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DISCUSSION PAPER SERIES

IZA DP No. 15725

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ISSN: 2365-9793

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ABSTRACT

Government Subsidies as a Risk-Sharing Policy Tool in Innovation Investment

Current literature on the impact assessment of government innovation subsidies is mainly empirical driven and lacks an overarching theoretical model to explain the conditions under which government subsidies create positive additionalities on private R&D investment. In this paper, we present a theoretical model that treats government subsidies as a risk-sharing vehicle for private R&D activities. More importantly, we argue that positive additionalities will be more likely to occur when the subsidies are allocated based on the risk-reward condition of the project. In addition, we show that the risk-sharing effect of government subsidies is influenced by a firm's absorptive capacity and the asset specificity of the project. By showing the conditions under which subsidies create positive additionality, we provide guidance to policymakers on how to improve the effectiveness of government support for innovation.

JEL Classification: D50, H81, O31, O38

Keywords: government subsidy, additionality, R&D and innovation, the risk-sharing model, absorptive capacity, asset specificity

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Introduction

Innovation is a key determinant for economic growth and an important means for tackling social needs. According to the Organisation for Economic Co-operation and Development (Appelt, Bajgar, Criscuolo & Galindo-Rueda, 2020), firms, governments, and universities are the main performers of R&D across most OECD and non-OECD countries. In OECD economies in particular, firms play a major role as R&D performers, where 70 percent of the total R&D is conducted by private or public enterprises. Subsidizing private innovation activities with public funding has been a common practice worldwide for decades (Carboni, 2017; David, Hall & Toole, 2000; Guo, Guo & Jiang, 2016).

The main rationale behind public support to innovation is to change a firm's behaviour to spur innovation at the firm level, both in terms of the decision to engage in innovation activities and increase the intensity of expenditure (Appelt et al., 2020; Borrás & Edquist, 2013; Czarnitzki & Hussinger, 2018). Since knowledge is mostly considered a public good, the assumption is that the accumulation of knowledge will inevitably create external spillovers and generate social benefits that are inappropriable by private firms (Arrow, 1962). In the case when knowledge is non-rival and non-excludable, private firms will not be able to appropriate the full benefit of their R&D investment, nor will they be able to protect their intellectual property through property rights laws (Lundvall & Borrás, 2005). Without public support for the in-appropriable positive social benefit, firms tend to underinvest in innovation because the risk they bear by investing in the R&D projects is not properly compensated (Arrow, 1962; Lundvall & Borrás, 2005). Therefore, providing support to private R&D is in the best interest of society to maximize social benefit (Nelson, 1959).

Furthermore, innovation is an uncertain and risky endeavour in nature, with several factors influencing the final outcome, which cannot be predicted *a-priori*. As argued by Dosi (1988), private profit-seeking agents will allocate resources to the exploration and development of new products and new processes if they know, or believe in the existence of unexploited scientific and technical opportunities; if they expect that there will be a market for their new products and processes; and if they expect some economic benefit, net of the incurred costs derived from the innovation activity. Innovation policy seeks to contribute to the creation of knowledge as a social good, and foster the positive outcomes from innovation activities including highly qualified employment, firm performance, and innovation outputs that seek to address social needs. Nelson (1959) and Arrow (1962) argue that government subsidies on private R&D contribute to positive external spillovers and address market failures.

In order to reach the optimal level of R&D investment for society, an important condition is that government subsidies should induce additional private R&D investment, the so-called "crowding-in" effect (Cerulli, 2010; David et al., 2000). If public subsidies instead substitute private R&D investment, then the total social wealth will be reduced, and the provision of government subsidies is an undesirable choice for society. For decades, extensive empirical research has been done to explore whether the provision of government subsidies creates positive additionalities in private R&D investment, and the results are divergent (David et al., 2000). Many scholars found a positive relationship between government subsidies and private R&D investment (e.g., Aerts & Schmidt, 2008; Carboni, 2017; Lee & Cin, 2010), indicating a crowding-in effect; whereas many others found no relationship between the two types of funding (e.g., Bronzini & Iachini, 2014; Dimos & Pugh, 2016; Szücs, 2020), in certain situations even a negative relationship, indicating a crowding-out effect (e.g., Marino, Lhuillery, Parrotta & Sala, 2016).

