Tuomas Takalo – Tanja Tanayama

Adverse selection and financing of innovation: is there a need for R&D subsidies?

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Adverse selection and financing of innovation: is there a need for R&D subsidies?

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Abstract

We study the interaction between private and public funding of innovative projects in the presence of adverse-selection based financing constraints. Government programmes 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. Firstly, the subsidy itself reduces the capital costs related to innovation projects by reducing the amount of market-based capital required. Secondly, the observation that an entrepreneur has received a subsidy for an innovation project provides an informative signal to market-based financiers. We also find that public screening works more efficiently if it is accompanied by subsidy allocation.

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

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

Innovaatioprojektien rahoitus ja haitallinen valikoituminen: onko tarvetta T&K-tukiin?

Suomen Pankin keskustelualoitteita 19/2008

Tuomas Takalo – Tanja Tanayama
Rahapolitiikka- ja tutkimusosasto

Tiivistelmä

Aikaisempi tutkimus on osoittanut, että epäsymmetrinen informaatio ja haitallinen valikoituminen vaikeuttavat erityisesti pienten innovatiivisten yritysten ulkoisen rahoituksen saantia. Tässä tutkimuksessa osoitetaan, että julkisen rahoittajan tarjoamat yksityisen sektorin tutkimus- ja kehitystoiminnan tuet voivat helpottaa rahoitusrajoitteita. Tukiainen itsessään luonnollisesti vähentää ulkoisen rahoituksen tarvetta, mutta koska julkinen rahoittaja yleensä arvioi tukihakemukset jollakin kriteerillä, pelkkä julkisen rahoituksen saanti toimii informatiivisena signaalina yksityisille rahoittajille. Yksityiset rahoittajat voivat siten tehdä parempia rahoituspäätöksiä, ja haitallisen valikoitumisen ongelma lievenee. Tutkimuksessa osoitetaan myös, että julkinen innovaatioprojektien arviointi on tehokkaampaa, jos siihen yhdistyy tukien myöntäminen.

Avainsanat: innovaatioiden rahoitus, rahoitusmarkkinoiden tehokkuus, T&K-tuet, haitallinen valikoituminen

JEL-luokittelu: D82, G28, H20, O30, O38

Contents

1 Introduction

Previous research suggests asymmetric information about the quality of an innovation project between the entrepreneur and the 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 of such policy tools is direct subsidies to corporate R&D. However, the theoretical literature linking financing constraints and R&D subsidies is sparse. Our goal is to analyze how a governmental R&D subsidy program works in the presence of financial constraints created by asymmetric information.

Based on the famous lemons problem identified by Akerlof (1970), there is a huge literature that singles out adverse selection as a major source of financing constraints. Entrepreneurs have better information about the quality of their own projects than lenders, whose valuation of the projects reflect average project quality. This may raise the rate of return required by lenders so high that it becomes unprofitable for an entrepreneur without sufficient internal funding to undertake an economically viable project.

Two interrelated solutions to the adverse-selection problem have been proposed: signaling and financial intermediation. An entrepreneur's willingness to invest in the project or to offer collateral could serve as a credible signal of the quality of her project (Leland and Pyle, 1977, and Bester, 1985). Reputation may also reduce financing constraints, because over time borrowers who manage to acquire good reputation encounter less severe informational problems (Diamond, 1989). Financial intermediaries such as banks in turn could alleviate financing constraints through information gathering, because they might be able to screen and monitor loan applicants at a cost advantage relative to individual lenders (see, eg Diamond, 1984, and Chan, Greenbaum and Thakor, 1986). In particular, it has been argued that venture capital and related organizations can, through intensive screening and monitoring, overcome informational problems and mitigate capital constraints (eg Lerner, 1998).

There are, however, several arguments why the proposed solutions may fail to eliminate financing constraints, especially in the case of science and technology-based start-ups. First, such entrepreneurs may lack the means to signal project quality. Human-capital intensive projects do not often involve collateralizable assets. Own wealth is insufficient or liquid, and is generally needed to invest in the project. Second, reputation building takes time and start-ups, almost by definition, cannot have established reputation. Third, the screening activities of financial intermediaries may be inefficient. According to the so called competition-stability tradeoff, competition in banking sector can reduce banks' information surplus and thereby their incentives to gather information (eg Keeley, 1990).[1] Information reusability can also be hampered

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

by intemporal 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.

Even venture capital organizations may fail to provide an adequate solution to financing constraints (see, eg Hall, 2002, and Lerner, 1998, 2002). Only a modest number of firms in specific sectors receive venture capital funding each year. Venture capital investments also 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. In addition, the threat of expropriation may undermine screening activities (Bhattacharya and Ritter, 1983, and Ueda, 2004). To obtain external funding, an entrepreneur needs to reveal valuable private information about her project to a financier, which creates a risk that the financier steals the information.

Informational problems are acknowledged to be particularly severe in financing of R&D projects (Hubbard, 1998, and Alam and Walton, 1995). 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. Such firms cannot have acquired reputation nor assets that can be offered as collateral. Moreover, credit worthiness of these firm is difficult to assess, and even venture capital organizations are likely to favor firms with some track records over pure start-ups (Amit, Brander and Zott, 1998).

In line with the funding gap hypothesis caused by adverse selection, there is indeed abundant evidence that R&D investment are sensitive to cash flow, at least in the case of newly established, small, technology-based firms (eg Hall, 1992, Hao and Jaffe, 1993, Himmelberg and Petersen, 1994, Bond, Harhoff and Van Reenen, 2003, and Bougheas, Görg and Strobl, 2001). Similarly, Finnish evidence points that newly established technology-based small and medium size firms may suffer from financial constraints (Hyytinen and Pajarinen, 2002).[2]

Given the problems in financing of R&D by small firms, Governments in several countries have intervened to reduce financing constraints. One widely-used policy tool is direct subsidies to corporate R&D. In contrast to some other innovation policy tools such as R&D tax credits, Government programs allocating direct subsidies are based on a specific selection scheme. This selection is done by ex-ante screening of the applications.

