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Thomas Gehrig and Rune Stenbacka

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Centre for Economic Policy Research
33 Great Sutton Street, London EC1V 0DX, UK
Tel: +44 (0)20 7183 8801
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Abstract

We characterize optimal subsidies for firms facing limitations in their ability to correctly classify risky R&D projects. We demonstrate that the optimal subsidy is an increasing function of firms' ability to reduce type-I errors in accepting projects with a success potential, and a decreasing function in their type-II error of adopting projects with no success potential. Moreover, the optimal subsidy is decreasing in the informational advantage regarding the assessment of project viability of private firms relative to the government.

JEL Classification: D83, H25, H83, L52

Keywords: Imperfect screening, Subsidy policies

Thomas Gehrig - thomas.gehrig@univie.ac.at
University of Vienna and CEPR

Rune Stenbacka - stenbacka@hanken.fi
Hanken School of Economics and Helsinki Graduate School of Economics

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R&D and Subsidy Policy with Imperfect Project Classification*

Thomas Gehrig[†]   Rune Stenbacka [‡]

November 30, 2022

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We characterize optimal subsidies for firms facing limitations in their ability to correctly classify risky R&D projects. We demonstrate that the optimal subsidy is an increasing function of firms' ability to reduce type-I errors in accepting projects with a success potential, and a decreasing function in their type-II error of adopting projects with no success potential. Moreover, the optimal subsidy is decreasing in the informational advantage regarding the assessment of project viability of private firms relative to the government.

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[†] University of Vienna and CEPR, ECGI, SRC and VGSF. E-mail: thomas.gehrig@univie.ac.at

[‡] Hanken School of Economics and Helsinki Graduate School of Economics, Helsinki, Finland. Email: rune.stenbacka@hanken.fi

1 Introduction

Externalities and appropriability problems are central features of R&D projects leading to underinvestment (Arrow, 1972, Hall 2005). R&D subsidies are a central policy instrument, pushing private project returns closer to the social returns (Martin, 2016). When deciding to implement an R&D project, a firm typically faces uncertainty regarding the overall success viability or the timing of potential success[1], as emphasized by Besanko et al. (2018) within the framework of a model capturing ambiguity.

We explore the effects on investments and subsidy rates of limitations in the ability of firms and policymakers to assess whether R&D projects have potential for success at the stage of project implementation. We formulate these limitations as screening imperfections with project classification errors of type-I and type-II. Further, we add a new dimension relevant for the design of subsidy policy by analysing how optimal policy depends on whether firms and policymakers face symmetric or asymmetric classification errors.

2 The Model

Consider the implementation of R&D projects, the size of which are normalized to one. The projects have returns

$$\tilde{R} = \begin{cases} R & \text{with probability} \quad \pi \\ -1 & \text{with probability } 1 - \pi. \end{cases} \tag{1}$$

With probability π the project succeeds, yielding a net return $R > 0$. With probability $1 - \pi$ the project has no commercial potential, and the capital invested is lost. The social value of successful projects is $W > R$, meaning that R&D projects generate positive externalities.

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[1] In R&D decisions imperfect assessments of researchers and experts must be aggregated. This leads the firm to optimally implement threshold decision rules (e.g. Sah and Stiglitz 1986, Gehrig et al. 2000). These decision rules will affect misclassification of projects.

We refer to project holders as firms. These are risk neutral and maximize expected profits. By investing the firm can affect the success probability π. The costs required to achieve success probability π increase as a convex function of this probability. Formally, the costs, $c(\pi)$, required to achieve a success probability π satisfy $c'(\pi) > 0$ and $c"(\pi) > 0$. Further, there are no costs associated with a zero success probability, $c(0) = 0$, whereas certain success, $c(1) > W$, is excessively costly.

Firms have limited ability to assess whether projects have a potential for commercial success or not at the time of project implementation. Formally, the firm faces uncertainty as to whether the first or second row in (1) will be realized. This uncertainty could refer to technology or product market factors. To capture these features we consider firms to face screening imperfections when deciding about project implementation. The screening imperfections, classification errors, are exogenous: α_F is the probability that a project with a potential to succeed is recognized, whereas β_F denotes the probability that a project without success potential is mis-classified as having such potential. When investing, the firm anticipates the screening imperfections prevailing at the stage of project implementation.