In response to the divergent empirical results on the relationship between public subsidies and private R&D investment, much research is done to investigate the possible contingencies that may lead to the inconsistent results. The more prevalent barriers to investing and conducting innovation are commonly related to financial constraints, and to knowledge and market-related aspects (D'Este, Iammarino, Savona & von Tunzelmann, 2012; De Fuentes, Santiago & Temel, 2020; Pellegrino & Savona, 2017). A common finding in current literature is that public subsidies contribute to addressing these two common barriers, since public support to innovation is more likely to create positive additionalities when they are provided to young and small firms (e.g., Becker, 2015; Bronzini & Iachini, 2014; Hyytinen & Toivanen, 2005), addressing the knowledge and financial constraints related aspects. Moreover, some findings indicate that financially constrained firms might reach higher benefits from public subsidies to innovation. For example, Carboni (2017) shows that public grants trigger the use of long-term to medium-term credit which might possibly help firms with financial constraints and foster their growth. These findings tend to support the theoretical argument that the ability to acquire public subsidies signals the capabilities of the firm and the quality of the project, thus increases the firm's access to external financing (Meuleman & De Maeseneire, 2012). Research also found that the effect of public subsidies on private R&D input is influenced by the size of the subsidies (Marino et al., 2016), the organizational structure of the funding agency (Guo et al., 2016), the firms' R&D intensity (Szücs, 2020) and financial conditions (Mateut, 2018).

Despite the empirical effort to understand the complexity of public subsidies on private R&D investment, current literature lacks an overarching theoretical model to help guide our understanding of the relationship (Dimos & Pugh, 2016). Building such a theoretical model contributes to the relevant literature, and has significant policy implications, in at least three ways. First, current empirical studies on the impact of government subsidies on private R&D activities are relatively scattered and inconclusive. The lack of guidance from a theoretical model on the subject contributes to the inconclusive empirical findings. Therefore, a theoretical model will provide guidance to the empirical research and may help reconcile the current divergent empirical findings on the impact assessment of government subsidies.

Second, the current literature lacks an abstract theoretical explanation of how the contingencies influence the effectiveness of government subsidies. Without an abstract theoretical model, current literature on the contingencies of impact assessment of innovation policies contributes more to the "what" questions rather than the "why" questions. Therefore, it is important to understand how absorptive capacities and asset composition influence the relationship between public subsidies and private R&D investment because they influence both the knowledge creation and appropriation processes (March, 1991; Un & Cuervo‐Cazurra, 2004) required to generate input additionality.

Third, as knowledge is non-rival and non-excludable in nature, the accumulation of knowledge becomes an important driver for the economic growth and international competitiveness of a region (Lundvall & Borrás, 2005). It is therefore in the best interest of the government and the society to share the risk with the private sector to reach the optimal level of R&D input. Thus, understanding the conditions under which public subsidies lead to positive additionality in R&D investment has important practical guidance to the policymakers on the efficient allocation of public resources.

This paper proposes a theoretical model that reveals the conditions under which public subsidies may lead to positive additionalities in private R&D investment using a risk-reward model. We follow the arguments by Arrow (1962) and Lundvall and Borrás (2005) and treat public subsidies as a risk-sharing vehicle to compensate for the excess risk bore by the firm due to the in-appropriability of social benefit. Using a simple risk-reward model, we show that the provision of government subsidies transfers a portion of deadweight loss due to opportunity costs to the public. The deadweight loss is the public support on the R&D that would be incurred in absence of all support (Baghana & Mohnen, 2009). More importantly, we show that positive additionalities will only be created when the subsidies are allocated based on the risk-reward condition of the project, rather than the financial condition of the firm. In other words, to create positive additionalities, government agencies should either fund firms with exceptional R&D projects but limited financial resources, or projects with a risk-reward condition marginal to self-sustainability in profitability, i.e., marginal projects in the sense of Carboni (2017), and Bronzini and Iachini (2014). Moreover, we show that the risk-sharing capability of the government subsidies is influenced by a firm's assimilation and transformation capabilities in knowledge creation, and the asset specificity of the allocation of the funding.