We develop a model of innovation finance where capital constrained entrepreneurs can try to tap a public agency for funding in addition to private funding sources. We analyze whether R&D subsidy policies can reduce

[2] 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.

adverse-selection based financing constraints. It turns out that under certain circumstances, they can. 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.

Our modeling framework builds on Holmström and Tirole (1997), which has subsequently been used to study entrepreneurial finance, eg 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. In particular, we study whether a subsidy by a public agency could 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).

Despite that R&D subsidies are ubiquitous in developed countries, the theoretical literature examining R&D subsidies is rather limited. 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 (eg Stenbacka and Tombak, 1998, and Maurer and Scotchmer, 2004).

There is, however, a large related literature 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.[3]

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, eg 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.

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

[3] 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). For more details on Tekes and on the Finnish innovation policy environment, see, eg Georghiu et al (2003). Some other examples of related R&D subsidy programs include the Advanced Technology Program (ATP) and the Small Business Innovation Research (SBIR) Program7 in US, 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.

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 $\lambda_H > \lambda_L$, $R_L > R_H$, $\lambda_H R_H > I > \lambda_L R_L$.[4]

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.[5]

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 unnecessarily complicate the analysis, we assume that c is a monetary cost.[6] 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 $1 + g$ $(0 < g < 1)$.[7] A successful project may generate social benefit to Government beyond the private return R_i. Such social benefit covers the

[4] 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.

[5] 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, eg Bester, 1985).

[6] 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.

[7] While the assumptions of a fixed subsidy and the absence of Government's budget constraint are used elsewhere in the literature (see, eg 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).

externalities generated by the project including, eg, 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 have 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: 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 equilibrium Government will screen an application with some positive probability and this probability measures the intensity of screening.[8]

2.3 Market-based financiers

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

[8] 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.

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.

The assumption that Government has a superior screening ability to private sector financiers is of course strong, but 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. In other words, we could assume that private sector 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.

Moreover, there are several factors that may support our assumptions, especially in the case of a small country like Finland. First, the public financier is often granting project specific funding, whereas private sector financiers, especially those using debt finance, typically operate at the firm level. Second, in theory, a benevolent public financier should not only be interested in the financial return generated by a project but also take into account the overall social benefits. The public financier should therefore in theory have a larger interest in screening than the market-based financiers. Third, since screening is a public good, private sector financiers can suffer from a free-riding problem. A public screening agency can offer a solution to the free-riding problem. This raises a fourth possibility why Government may have a better screening technology: Government's investments in screening can crowd out private sectors' incentives to screen. A subsidy in itself should also reduce the stake the private sector 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 sector financiers to economize on screening investments.[9] 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. At the same time, there seems to be a common impression that the private financial markets are underdeveloped in terms of their screening technology.

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

[9] The free-riding problem among investors is traditionally given as a rationale for the existence of financial intermediaries (eg 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.

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,[10] and we restrict our attention to a 'realistic' subspace of contracts where i) parties are protected by limited liability; ii) markets must clear;[11] and iii) the financial contract cannot specify a positive reward for an entrepreneur to refrain from investing.[12]

3 Innovation finance without public funding

We begin with analyzing the case without public support of innovation. This case 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.

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.

An entrepreneur is willing to launch the project if her expected profit from the project is at least as much as the entrepreneur would get from investing the initial capital into alternative sources, ie, the market value of

[10] Equivalently, project returns are verifiable up to R_H as, eg in Bolton and Sharfstein (1990). In this case the distinction between debt and equity becomes moot. Following, eg 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.

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

[12] 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.

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

$$\lambda_i R_i^E \geq A \tag{3.1}$$

When (3.1) binds,

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

captures the i-type entrepreneur's pledgeable income, that is, the maximum amount an entrepreneur of type i can credibly promise to pay back to a financier in the case of success.

We will first identify the region of initial capital in which high-type entrepreneurs have no means to credibly signal their quality. Low-type entrepreneurs can always pretend to be high-type entrepreneurs if the low types' pledgeable income is higher, ie, when $R_L^{F\max} \geq R_H^{F\max}$. Solving this inequality for A gives

$$A \leq \hat{A} \equiv \frac{\lambda_L \lambda_H (R_L - R_H)}{\lambda_H - \lambda_L} \tag{3.2}$$

When the initial wealth is less than $\hat{A}$, 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 (3.2) holds, a high-type entrepreneur has no means to truthfully signal her quality even if she had an incentive to do so. A low-type entrepreneur could offer the financier a larger return but it is not in her interest to reveal her type. Hence, both types offer the same repayment to the financier.

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. The minimum repayment F that a financier requires to invest in a project of an average quality is then

$$F = \frac{I - A}{\bar{\lambda}} \tag{3.3}$$

where $\bar{\lambda} = p\lambda_H + (1-p)\lambda_L$ is the expected success probability in a pooling equilibrium. The maximum repayment that a high-type entrepreneur, and by implication, a low-type entrepreneur, are willing to offer to the financier is $R_H^F = R_H - \frac{A}{\lambda_H}$. As a result, projects can get market-based funding as long as

$$\frac{I - A}{\bar{\lambda}} \leq R_H - \frac{A}{\lambda_H} \tag{3.4}$$

Equation (3.4) is the financier's participation constraint when $A \leq \hat{A}$. The left hand side of (3.4) is the minimum repayment that the financier requires to invest in a project and the right hand side is the maximum repayment any entrepreneur can promise to the financier. Solving (3.4) for A gives

$$A \geq \bar{A} \equiv \frac{\lambda_H \left(I - \bar{\lambda} R_H\right)}{\lambda_H - \bar{\lambda}} \tag{3.5}$$

In (3.5), $\bar{A}$ gives the threshold value of initial capital needed to get financing, when the financier anticipates all the entrepreneurs to seek financing. Entrepreneurs with $A < \bar{A}$ cannot get market-based financing for their project.