As the social value of a successful project exceeds the private value ($W \geq R$), the government has incentives to internalize the associated externalities by committing to a subsidy rate s. At the outset the government makes its subsidy commitment prior to receiving any signal regarding project viability. Also the government operates with a view that projects are implemented subject to signal imperfections: With probability α_G a project with success potential is recognized and therefore implemented. With probability β_G a project without success potential is mis-classified, meaning that resources are channelled to a project without return potential.

The sequence of decisions is as follows. The government commits to a subsidy rate s. The subsidy rate is determined prior to project-specific observations and in anticipation of the firm's optimal R&D investment, but without knowledge regarding the outcome of the firm's project classification. Conditional on the subsidy policy the firm subsequently invests in order to raise the success probability π. The decision to implement the project is taken subject to screening imperfections, prior to the resolution of uncertainty regarding the success potential of the project.[2] We summarize the timing of decisions as follows:

1. The government commits itself to a subsidy rate.
2. The firm exerts effort to enhance the likelihood π of project viability at cost $c(\pi)$.
3. With signal classifying project as viable: Implement. Otherwise: Do not implement.
4. Uncertainty is resolved and payments are made.

We assume that it is optimal for the firm to implement projects classified as viable, but not those classified as not viable. In the Appendix, more precisely (10), we characterize analytically the combination of parameters for this to hold true. Intuitively, condition (10) means that the screening must generate a signal with sufficiently high precision. In particular, this is satisfied for the combination with α_F sufficiently close to one and β_F sufficiently close to zero.

3 Optimal Investment

The firm faces the following optimization problem:

$$max_{\pi} \;\; \alpha_F \pi R \;\; - \beta_F (1-\pi) \;\; - \;\; (1-s)c(\pi).$$

The first term captures the expected return from a correctly classified project of high quality. The second term denotes the expected loss associated with a mis-classification of a project without return potential. Through effort the firm can reduce the expected loss associated with this type-II error. The third term captures the costs of reaching the success probability π net of the subsidy from the government. [3]

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[2] Empirical studies have focused on whether firms make use of subsidy decisions to update their assessments regarding project characteristics. We build on Howell (2017), assuming no such updates.

[3] We assume that R&D effort is observable, because the subsidy depends on the costs of effort. However, the R&D effort is not verifiable to third parties, likes courts, and therefore it is non-contractible. The main reason is that it requires project-specific expertise to separate costs of R&D effort from other costs, and third parties do not have such expertise.

Conventional optimization yields the following result.

Result 1 *The optimal effort invested in an implemented project satisfies the condition*

$$c'(\pi^*) = \frac{\alpha_F R + \beta_F}{1-s}. \tag{2}$$

From (2) we can draw the following conclusions. It is optimal to expand the R&D investment if

- the likelihood of recognizing a high-quality project α_F is enhanced:

$$\frac{\partial \pi^*}{\partial \alpha_F} = \frac{R}{(1-s)c"(\pi^*)} > 0. \tag{3}$$

- the likelihood of misclassifying a project without potential β_F is enhanced:

$$\frac{\partial \pi^*}{\partial \beta_F} = \frac{1}{(1-s)c"(\pi^*)} > 0. \tag{4}$$

- the subsidy is increased:

$$\frac{\partial \pi^*}{\partial s} = \frac{c'(\pi^*)}{(1-s)c"(\pi^*)} > 0. \tag{5}$$

A higher probability of recognizing a project with potential increases the expected return of investment, and therefore stimulates investment. A higher probability of misclassification of a project without potential induces the firm to increase its investment in order to avoid the associated expected loss.

By reducing the investment costs a higher subsidy rate enhances the investment effort as demonstrated by (5). This is consistent with an extensive empirical as well as theoretical literature, including, for example, Takalo et al. (2022), Acemoglu et al. (2018), Lach et al. (2021) and Czarnitzki and Toole (2007). Acemoglu et al. (2018) as well as Takalo et al. (2022) estimate empirically the effects of

R&D subsidies on investments and welfare[4], whereas Lach et al. (2021) conduct a theoretical study highlighting how the contractual design of the public R&D support impacts on the private investments.