In the next section, we develop a basic risk-sharing model for the effects of government subsidies on dead-weight losses of innovation. We further explore the role of absorptive capacity and asset specificity on the efficacy of government subsidies in sharing the risk associated with innovation. We conclude by discussing theoretical and practical implications, and providing guidance to future research.

The basic model

Consider a simple risk-reward model with two periods. At t_0 period, an initial R&D investment budget of $I_0>0$ was required. At t_1, the R&D project has a probability of success of $1 \geq r_0 \geq 0$ and either receives a reward of B_0>0 if it succeeds or suffers a loss $I_0 \geq L_0 \geq 0$ if it fails. The outcome of the R&D project at t_1 can be written as:

$$\begin{cases} I_0 + B_0, & if\ succeeds\ with\ a\ probability\ of\ r_0 \\ I_0 - L_0, & if\ fails\ with\ a\ probability\ of\ (1 - r_0) \end{cases} \tag{2.1}$$

Given the R&D investment budget I_0, the expected cash flow of the program, Π, can be written as:

$$\Pi = r_0 * E(I_0 + B_0) + (1 - r_0) * E(I_0 - L_0)$$

$$= I_0 + r_0 * E(B_0) - (1 - r_0) * E(L_0) \tag{2.2}$$

This means that the expected return Π equals the initial investment I_0 plus the expected reward if succeeds, $r_0 * E(B_0)$, minus the expected loss if fails, $(1 - r_0) * E(L_0)$.

Assume that the firm is not financially constrained, meaning that as long as the project meets the conditions of novelty, potential market demand, and a positive expected net cash flow, it will be carried out. Also, we assume that the project will be carried out only when the expected net return is at least equal or greater than the opportunity cost if the initial funding I_0 is used elsewhere. The opportunity cost can be expressed as the forgone project with a rate of return at i_0.

$$I_0 + r_0 * E(B_0) - (1 - r_0) * E(L_0) \geq (1 + i_0) I_0 \tag{2.3}$$

Or

$$E(B_0) \geq \frac{(1-r_0)}{r_0} * E(L_0) + \frac{i_0}{r_0} * I_0 \tag{2.4}$$

The line of the boundary condition (C_0) is when the expected return just trades off the expected loss plus the opportunity cost:

$$C_0: \quad E(B_0) = \frac{(1-r_0)}{r_0} * E(L_0) + \frac{i_0}{r_0} * I_0 \tag{2.5}$$

where $\frac{(1-r_0)}{r_0}$ is the slope of the boundary condition where a risk-neutral firm is indifferent between invest or not invest in the R&D project, and $\frac{i_0}{r_0} * I_0$ is the deadweight loss due to opportunity cost. An immediate implication from equation (2.4) is that, if not financially constrained, a rational firm will invest in the R&D project as long as the expected benefit is equal to or higher than the sum of the proportional expected loss if the project fails and the deadweight loss due to opportunity cost. That is, in order for the project to be invested, it should at least have the same level of expected net return as the alternative choices of capital allocation.

Proposition 1: For an R&D project to be carried out, the expected benefit from the project should be no less than the sum of the weighted expected loss **and the deadweight loss due to opportunity costs.**

Figure 1 illustrates the boundary conditions of the decision to invest in the R&D project. For a simple illustration, if a project's anticipated risk-reward condition falls in the area above the boundary line (e.g., project P_1), the project will be carried out; whereas if a project falls below the boundary line (e.g., project P_2), the project will not be carried out. Note that if r_0=1, then from equation (2.4) we know that the R&D project will be invested as long as the expected benefit is equal to, or greater than, the deadweight weight loss. To see this, assume the boundary condition of the decision on the R&D project is expressed as $E(B_0) = k^* * E(L_0) + \frac{i_0}{r_0} * I_0$, where $k^* = \frac{(1-\mathrm{r}_0)}{\mathrm{r}_0}$ is the slope of the boundary. When $\mathrm{r}_0 = 1$, $k^* = 0$. The boundary condition is a horizontal line $E(B_0) = i_0 * I_0$, meaning that as long as the expected benefit is more than the opportunity cost, the project is going to be carried out. Similarly, when r_0= 0.5, k^* = 1. The boundary condition is the line where $E(B_0) = E(L_0) + 2i_0 * I_0$. The project will be carried out as long as the expected benefit $E(B_0)$ is equal to, or greater than, the sum of the expected loss, $E(L_0)$, and the weighted deadweight loss $2i_0 * I_0$.