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, the minimum amount that a financier requires to invest in a project of unknown entrepreneurial quality continues to be the pooling one, as long as also low-type entrepreneurs can afford offering F to the financier. This happens when $R_L^{F\max} \geq F$ or, equivalently, when

$$\frac{(I-A)}{\bar{\lambda}} \leq R_L - \frac{A}{\lambda_L} \tag{3.6}$$

The left hand side of (3.6) 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 (3.6) for A gives us

$$A \leq \dot{A} \equiv \frac{\lambda_L(\bar{\lambda}R_L - I)}{p\,(\lambda_H - \lambda_L)} \tag{3.7}$$

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

$$A \leq \frac{\lambda_L(\lambda_H R_L - I)}{\lambda_H - \lambda_L} \equiv \ddot{A} \tag{3.8}$$

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 $\dot{A} \leq A \leq \ddot{A}$, a low-type entrepreneur can pretend to be of high-type by offering $\frac{I-A}{\lambda_H}$ to the financier. Therefore, when $\dot{A} \leq A \leq \ddot{A}$, there is a semi-separating equilibrium in which all the high-type entrepreneurs and a share of low-type entrepreneurs are funded. In other words, only a share of low-type entrepreneurs applies for funding.

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), $p \in [0,1]$, $A \in [0,I]$. When $A < min\{\hat{A},\bar{A}\}$, market-based financiers are willing to fund no projects. Note that for this region, the upper bound of p is $\frac{I-\lambda_L R_H}{(\lambda_H-\lambda_L)R_H}$. 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, any 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 H-type entrepreneurs but no projects by L-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-type entrepreneurs 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 ($A < min\{\hat{A}, \bar{A}\}$) no entrepreneur is financed. In other words, there is a funding gap. From the social point of view it is efficient that low-type entrepreneurs do not get financing. High-type entrepreneurs should, however, get financing as in the complete information case. Financial constraints that prevent high-type entrepreneurs with $A < min\{\hat{A}, \bar{A}\}$ 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.

We summarize the main result of the section in the following proposition.

Proposition 1 *In a population where the share of high-type entrepreneurs p fulfills* $p \leq \frac{I-\lambda_L R_H}{(\lambda_H-\lambda_L)R_H}$, *high-type entrepreneurs with* $A < min\{\hat{A}, \bar{A}\}$ *suffer from the funding gap that prevents them from undertaking economically viable innovation projects.*

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 focus on region 1 of Figure 1 where the funding gap prevails, and proceed under the assumption that receiving a subsidy is both a necessary and sufficient condition to secure the additional external funding from private sources.[13] 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. In other words, in this section we assume that with the subsidy an entrepreneur can launch an innovation project that could not be undertaken otherwise.

Because the subgame considered in this section is more complicated than the standard adverse selection model outlined in the previous section, let us be somewhat more rigorous in describing 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 whether to apply (AP) for an R&D subsidy or not (NAP). In other words, the entrepreneur chooses an action $a^E \in A^E = \{AP, NAP\}$ where A^E is the action space of the entrepreneur.
[2.] Government receives the application, but does not observe the type of the entrepreneur. It has to decide whether to screen (SC) the application or not (NSC), ie, Government chooses an action $a_1^G \in A_1^G = \{SC,\ NSC\}$ where A_1^G is the Government's action space at this stage.
[3.] Government decides whether to give the entrepreneur a fixed subsidy of S or not. At this stage, Government chooses an action $a_2^G \in A_2^G = \{S,\ NS\}$ where A_2^G is the Government's action space.
[4.] The entrepreneurs who received the subsidy obtain market-based funding and can execute their projects, and payoffs are realized as shown below.

Since the entrepreneur's action in the last stage of the game is trivial, 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's pure strategy s^E equals her action a^E and her pure-strategy space is $\Sigma^E = A^E = \{AP, NAP\}$. 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 $\Pi_{s^G}^{G,i}$ 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

[13] 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.

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

$$\Pi_{SC}^{G,H} = \lambda_H(R_H + W) - I - gS - c - \sigma \quad (4.1)$$

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 sector 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 an argument, the net cost of the subsidy to Government consists of the shadow cost of public funds gS and the screening cost σ. Equation (4.1) also shows how a successful project of a high-type entrepreneur generates a social benefit W to Government beyond the returns captured by private sector agents.

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

$$\Pi_{NSC,S}^{G,H} = \lambda_H(R_H + W) - I - gS - c \quad (4.2)$$

which is identical to (4.1) save the cost of screening σ. Government's payoff for the same strategy $s^G = (NSC, S)$ when the applicant is of a low type is given by

$$\Pi_{NSC,S}^{G,L} = \lambda_L R_L - I - gS - c \quad (4.3)$$

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

$$\Pi_{SC}^{G,L} = -c - \sigma \quad (4.4)$$

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

$$\Pi_{NSC,NS}^{G,i} = -c \quad (4.5)$$

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 either the strategy $s^G = SC$

or s^G =*(NSC,S)*, and if Government follows the strategy s^G =*(NSC, NS)*, she does not get a subsidy. Similarly, if Government follows either 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 payoff of an entrepreneur of type $i \in \{H,L\}$ when she gets a subsidy $\left(a_2^G = S\right)$ is given by