4 Optimal Policy

The government commits to a subsidy policy in anticipation of the firm's optimal investment and subject to classification errors. In light its assessment of the classification errors regarding project viability it determines the subsidy rate in order to solve

$$max_s \quad \alpha_G \pi^* W \; - \; \beta_G(1-\pi^*) \; - \; (1+s)c(\pi^*).$$

Based on straightforward optimization combined with (2) the following result presents a general characterization of optimal subsidy policy.

Result 2 *The socially optimal subsidy rate targeting an implemented project satisfies the condition*

$$\frac{\partial \pi^*}{\partial s}[\alpha_G W + \beta_G - \frac{1+s}{1-s}(\alpha_F R + \beta_F)] = c(\pi^*). \tag{6}$$

In (6), the left-hand side captures the indirect effects, whereby the subsidy enhances the investment. The right-hand side measures the direct cost-increasing effect associated with the subsidy rate. To gain more insights concerning the optimal policy we analyse the functional form

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[4] Takalo et al. (2022) show that R&D subsidies tend to excessively expand investments from the perspective of welfare. Acemoglu et al. (2018) explore the welfare effects of R&D subsidies on creative destruction by separating the effects on incumbent firms from those on entrants.

$$c(\pi) = \frac{K\pi^{\gamma}}{\gamma}\ , \tag{7}$$

where $\gamma > 1$ and $K > \gamma W$.

In (7), the parameter γ measures the complexity of the the R&D project. By (2), for (7) the investment determined by the firm is

$$[\pi^{*}]^{\gamma-1} = \frac{\alpha_F R + \beta_F}{K(1-s)} \tag{8}$$

Based on substitution of (8) into (6) we characterize the optimal subsidy policy as follows.

Result 3 *With the cost function (7) the socially optimal subsidy rate, s^*, is characterized by*

$$\begin{cases} \frac{1+s^*}{1-s^*} = \frac{\alpha_G W+\beta_G}{\alpha_F R+\beta_F} - \frac{\gamma-1}{\gamma} & \textit{if } \frac{\alpha_G W+\beta_G}{\alpha_F R+\beta_F} - \frac{\gamma-1}{\gamma} > 1 \\ 0 & \textit{if } \frac{\alpha_G W+\beta_G}{\alpha_F R+\beta_F} - \frac{\gamma-1}{\gamma} \leq 1 \end{cases} \tag{9}$$

The function $g(s^*) = \frac{1+s^*}{1-s^*}$, in left-hand side of the upper row in (9), is strictly increasing as a function of the subsidy rate and it satisfies that $g(0) = 1$. Therefore, the socially optimal subsidy rate is uniquely defined.

From (9), the condition for optimal policy to call for a positive subsidy is given by $\frac{\alpha_G W+\beta_G}{\alpha_F R+\beta_F} > 2 - \frac{1}{\gamma}$. Without classification errors, meaning that $\alpha_F = \alpha_G = 1$ and $\beta_F = \beta_G = 0$, the condition for the optimal policy to involve subsidies is given by $\frac{W}{R} > 2 - \frac{1}{\gamma}$. This condition is determined by the externality generated by a successful project and the complexity of the project.

We present our characterization of optimal subsidy policy by separating the configuration where the firm and the government operate subject to symmetric assessments regarding the classification errors ($\alpha_F = \alpha_G = \alpha$ and $\beta_F = \beta_G = \beta$) from that with asymmetric classification errors.

4.1 Symmetric classification errors

With symmetric classification errors the threshold for introducing a subsidy is lower than that without classification errors, because $\frac{\alpha W+\beta}{\alpha R+\beta} > \frac{W}{R}$. Thus, classification errors make it optimal to introduce the subsidy policy at a lower level of the externality generated by the project. From (9) we can also derive the comparative statics properties of the optimal subsidy as follows.

Result 4 *Symmetric assessments regarding the classification errors lower the threshold for introducing a subsidy. The optimal subsidy rate is (a) increasing in α, and (b) decreasing in β.*

From Result 4 we conclude that the optimal subsidy rate depends importantly on the nature of the classification error. A higher ability to correctly classify high-quality projects increases the optimal subsidy rate. In contrast, a higher probability of incorrectly subsidizing a low-quality project reduces the optimal subsidy rate.

4.2 Asymmetric classification errors

We next characterize optimal subsidy policy in an asymmetric configuration with different assessments of the firm and the government regarding the precision to assess project viability.

