a subsidy program. From equation (6) we know that $\hat{A} \equiv \frac{\lambda_L\lambda_H(R_L-R_H)}{\lambda_H-\lambda_L}$ and it does not change when a subsidy program is introduced, since the participation constraint of an entrepreneur remains the same. What happens is that the $\bar{A}$-curve shifts downward. Whether the shift reduces financial constraints depends on the value of $\hat{p}$.

Proposition 5 *R&D subsidy program reduces financial constraints, when* $p \in \left[\frac{(\hat{p}-\alpha_{SC})\mu}{(1-\hat{\underline{p}})+(\hat{\underline{p}}-\alpha_{SC})\mu}, \frac{I-\lambda_L R_H}{(\lambda_H-\lambda_L)R_H}\right]$ *, where* α_{SC} *and* μ *are the equilibrium strategies and* $\hat{\underline{p}} = \frac{I-S+c-\lambda_L R_L}{\lambda_H R_H-\lambda_L R_L}$ *.*

Propositions 4 and 5 summarize the main result. R&D subsidies and the related screening process can help financially constrained entrepreneurs to get external financing for their innovation projects, if the share of high-type entrepreneurs in the population is sufficiently high. Two different channels generate this effect. Part i) of Proposition 4 presents a trivial one: a subsidy reduces the amount of external capital needed, thus reducing capital costs. The more interesting channel is depicted in the second part of Proposition 4: subsidy observation provides additional information to market-based financiers about the quality of the project. With this additional information, market-based financiers are willing to fund entrepreneurs with a subsidy with a lower rate of return and this reduces the funding gap.

The expected total welfare effect of R&D subsidies to a society, with p belonging to the interval stated in Proposition 5, depends on the distribution of initial wealth. The initial wealth required to get financing from private sources becomes smaller, i.e. $\bar{A}$ is transformed to $\bar{A}^S$. Figure 6 presents the the pledgeable incomes of a low and high type entrepreneurs, $R_L^{F\max}$ and $R_H^{F\max}$, and the share of a successful project that a financier requires to invest in the project with and without a subsidy, F^S and F. When a subsidy program is introduced the repayment required by a financier declines from F to F^S and, as a result, the funding gap region reduces from $[0, \bar{A}]$ to $[0, \bar{A}^S]$.

The expected net benefit to the society from one project that has received a subsidy is

$$E(\Pi^G) = \alpha_{SC} E(\Pi^G_{SC}) + (1 - \alpha_{SC}) E(\Pi^G_{NSC,S}).$$

In equilibrium Government is indifferent between the strategies *SC* and *NSC,S*, which implies that the expected payoffs from these two strategies are equal. This gives

$$E(\Pi^G) \quad = \quad E(\Pi^G_{SC}) = E(\Pi^G_{NSC,S}) =$$

$$\frac{(I + gS - \lambda_L R_L)\left[\lambda_H\left(R_H + W\right) - I - gS - c\right)] - \sigma\left[\lambda_H\left(R_H + W\right) - \lambda_L R_L\right]}{I + gS - \lambda_L R_L}.$$

Depending on the value of σ this can be either positive or negative. If

$$\sigma < \frac{(I + gS - \lambda_L R_L)\left[\lambda_H\left(R_H + W\right) - I - gS - c\right)]}{\lambda_H\left(R_H + W\right) - \lambda_L R_L)}$$

then $E(\Pi^G)$ is positive.[23]

The expected total net benefit to the society depends on the share of entrepreneurs whose initial wealth is in the interval $[\bar{A}^S, \bar{A}]$. As the mass of entrepreneurs is normalized to unity, the total net benefit to the society is

$$E(\Pi^G)\int_{\bar{A}^S}^{\bar{A}} G(A)dA.$$

Clearly the outcome is not the first-best: also some low-type entrepreneurs are financed. However, if the total net benefit to the society is positive, the subsidy program improves the market outcome under asymmetric information.