$$\Pi^{E,i}_S = \lambda_i \left(R_i - F^S\right) - A \tag{4.6}$$

and when she does not get a subsidy $\left(a_2^G = NS\right)$, her payoff is

$$\Pi^{E,i}_{NS} = -c \tag{4.7}$$

In (4.6), 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 but it 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. We focus on PBE where 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 $s^E \in \Sigma^E = \{AP, NAP\}$.[14] 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 $\mu_{s^E}$and α_{s^G} are probability distributions we will write that $\mu_{AP} = \mu$, $\mu_{NAP} = 1-\mu$, and $\alpha_{NSC,NS} = 1-\alpha_{SC}-\alpha_{NSC,S}$ $(\mu, \alpha_{SC}, \alpha_{NSC,S} \geq 0)$. In other words, 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 optimal strategies for a low-type entrepreneur. Low-type entrepreneur's expected payoff from applying given that Government follows a mixed strategy α_{s^G} is

$$E(\Pi^{E,L,}_{AP}) = (1 - \alpha_{NSC,S})\Pi^{E,L}_{NS} + \alpha_{NSC,S}\Pi^{E,L}_S \tag{4.8}$$

and from not applying zero.

[14]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. That is, the region in which high-type entrepreneurs suffer from the funding gap, and screening is a plausible strategy for Government. Briefly, the reason why H-types always apply in the equilibrium we focus on is that the market-based financiers interpret all entrepreneurs without subsidies as L-types and do not give them the additional funding required to implement the project.

If $E(\Pi_{AP}^{E,L}) > 0$, a low-type entrepreneur always applies and if $E(\Pi_{AP}^{E,L}) < 0$, she never applies. If $E(\Pi_{AP}^{E,L}) = 0$, low-type entrepreneur is indifferent, and uses a mixed strategy $\mu, (1-\mu)$. Substituting (4.6) for $\Pi_{S}^{E,L}$ and $-c$ (from (4.7)) for $\Pi_{NS}^{E,L}$ in (4.8) and solving the inequalities shows that

- 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 ($\mu = 0$); and
- 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 $(1-\mu)$.

Given Government's mixed strategy α_{s^G}, the expected payoff of a high-type entrepreneur from applying is

$$E(\Pi_{AP}^{E,H}) = (\alpha_{SC} + \alpha_{NSC,S})\Pi_{S}^{E,H} + (1 - \alpha_{SC} - \alpha_{NSC,S})\Pi_{NS}^{E,H} \tag{4.9}$$

where $\Pi_{S}^{E,H}$ and $\Pi_{NS}^{E,H}$ are specified by (4.6) and (4.7). If a high-type entrepreneur does not apply for a subsidy her net payoff is zero. Consequently, the assumption that high-type entrepreneurs always apply implies that in equilibrium, the condition

$$E(\Pi_{AP}^{E,H}) > 0 \tag{4.10}$$

must hold.

Let us turn to the Government's optimal strategies. 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

$$\theta = \frac{p}{p + \mu(1-p)} \tag{4.11}$$

Government's expected payoff from choosing pure strategy screening ($\alpha_{SC} = 1$) is $E(\Pi_{SC}^{G}) = \theta\Pi_{SC}^{G,H} + (1-\theta)\,\Pi_{SC}^{G,L}$ which, by using (4.1) and (4.4), can be written as

$$E(\Pi_{SC}^{G}) = \theta\left[\lambda_H\left(R_H + W\right) - I - gS\right] - c - \sigma \tag{4.12}$$

Similarly, using (4.2) and (4.3) we see that Government's expected payoff from $\alpha_{NSC,S} = 1$ is

$$E(\Pi_{NSC,S}^{G}) = \theta\left[\lambda_H\left(R_H + W\right)\right] + (1-\theta)\lambda_L R_L - I - gS - c \tag{4.13}$$

Finally, from choosing pure-strategy s^G =*(NSC, NS)* ($\alpha_{SC} = \alpha_{NSC,S} = 0$), the Government's payoff is simply given by (4.5) as $E(\Pi_{NSC,NS}^{G})$ = -*c*.

If $E(\Pi^G_{SC}) > \max\left\{E(\Pi^G_{NSC,S}), -c\right\}$, it is optimal for Government to choose pure strategy SC ($\alpha_{SC} = 1$). If $E(\Pi^G_{NSC,S}) > \max\left\{E(\Pi^G_{SC,S}), -c\right\}$, then $s^G = (NSC, S)$ ($\alpha_{NSC,S} = 1$) is optimal for Government and if both $E(\Pi^G_{SC})$ and $E(\Pi^G_{NSC,S})$ are smaller than -*c*, pure strategy $s^G = (NSC, NS)$ ($\alpha_{SC} = \alpha_{NSC,S} = 0$) is optimal. Whenever the payoffs from pure strategies are equal, Government is indifferent between the corresponding pure strategies.

It turns out that Government's best response to a low-type's mixed strategy depends on the value of μ. Let us define $\underline{L} = \left(\frac{p}{1-p}\right)\left(\frac{\sigma}{I+gS-\lambda_L R_L-\sigma}\right)$, $\bar{L} = \left(\frac{p}{1-p}\right)\left(\frac{\lambda_H(R_H+W)-I-gS-\sigma}{\sigma}\right)$ and $\hat{L} = \left(\frac{p}{1-p}\right)\left(\frac{\lambda_H(R_H+W)-I-gS}{I+gS-\lambda_L R_L}\right)$. The order of $\underline{L}$and $\bar{L}$ and the magnitude of $\underline{L}$, $\bar{L}$ and $\hat{L}$ – and thus the set of sensible Government strategies – depends on the values of σ and p. When $\underline{L} < \bar{L}$ it holds that

- if $\mu < \underline{L}$, the best strategy for Government is (*NSC, S*) ($\alpha_{NSC,S} = 1$);
- if $\underline{L} < \mu < \bar{L}$, the best strategy for Government is SC ($\alpha_{SC} = 1$);
- if $\mu > \bar{L}$, the best strategy for Government is (*NSC, NS*) ($1 - \alpha_{SC} - \alpha_{NSC,S} = 1$);
- if $\mu = \underline{L}$, Government is indifferent between SC and (*NSC, S*); and
- if $\mu = \bar{L}$, Government is indifferent between SC and (*NSC, NS*).