We initially focus on a scenario where the firm has more precise information[5]. We capture this feature by the following configuration: $\alpha_F = \alpha_G + \Delta$ and $\beta_F = \beta_G - \Delta$, where Δ captures the informational advantage of the firm. Substituting these parameters into (9) we find that a higher informational advantage for the firm (higher Δ) leads to a reduction in the socially optimal subsidy rate.

Next we consider the alternative case with an informational advantage for the government. We capture this configuration with the following combination of classification errors: $\alpha_F = \alpha_G - \Delta$ and $\beta_F = \beta_G + \Delta$. Applying an analogous procedure we find that the a higher informational advantage for the government (higher Δ) leads to an increase in the socially optimal subsidy rate.

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[5] Besanko et al. (2018) also analyze this configuration with firms having an informational advantage.

We summarize these findings in the following way.

Result 5 *The socially optimal subsidy rate decreases (increases) as a function of the informational advantage regarding the assessment of project viability of the firm (government).*

We have introduced informational advantages in a way identical for both types of classification errors. In order to intuitively explain Result 5 it is instructive to focus on the type-II errors (β-errors). By (4), a higher type-II error increases effort. An informational advantage for the firm means that the firm faces a lower β, implying lower effort provision. It seems natural that the policy response is then to counteract this effect by stimulating the effort incentives with a higher subsidy rate.

5 Conclusion

We characterized optimal R&D investments when firms face screening imperfections. The optimal investments are increasing functions of type-I and type-II errors. With symmetric assessments of the classification errors regarding project viability by the firm and the government and in anticipation of optimal investments the socially optimal subsidy rate is increasing (decreasing) in the type-I (type-II) error. Further, the optimal subsidy rate is decreasing (increasing) in the informational advantage of the firm (government).

Our analysis could be extended to capture investments in information acquisition by the firm and the government so that the classification errors are endogenous. Within such a framework it would be particularly interesting to compare the outlays for R&D subsidies with the optimal investments in information acquisition by the government.

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7 Appendix

Under which condition is it optimal for the firm implement a project classified as viable, whereas not to implement a project classified as nonviable?

Let $\tilde{s}$ denote the firm's signal regarding the viability of the project. We let $\tilde{s} = H$ denote the signal that the project is viable, whereas $\tilde{s} = L$ denotes the signal that the project is not viable. Application of Bayes' rule then implies that the conditional probability of return realization $\tilde{R} = R$ conditional on signal $s = H$ is then

$$Pr(\tilde{R} = R | \tilde{s} = H) \; = \; \frac{\alpha_F \; \pi}{\alpha_F \; \pi \;\; + \beta_F \; (1 - \pi)}.$$

Similarly, the the conditional probability of return realization R conditional on signal $s = L$ is

$$Pr(\tilde{R} = R | \tilde{s} = L) \; = \; \frac{(1 - \alpha_F) \; \pi}{(1 - \alpha_F) \; \pi \;\; + \; (1 - \beta_F) \; (1 - \pi)}.$$

Therefore, conditional on the signal the expected value of the project is

$$E[\tilde{R} | \tilde{s} = H] \; = \; \frac{\alpha_F \; \pi \, R \;\; - \;\; \beta_F (1 - \pi)}{\alpha_F \; \pi \;\; + \beta_F \; (1 - \pi)}$$

and

$$E[\tilde{R} | \tilde{s} = L] \; = \; \frac{(1 - \alpha_F) \; \pi \, R \;\; - \;\; (-\beta_F)(1 - \pi)}{(1 - \alpha_F) \; \pi \;\; + \;\; (1 - \beta_F) \; (1 - \pi)} \; ,$$

respectively.

It is optimal for the firm to implement only those projects classified as viable if

$$E[\tilde{R} | \tilde{s} = H] \; > \; 0 \; > \; E[\tilde{R} | \tilde{s} = L],$$

which is equivalent to

$$\frac{\alpha_F}{\beta_F} \, R \;\; > \;\; \frac{1 - \pi}{\pi} \quad \text{and} \quad \frac{1 - \alpha_F}{1 - \beta_F} \, R \;\; < \;\; \frac{1 - \pi}{\pi}. \tag{10}$$