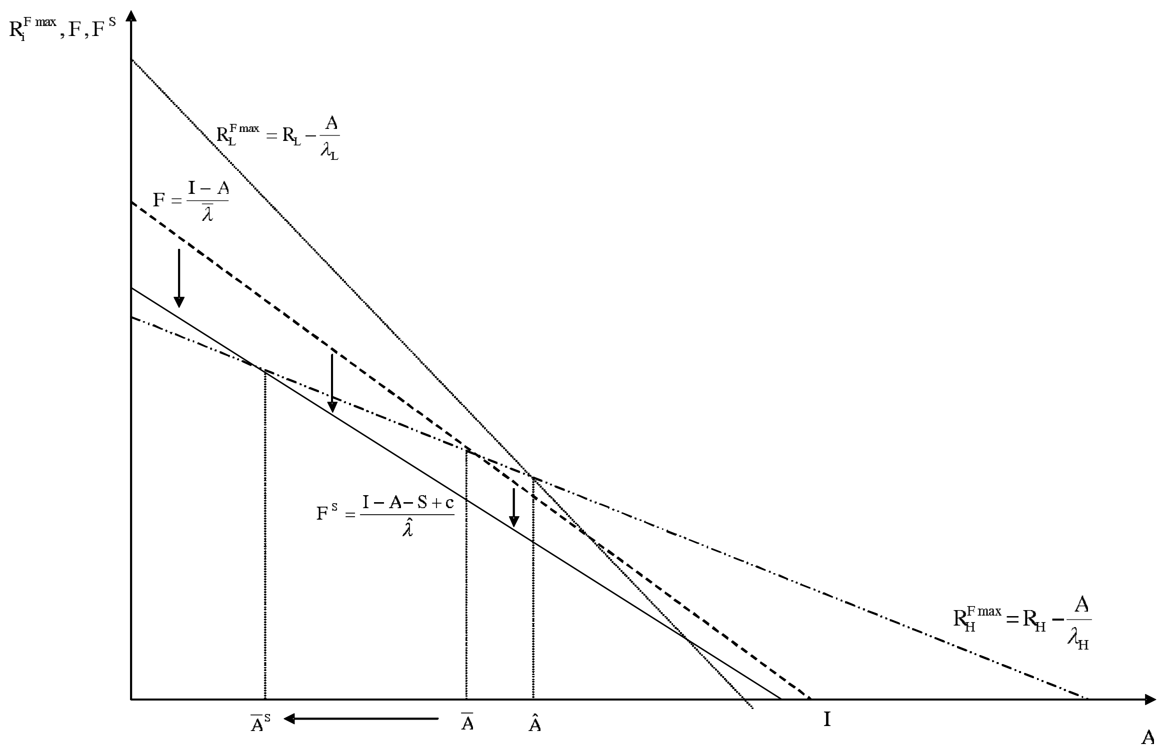

Figure 6: Change in funding gap region as a subsidy program is introduced.

[23]Note that this restriction on σ is the same as the one derived by taking into account the possibility that Government can close down the program, see footnote 22.

6 Conclusions

Financial constraints are one of the rationales used to justify government intervention in the form of R&D subsidies. This study provides insights into the questions of whether and how R&D subsidies could be expected to alleviate financial constraints. The following conclusions can be drawn:

- Asymmetric information about the quality of R&D projects creates financing constraints for collateral-poor firms, if there is non-negligible share of non-viable projects within the economy.
- R&D subsidy policies that involve screening of the projects are sustainable, if the screening costs are low enough.
- The higher the expected loss generated by low-quality projects and the lower the share of high-quality projects in the economy, the higher the screening costs can be without rendering screening activities unsustainable.
- R&D subsidies can reduce financing constraints for two different reasons: 1) The subsidy in itself reduces the cost of external capital because the need for market-based financing diminishes. 2) If market-based financiers can observe that a project has received a subsidy from the public agency, the subsidy provides an informative signal about the quality of the R&D project. Such a subsidy-observation increases the success probability of the project anticipated by the market-based financier. This reduces the cost of external capital for subsidized projects.

These findings highlight that the screening activities typically embedded into R&D subsidy policies can have a role of their own in reducing financial constraints. Instead of merely allocating subsidies, the public agency could have a certification role and yet reduce the financing constraints. This raises the question of whether, in terms of financial constraints, it would suffice to reduce the asymmetry of information merely through screening. We find, however, that granting funding besides screening not only strengthens the leverage effect but also makes screening more efficient in discouraging low-quality entrepreneurship.

While this paper is more a positive analysis of application and allocation of R&D subsidies rather than normative welfare analysis of R&D subsidies, the findings suggest that under certain conditions R&D subsidy policies may be welfare improving. However, we focus on the range of parameter values where all entrepreneurs suffer from financing constraints. If high-type entrepreneurs not suffering from financing constraints get subsidies, this limits the welfare-improving prospects of subsidy policies. Nonetheless, the screening activities of the public financier may prevent some low-type entrepreneurs from getting such market-based financing they would obtain in the absence of public funding. But even in the funding gap region the outcome is not fully efficient - also some low-quality projects are funded, and future work should consider optimal policy.