When $\underline{L} > \bar{L}$ it holds that

- if $\mu < \hat{L}$, the best strategy for Government is (*NSC, S*) ($\alpha_{NSC,S} = 1$);
- if $\mu > \hat{L}$, the best strategy for Government is (*NSC, NS*) ($1 - \alpha_{SC} - \alpha_{NSC,S} = 1$); and
- if $\mu = \hat{L}$, Government is indifferent between (*NSC, NS*) and (*NSC, S*).

Figure 3 presents sensible strategies for different sets of values of parameters σ and p. Note that based on Proposition 1, we know that in the presence of financing constraints $p \leq \frac{I-\lambda_L R_H}{(\lambda_H-\lambda_L)R_H}$. The figure identifies 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)*.

Proposition 2 *Screening is a plausible strategy for government if*

$$\sigma \leq min\left\{\frac{(I+gS-\lambda_L R_L)(\lambda_H(R_H+W)-I-gS)}{\lambda_H(R_H+W)-\lambda_L R_L}, (1-p)(I+gS-\lambda_L R_L)\right\}.$$

Propositions 1 and 2 identify the parameter regions which are the focus of this paper. Since our aim is to analyze the screening activities of Government, we consider regions 1 and 2 from Figure 3 and restrict σ to fulfill the condition presented in Proposition 2. This restriction implies that $\underline{L} < \bar{L}$. In addition this parameter restriction rules out the unrealistic case that if all entrepreneurs apply it is never optimal for Government to just grant subsidies to all.[15]

Within the region of interest, the plausible strategies for Government depend on whether $\bar{L}$ is greater or smaller than one. If $\bar{L}$ is greater than one, then the strategy (*NSC, NS*) is not a plausible option for Government. In practice $\bar{L}$ is smaller than 1 only 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.

Figure 4 below summarizes the optimal strategies for Government. Note that if $\bar{L}$ is larger than 1, the area in which screening is the optimal strategy extends to one and (*NSC, NS*) is no longer a plausible strategy for Government.

We can now state the main result of this section.

Proposition 3 *In a PBE of the game*

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

PROOF. Let first prove that there is no pure strategy equilibrium in this game. If a low-type entrepreneur always applies, $\alpha_{NSC,S} > \frac{c}{\lambda_L(R_L-F^S)-A+c}$ must hold. However, if $\mu = 1$, it is optimal for Government to choose (*NSC, NS*), implying that $\alpha_{NSC,S} = 0$. If a low-type entrepreneur never applies then $\alpha_{NSC,S} < \frac{c}{\lambda_L(R_L-F^S)-A+c}$. But if μ =0, it is optimal for Government to set $\alpha_{NSC,S} = 1$, which is larger than $\frac{c}{\lambda_L(R_L-F^S)-A+c}$.

For a low-type to be willing to use a mixed strategy $\mu > 0$, $\alpha_{NSC,S}$ must be equal to $\frac{c}{\lambda_L(R_L-F^S)-A+c}$. Given that $\alpha_{NSC,S} > 0$, 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 $\alpha_{SC} = \frac{\lambda_L(R_L-F^S)}{\lambda_L(R_L-F^S)-A+c}$. This Government strategy satisfies $\alpha_{SC} + \alpha_{NSC,S} > \frac{c}{\lambda_H(R_H-F^S)-A+c}$, as required by the assumption that high-type entrepreneurs always apply. When Government

[15] Substituting p for θ in equations (4.11) and (4.12) gives that (*SC*) is better than (*NSC,S*) if $\sigma < (1-p)(I + gS - \lambda_L R_L)$ and (*NSC, NS*) is better than (*NSC, S*) if $p < \frac{I+gS-\lambda_L R_L}{\lambda_H W-\lambda_L R_L}$.

randomizes between SC and (NSC,S), a low-type entrepreneur applies with probability $\mu = \underline{L} = \left(\frac{p}{1-p}\right)\left(\frac{\sigma}{I+gS-\lambda_L R_L-\sigma}\right)$. $\square$

The above equilibrium is based on the assumption that the subsidy program is in place and Government chooses whether to screen or not. In other words, 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 identified 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.[16]

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.[17]

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. Appendix presents 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 (p or the equilibrium value of θ is sufficiently high), 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 easy: an increase in the screening cost 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 the screening probability that increases with S. If S increases, low-type entrepreneurs anticipate an increase in the screening probability and are less likely to apply. Hence, public screening works more efficiently in discouraging low-type entrepreneurship if it accompanied with subsidy allocation.

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

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

5 Public and private funding of innovations

We are ready to 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 have enough initial wealth to apply for a subsidy ($A > c$) and need external market-based financing in addition to the subsidy to be able to undertake the innovation project ($A - c + S < I$).