[Insert Figure 1 Here]

Figure 2 shows how the change in boundary conditions with the change in the success rate. Note that the success rate not only changes the slope of the boundary line, but also the deadweight loss. When r_0 increases, both $\frac{(1-r_0)}{r_0}$ and $\frac{i_0}{r_0}$ decrease, meaning that a firm requires less benefit from the R&D project, and bears less deadweight losses, to decide to invest in the R&D project if it has a higher success rate. When r_0 decreases, both $\frac{(1-r_0)}{r_0}$ and $\frac{i_0}{r_0}$ increase, meaning that both the expected consequence of the loss and the weighted opportunity costs increase. The project needs to be more profitable to offset the increase in both the expected loss and the deadweight loss. Practically, a higher success rate indicates less uncertainty in outcome, therefore a higher expected net cash flow and a lower possibility that the money can be better used elsewhere.

[Insert Figure 2 Here]

Please note that the presented simple model is analogous to the marginal equilibrium model proposed by Howe and McFetridge (1976) and David et al. (2000). The expected cash flow of the project, Π, is calculated as the difference between the total expected return minus the total expected cost. Therefore, according to the Howe-McFetridge model, Π should be maximized when the marginal return equals the marginal cost. For simplification purposes, assume that the initial R&D input can only change the success rate, but not the outcomes of the project, and that the benefit if the project succeeds is always higher than the initial R&D input. Then the Howe-McFetridge model can be rewritten as a simple risk-reward condition where the success rate is a concave function of the initial R&D investment I_0, as shown in Figure 3.

[Insert Figure 3 Here]

In reality, this means that as more initial budget is dedicated to the project, the project is more likely to succeed, and thus generate higher marginal benefit than the marginal addition in R&D input. For example, better equipment can be purchased, and better R&D personnel can be hired. In this case, it is in the firm's best interest to keep investing in the R&D project until the success rate is maximized. The marginal effect of the additional initial budget on the success rate is on a decreasing scale so that there exists an optimal initial R&D budget, $\tilde{I}_0$, at which point the success rate is maximized. It is then derivable that the net cash flow Π, which is the net of expected return minus the expected cost, is also a concave function of the initial private R&D budget. This means that there exists an optimal private R&D investment budget under which the expected net cash flow is maximized. 2

Subsidies with no influence on the risk-reward conditions

Now consider a simple case that non-refundable, interest-free government subsidies are available at zero cost. Assume that the provision of government subsidies does not change the risk-reward condition of the project, meaning that providing the government subsidies does not create additional knowledge for the firm and, thus, does not change the success rate or the expected benefit or loss of the project. We will relax these restrictions in the next sections. Even without influencing the risk-reward condition of the project, there are at least two reasons why government subsidies may influence private R&D investment: as a supplement for financing and

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2 Please see Appendix 1 for detail.

as a risk-sharing vehicle.

Government subsidies as supplement for financing

Equation (2.4) can also be rewritten to show the maximum R&D expenditure a firm is willing to invest given a set of expected benefit, expected loss, and success rate:

$$I_0^* \leq \frac{r_0 * E(B_0) - (1-r_0) * E(L_0)}{i_0} \qquad (3.1.1)$$

Therefore, if we can predict the expected benefit, loss, and success rate, the maximum initial investment a firm is willing to pay is the difference between the weighted expected benefit and the weighted expected loss, scaled by the rate of the opportunity cost. To put it simply, a profit-seeking firm will not commit more initial R&D input than the expected net benefit of the project.