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Appendix: Proofs of the Results

PROOF OF PROPOSITION 1: Since a low-type entrepreneur never wants to reveal her type, both types offer the same repayment to the financier when (6) holds, and so either all entrepreneurs get funding or no-one gets when $A < \hat{A}$. As (5) gives the threshold value of initial capital needed to get financing, when the financier anticipates all the entrepreneurs to seek financing, the entrepreneurs with $A < min\left\{\hat{A}, \bar{A}\right\}$ do not receive funding. From (6) and (5) we observe that $\hat{A}$ is independent of p whereas $\bar{A}$ is decreasing in p. Solving$\hat{A} < \bar{A}$ for $p$gives $p < \frac{I-\lambda_L R_L}{\lambda_H R_H - \lambda_L R_L}$, i.e., for $p \geq \frac{I-\lambda_L R_L}{\lambda_H R_H - \lambda_L R_L}$ (5) is the binding constraint. From (5) we obtain that $\bar{A} \geq 0$ when $p \leq \frac{I-\lambda_L R_H}{(\lambda_H - \lambda_L) R_H}$. □

PROOF OF LEMMA 1: High-type entrepreneurs always apply if $E(\Pi_{AP}^{E,H}) > 0$ holds in equilibrium. Substituting (15) and (16) (with $i = H$) for (17) shows that $E(\Pi_{AP}^{E,H}) > 0$ if $\alpha_{SC} + \alpha_{NSC,S} > \frac{c}{\lambda_H(R_H - F^S) - A + c}$. Similarly, low-type entrepreneurs always apply (μ= 1) if $E(\Pi_{AP}^{E,L}) > 0$, which can be rewritten after substituting (15) and (16) (with $i = L$) for (18 as $\alpha_{NSC,S} > \frac{c}{\lambda_L(R_L - F^S) - A + c}$. Correspondingly, low types never apply ($\mu = 0$) if $E(\Pi_{AP}^{E,L}) < 0$,i.e., if $\alpha_{NSC,S} < \frac{c}{\lambda_L(R_L - F^S) - A + c}$. It immediately follows that if $\alpha_{NSC,S} = \frac{c}{\lambda_L(R_L - F^S) - A + c}$, low-types are indifferent between applying and not ($E(\Pi_{AP}^{E,L}) = 0$) and use a mixed strategy $(\mu, 1-\mu)$.□

PROOF OF LEMMA 2: If $E(\Pi_{SC}^{G}) > \max\left\{E(\Pi_{NSC,S}^{G}), -c\right\}$, it is optimal for Government to choose pure strategy SC ($\alpha_{SC} = 1$). If $E(\Pi_{NSC,S}^{G}) > \max\left\{E(\Pi_{SC}^{G}), -c\right\}$, then $s^G = (NSC, S)$ ($\alpha_{NSC,S} = 1$) is optimal for Government and if both $E(\Pi_{SC}^{G})$ and $E(\Pi_{NSC,S}^{G})$ are smaller than -c, pure strategy $s^G = (NSC, NS)$ ($\alpha_{SC} = \alpha_{NSC,S} = 0$) is optimal. Inserting (19) into (20) and (21) shows that $E(\Pi_{SC}^{G}) > E(\Pi_{NSC,S}^{G})$ if $\mu > \underline{\mu} \equiv \left(\frac{p}{1-p}\right)\left(\frac{\sigma}{I+gS-\lambda_L R_L - \sigma}\right)$. Similarly, by using (19) and (20) it turns out that $E(\Pi_{SC}^{G}) > -c$ if $\mu < \overline{\mu} \equiv \left(\frac{p}{1-p}\right)\left(\frac{\lambda_H(R_H+W)-I-gS-\sigma}{\sigma}\right)$. As a result, Government sets $\alpha_{SC} = 1$ if $\mu \in \left(\underline{\mu}, \overline{\mu}\right)$. It immediately follows that if $\mu < \underline{\mu} < \overline{\mu}$, $E(\Pi_{NSC,S}^{G}) > E(\Pi_{SC}^{G}) > -c$, meaning that Government chooses $\alpha_{NSC,S}$=1, and that if $\mu > \overline{\mu} > \underline{\mu}$, $E(\Pi_{NSC,S}^{G}) < E(\Pi_{SC}^{G}) < -c$, implying $\alpha_{SC} = \alpha_{NSC,S} = 0$.