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. The market-based financiers' beliefs in the non-singleton information sets, $\hat{\lambda}$, is determined by Bayes' Rule using the prior probabilities and the equilibrium strategies. Then, if the entrepreneur has been granted a subsidy, market-based financiers' participation constraint reads as

$$I - A - S + c \leq \hat{\lambda} F^S \tag{5.1}$$

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

$$\hat{\lambda} = P(H|S)\lambda_H + [1 - P(H|S)]\lambda_L \tag{5.2}$$

In (5.2), $P(H|S)$ 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 H-types always apply, the financier knows for sure that an entrepreneur without a subsidy is a low-type entrepreneur. Given that financiers must break-even, equation (5.1) holds with equality and the share of a successful project given to a financier is

$$F^S = \frac{I - A - S + c}{\hat{\lambda}} \tag{5.3}$$

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

$$\frac{I - A - S + c}{\hat{\lambda}} \leq R_H - \frac{A}{\lambda_H} \tag{5.4}$$

The right hand side of the equation (5.4) 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 (5.4) for A shows that if the entrepreneur has been granted an R&D subsidy, the private financiers grant funding if

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

Proposition 4 *Entrepreneurs with an R&D subsidy can get market-based financing with less initial capital, ie* $\bar{A} > \bar{A}^S$, *if* $\hat{\lambda} \geq \bar{\lambda}$.

PROOF. $\bar{A} > \bar{A}^S \Leftrightarrow \left(\frac{\lambda_H}{\lambda_H - \bar{\lambda}}\right)(I - \bar{\lambda} R_H) > \left(\frac{\lambda_H}{\lambda_H - \hat{\lambda}}\right)(I - S + c - \hat{\lambda} R_H) \Leftrightarrow (\hat{\lambda} - \bar{\lambda})(\lambda_H R_H - I) + (\lambda_H + \bar{\lambda})(S - c) > 0$. 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 $\hat{\lambda} = \bar{\lambda}$. □

Proposition 5 *Due to Government screening, the fact that an entrepreneur has received an R&D subsidy provides an informative signal to the financier, ie* $\hat{\lambda} > \bar{\lambda}$.

PROOF. $\hat{\lambda} = \hat{p}\lambda_H + (1 - \hat{p})\lambda_L > \bar{\lambda}$, 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 $0 < \mu < 1$). □

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 (3.2) 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 6 *R&D subsidy program reduces financial constraints, when* $p \in \left[\frac{(\hat{p}-\alpha_{SC})\mu}{(1-\underline{\hat{p}})+(\underline{\hat{p}}-\alpha_{SC})\mu}, \frac{I-\lambda_L R_H}{(\lambda_H-\lambda_L)R_H}\right]$ *, where* α_{SC} *and* μ *are the equilibrium strategies and* $\underline{\hat{p}} = \frac{I-S+c-\lambda_L R_L}{\lambda_H R_H - \lambda_L R_L}$.

PROOF: $\bar{A} > \bar{A}^S$ 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 5 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 6. □

Propositions 4, 5 and 6 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. The first one presented in Proposition 4 is a trivial one: a subsidy reduces the amount of external capital needed, thus reducing capital costs. The more interesting channel is the second one presented in Proposition 5: 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 6, depends on the distribution of initial wealth. What happens is that the initial wealth required to get financing from private sources becomes smaller, ie $\bar{A}$ 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

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

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

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

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

then $E(\Pi^G)$ is positive.[18]

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

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

[18] 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 16.

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.

6 Conclusions

This study examined the role of R&D subsidies in reducing financial constraints created by adverse selection. Financial constraints are one of the rationales used to justify government intervention in the form of R&D subsidies. The findings of this study provide insights into under which conditions and through which channels 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 within the economy, the higher the screening costs can be without rendering screening activities unsustainable.
- Under the above circumstances R&D subsidies can reduce financing constraints. This effect is generated through two different channels: 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. 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 related to 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.

Even if we consider public screening to be a solution to the financial constraints, an additional question is: do we need a public screening agency or are there ways to increase the screening activities of market based financiers? It can be argued that public screening activities only crow out private ones and hinder the development of efficient screening technologies in financial market..

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

In this appendix 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. 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 (or p) is sufficiently close to unity, there are financially constrained high-type entrepreneurs and the denominator of the partial derivatives is positive.

Figures 1–6

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

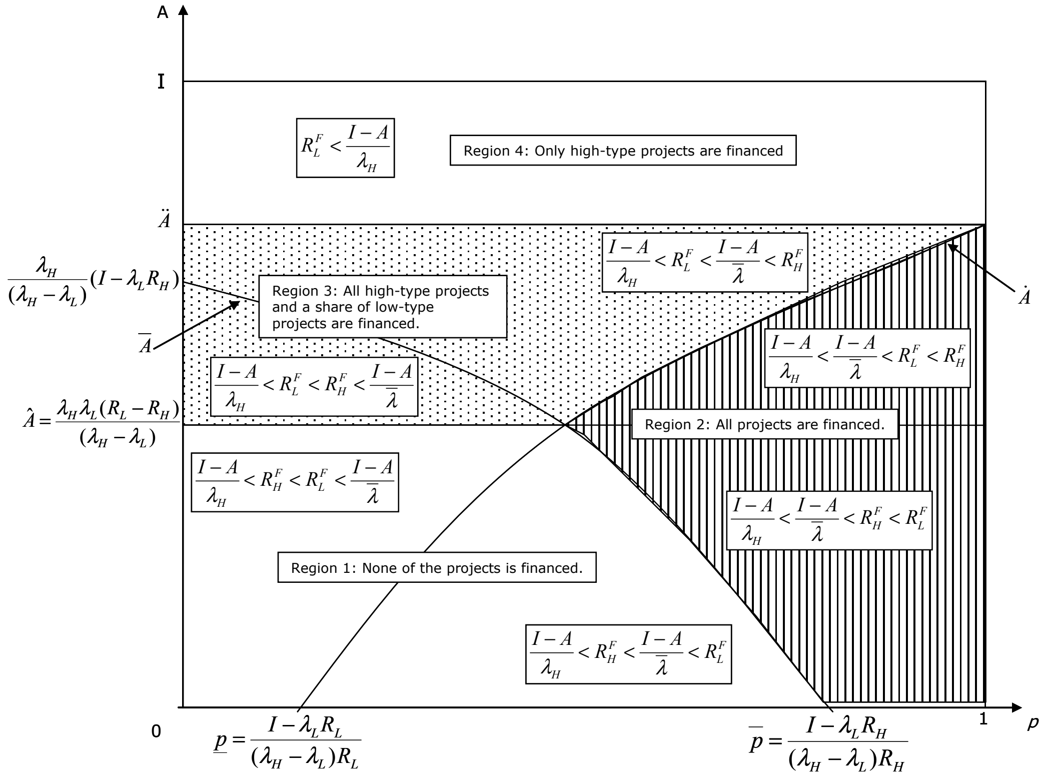


Figure 2. **Extensive-form representation of the application process with perfect screening**

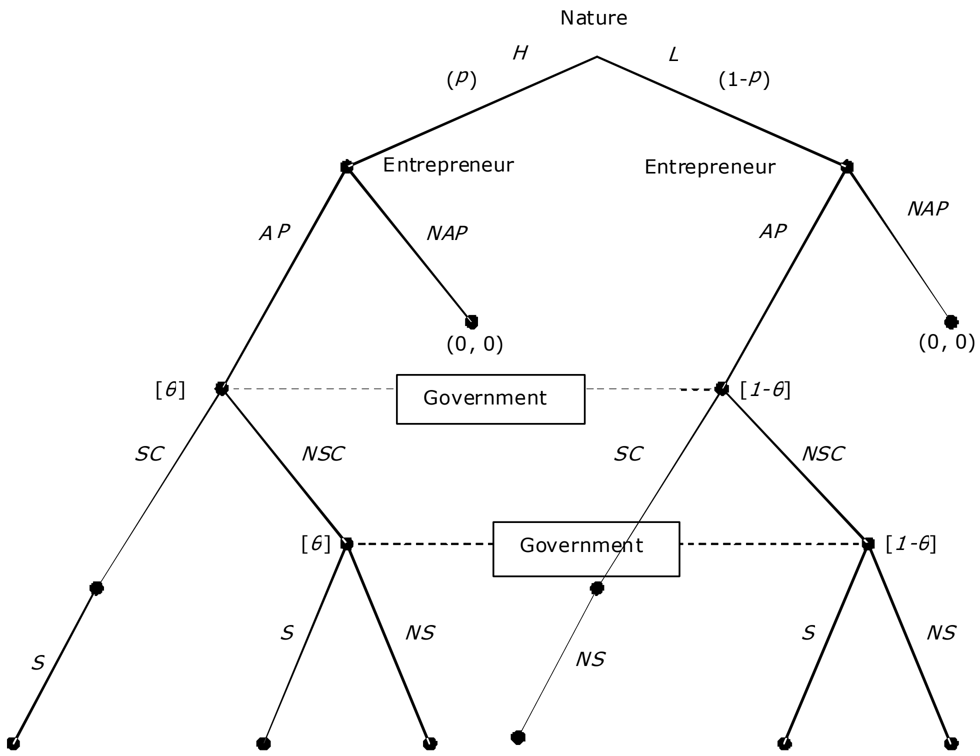


Figure 3. **Plausible government strategies with different values of screening costs (σ) and different share of high-type entrepreneurs in the economy (p)**