Government is indifferent between pure strategy SC and pure strategy (NSC, NS) and hence uses a mixed strategy $\alpha_{SC}$and$1-\alpha_{SC}$ when $E(\Pi^G_{SC}) = -c$, i.e., when $\mu = \overline{\mu}$. In turn, Government randomizes between SC and (NSC, S) with probabilities$\alpha_{SC}$and $\alpha_{NSC,S} = 1-\alpha_{SC}$ when $E(\Pi^G_{SC}) = E(\Pi^G_{NSC,S})$, i.e., when $\mu = \underline{\mu}$. □

PROOF OF PROPOSITION 2: Lemma 2 implies that screening is a plausible strategy if $\mu \in \left[\underline{\mu}, \overline{\mu}\right]$. This is a non-empty set if $\sigma \leq \frac{(I+gS-\lambda_L R_L)(\lambda_H(R_H+W)-I-gS)}{\lambda_H(R_H+W)-\lambda_L R_L}$. We also need to make sure that$\underline{\mu} \leq 1$, i.e., that $\sigma \leq (1-p)(I+gS-\lambda_L R_L)$. □

PROOF OF PROPOSITION 3: Let first prove that there is no pure strategy equilibrium in this game. Note from (15) that $\Pi^{E,i}_S > 0$ implies that $\frac{c}{\lambda_i(R_i-F^S)-A+c} \in (0,1)$.If a low-type entrepreneur always applied ($\mu = 1$), Lemma 1 shows that $\alpha_{NSC,S} > \frac{c}{\lambda_L(R_L-F^S)-A+c}$ should hold. However, Lemma 2 suggests that if $\mu = 1$, it would be optimal for Government either to choose (NSC, NS) or (SC) implying that $\alpha_{NSC,S} = 0$. If a low-type entrepreneur never applied ($\mu = 0$), Lemma 1 implies $\alpha_{NSC,S} < \frac{c}{\lambda_L(R_L-F^S)-A+c}$ should hold. But if $\mu = 0$, it would be optimal for Government to set $\alpha_{NSC,S} = 1$(Lemma 2), which is larger than $\frac{c}{\lambda_L(R_L-F^S)-A+c}$. A similar argument shows that an equilibrium where Government randomizes between (NSC, NS) and (SC), implying that low types will not apply, does not exists.

Lemma 1 shows that for a low-type to be willing to use a mixed strategy $0 < \mu < 1$, $\alpha_{NSC,S}$ must be equal to $\frac{c}{\lambda_L(R_L-F^S)-A+c}$. Given that $\alpha_{NSC,S} > 0$, Lemma 2 shows that the only possible mixed strategy for Government is to randomize between SC and (NSC,S) with probabilities $\alpha_{NSC,S} = \frac{c}{\lambda_L(R_L-F^S)-A+c}$ and $\alpha_{SC} = 1 - \alpha_{NSC,S} = \frac{\lambda_L(R_L-F^S)-A}{\lambda_L(R_L-F^S)-A+c}$. This Government strategy satisfies $\alpha_{SC} + \alpha_{NSC,S} > \frac{c}{\lambda_H(R_H-F^S)-A+c}$, which prompts high-type entrepreneurs always apply by Lemma 1. When Government randomizes between SC and (NSC,S), Lemma 2 dictates that a low-type entrepreneur applies with probability $\mu = \underline{\mu} = \left(\frac{p}{1-p}\right)\left(\frac{\sigma}{I+gS-\lambda_L R_L-\sigma}\right)$. Inserting this into (19) shows that Government's belief is given by $\theta = \frac{I+gS-\lambda_L R_L-\sigma}{I+gS-\lambda_L R_L}$.□

PROOF OF PROPOSITION 4: i) $\bar{A} > \bar{A}^S \Leftrightarrow \left(\frac{\lambda_H}{\lambda_H - \bar{\lambda}}\right)(I - \bar{\lambda}R_H) > \left(\frac{\lambda_H}{\lambda_H - \hat{\lambda}}\right)(I - S + c - \hat{\lambda}R_H) \Leftrightarrow (\hat{\lambda} - \bar{\lambda})(\lambda_H R_H - I) + (\lambda_H + \bar{\lambda})(S - c) > 0$. From the last inequality we can see that it holds if $\hat{\lambda} \geq \bar{\lambda}$. High-type projects are economically viable, therefore $\lambda_H R_H - I > 0$. Since we are analyzing entrepreneurs that have been granted an R&D subsidy, $(\lambda_H + \bar{\lambda})(S - c) > 0$, if $S > c$ and $\bar{A} > \bar{A}^S$ even if $\hat{\lambda} = \bar{\lambda}$.

ii) $\hat{\lambda} = \hat{p}\lambda_H + (1 - \hat{p})\lambda_L > \bar{\lambda}$, if $\hat{p} > p$. Knowing that $\hat{p} = \alpha_{SC} + (1 - \alpha_{SC})\theta$ gives us that for $\hat{p} > p$, α_{SC} must satisfy $\alpha_{SC} > \frac{p - \theta}{1 - \theta}$. This is true since $p < \theta = \frac{p}{p + \mu(1-p)} < 1$ $(0 < p < 1$ and $0 < \mu < 1)$. □