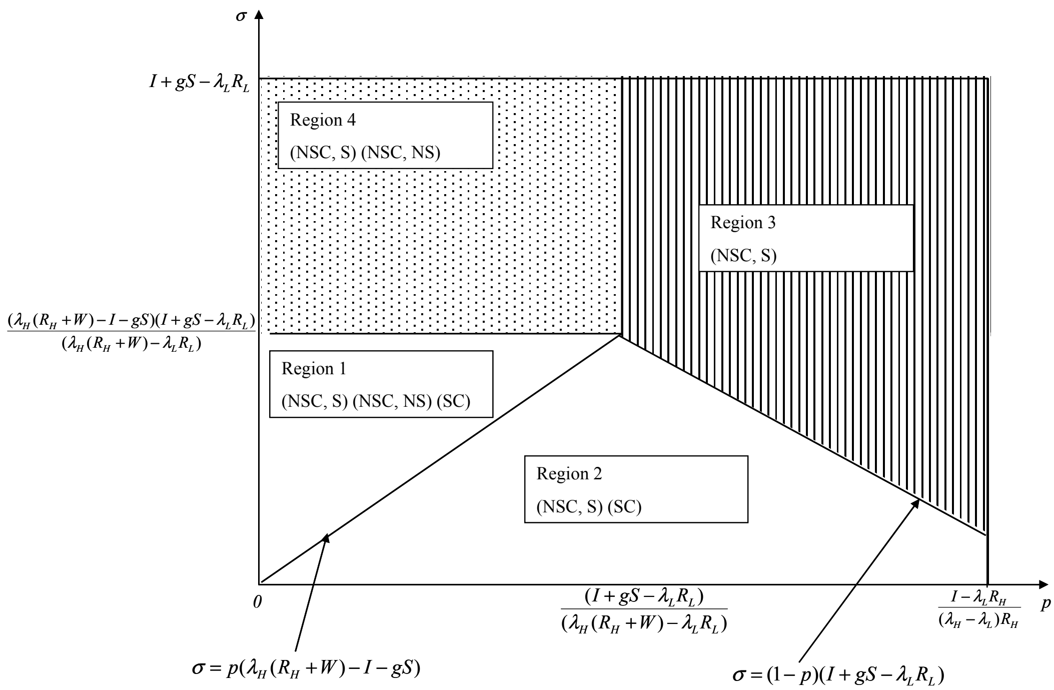


Figure 4. **Optimal strategies for government with different values of μ**

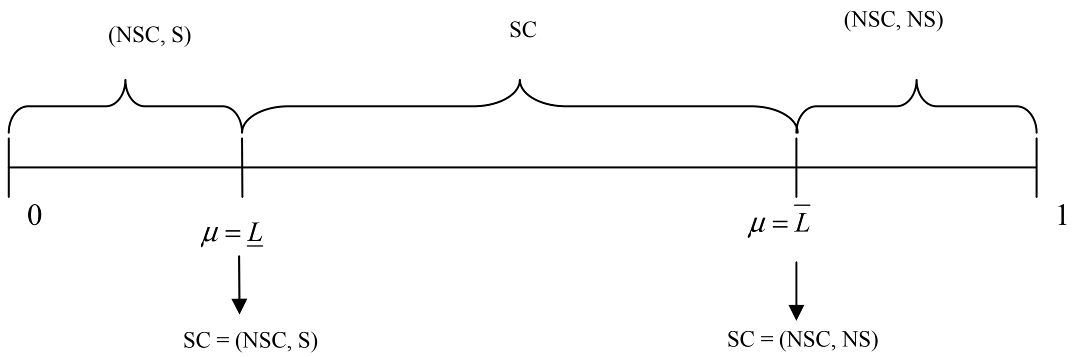


Figure 5. **Change in region 1, when a subsidy program is introduced**

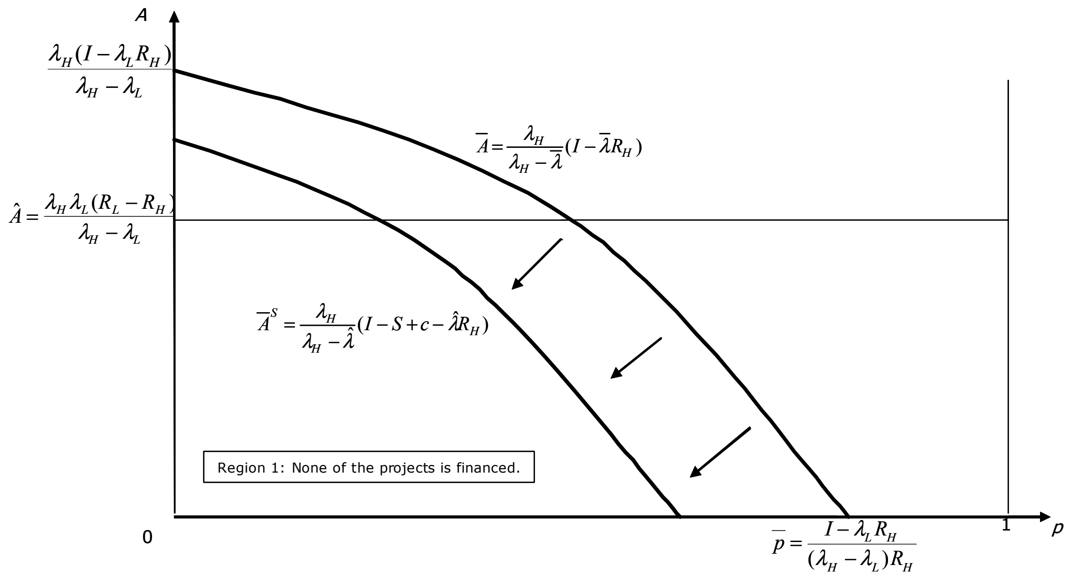
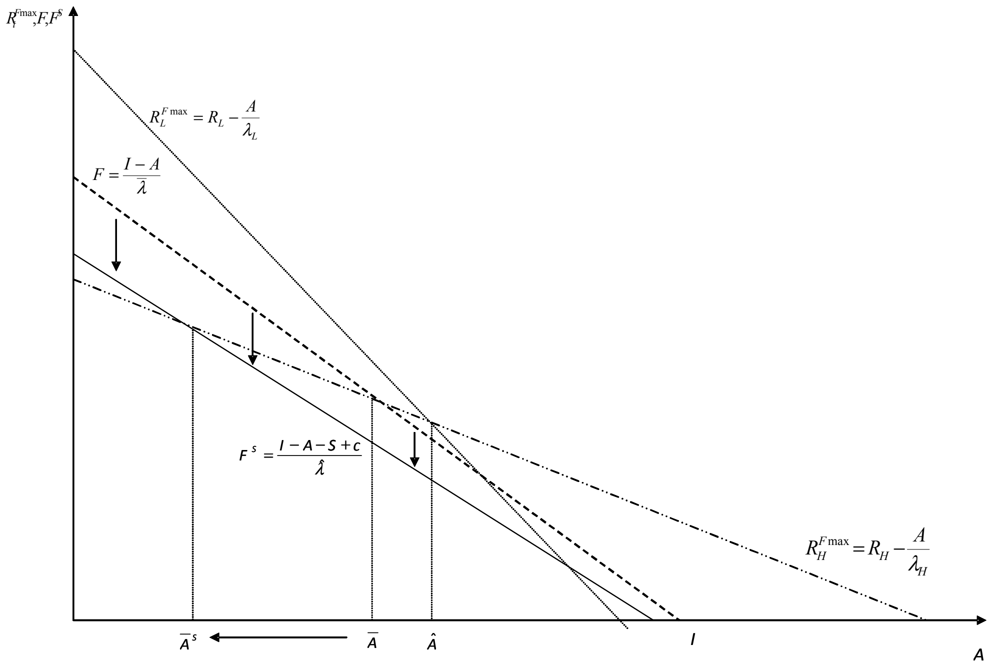


Figure 6. **Change in funding gap region as a subsidy program is introduced**



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