PROOF OF PROPOSITION 5: $\bar{A} > \bar{A}^S$ must hold for a specific value of $\hat{p}$, if the subsidy program reduces financial constraints. It can be shown that $\bar{A} > \bar{A}^S \Leftrightarrow \hat{p} \geq \frac{I - S + c - \lambda_L R_L}{\lambda_H R_H - \lambda_L R_L} = \underline{\hat{p}}$. Proposition 1 gives that in the funding gap region $p < \frac{I - \lambda_L R_H}{(\lambda_H - \lambda_L) R_H} = \bar{p}$. It can be shown that $\bar{p} > \underline{\hat{p}}$. In addition we know from Proposition 4 that for a given p, $\hat{p} > p$, so the lower bound of p is smaller than $\underline{\hat{p}}$. Substituting for $\frac{p}{p + \mu(1-p)}$ for θ in $\hat{p} = \alpha_{SC} + (1 - \alpha_{SC})\theta$ gives the implicit form for p as a function of $p, \hat{\alpha}_{SC}$ and μ that is $p = \frac{(\hat{p} - \alpha_{SC})\mu}{(1 - \hat{p}) + (\hat{p} - \alpha_{SC})\mu}$. Substituting $\underline{\hat{p}}$ for $\hat{p}$ gives the lower bound of p in the implicit form and the interval in Proposition 5. □

COMPARATIVE STATICS OF GOVERNMENT SCREENING: We briefly sketch the comparative statics of Government screening probability α_{SC} in the full game where the entrepreneur's repayment obligation $F^S$is endogenous. After tedious algebra, it turns out that the partial derivatives of α_{SC} with respect to σ, c, A, and S are given by

$$\frac{\partial \alpha_{SC}}{\partial \sigma} = \frac{\lambda_L \left(\frac{(\lambda_H - \lambda_L)\alpha_{SC}}{I^S - \lambda_L R_L}\right)(I - A - S + c)c}{[\hat{\lambda}(\lambda_L(R_L - F^S) - A + c)]^2 - (\lambda_H - \lambda_L)(1 - \theta)(I - A - S + c)c},$$

$$\frac{\partial \alpha_{SC}}{\partial c} = -\frac{\hat{\lambda}^2 \lambda_L \left(\hat{\lambda}(R_L - F^S) + c\right)}{[\hat{\lambda}(\lambda_L(R_L - F^S) - A + c)]^2 - (\lambda_H - \lambda_L)(1 - \theta)(I - A - S + c)c},$$

$$\frac{\partial \alpha_{SC}}{\partial A} = -\frac{\hat{\lambda}\left(\lambda_L + \hat{\lambda}\right)c}{[\hat{\lambda}(\lambda_L(R_L - F^S) - A + c)]^2 - (\lambda_H - \lambda_L)(1-\theta)(I - A - S + c)c},$$

and

$$\frac{\partial \alpha_{SC}}{\partial S} = -\frac{\lambda_L\left[\hat{\lambda} + (\lambda_H - \lambda_L)(1-\alpha_{SC})\left(\frac{g\sigma}{(I_S - \lambda_L R_L)^2}\right)(I - A - S - c)\right]c}{[\hat{\lambda}(\lambda_L(R_L - F^S) - A + c)]^2 - (\lambda_H - \lambda_L)(1-\theta)(I - A - S + c)c}.$$

If the denominator is positive then $\frac{\partial \alpha_{SC}}{\partial \sigma} < 0$, $\frac{\partial \alpha_{SC}}{\partial c} < 0$, $\frac{\partial \alpha_{SC}}{A} < 0$ and $\frac{\partial \alpha_{SC}}{S} > 0$. Note first that in equilibrium θ is given by the exogenous parameters as $\theta = 1 - \frac{\sigma}{I + gS - \lambda_L R_L}$. It can then be shown that when $\theta = 1$ the denominator is positive. Moreover it can be shown that the denominator reaches it's minimum, which is negative, at a negative value of θ. As a function of θ, the denominator is an upward opening parabola, so by continuity there must be an interval of $\theta \in [\hat{\theta}, 1]$, where the denominator is positive. The restrictions imposed on σ and p imply that in the funding gap region $\theta \in \left[\frac{I - gS - \lambda_L R_L}{\lambda_H(R_H + W) - \lambda_L R_L}, 1\right]$. Consequently, if θ is sufficiently close to unity, there are financially constrained high-type entrepreneurs and the denominator of the partial derivatives is positive.