Note that a minimum initial private R&D budget, $\widehat{I_0}$, also exist in order for the project to be carried out. A firm's actual R&D investment I_1 needs to fall between the two boundaries, $I_1 \in (\widehat{I_0}, I_0^*)$, in order for the project to be carried out. If a firm is financially constrained and is unable to commit to the minimum R&D investment ($I_1 < \widehat{I_0}$), then the R&D project will not be carried out even if the project has a positive expected net cash flow. In order for the project to be carried out, government subsidies that at least equals the shortage will need to be provided ($S_0 \geq \widehat{I_0} - I_1$). In this case, crowding-in will always happen because, without the subsidy, the project will always be abandoned. The amount of additionalities created equals the initial private R&D investment budget I_1.

Although it seems that funding an R&D project with a limited budget is socially beneficial, the danger, however, is that many financially constrained firms may also have low productivity, i.e., a low risk-reward condition or a high risk of failure. In the sense of Gustafsson, Tingvall and Halvarsson (2020), these financially constrained firms with low productivity may need to actively seek subsidy opportunities to fund their R&D projects because they need to transfer the high risk of failure to the public. Funding these projects is not necessarily efficient because more subsidies will be needed to compensate for the high opportunity cost. Therefore, guidance to subsidy policymakers is that government subsidies should be distributed to financially constrained firms with potentially profitable R&D projects. In other words, to create more additionality in private R&D investment, the government agencies should "pick the winner" in terms of the potential of the project, not in terms of the financial status of the firm.

Proposition 2: In order to create additionalities in R&D investment, government subsidies are better given to projects with a good risk-reward condition but a low initial budget due to the financial constraints of the firm.

Current empirical research tends to support the prediction that crowding-in effects are more likely to happen for financially constrained firms. For example, Mateut (2018) found that there is a positive relationship between government subsidies and private R&D activities, i.e., a crowding-in effect, and the relationship is stronger when the firm is financially constrained. Moreover, Bronzini and Iachini (2014) found that small enterprises tend to have positive additionalities in private R&D investment when they receive government subsidies, whereas large firms do not. Since small firms are more likely to be financially constrained, and have a higher cost of financing (Bronzini & Iachini, 2014), they are more likely to give up promising R&D projects due to limited resources. Therefore, subsidizing small firms is more likely to create crowding-in effects because the subsidies function as a cheaper alternative source of financing. In addition, Meuleman and De Maeseneire (2012) argue that government subsidies have a signalling effect on the capital market so that firms receiving government subsidies also have better access to debt financing. This will in turn help the financially constrained firms to acquire additional financing for its private R&D investment.

In reality, the expected benefit, loss, and success rate may all be a function of the level of R&D investment a firm commits to the project. For example, with a higher private R&D budget, the firm can alter the innovation strategy and hire more capable R&D personnel, purchase more advanced equipment, and change the size and scope of the projects, thereby increasing both the probability of success and the expected net benefit. A profit-seeking firm should be self-motivated to invest in the R&D project until they reach the desired risk-reward condition. For simplification reasons, for the remainder of the paper, we will assume that the success rates and net benefits of R&D projects are independent of changes in the initial private R&D budget, and the firm is not financially constrained. This will ensure that the firms' R&D investment decisions and the governments' decisions on subsidies distribution are focused on the risk-reward condition of the project itself, rather than the financial conditions of the firms.

Government Subsidies as risk sharing vehicle

Now consider the situation under which the firm is not financially constrained. It is derivable in this case that equation (2.4) is a sufficient condition for the project to be funded, meaning that the decision on whether to invest in the R&D project is based on the risk-reward condition of the project rather than the financial condition of the firm. In this case, the goal of government subsidies is likely not to provide a cheaper source of financing, because otherwise government subsidies will always crowd out more expensive financing from the capital market.

Assume that the government subsidies $S_0>0$ is available at zero cost at t_0, and the amount is non-refundable at t_1 regardless of whether the project fails or succeeds. Then the initial investment is now $I_0 + S_0$. If the project succeeds, the subsidies become a part of the reward; and if the project fails, a fraction of the loss is absorbed by the subsidies at zero cost. We consider the same two conditions as (2.1).

$$\begin{cases} I_0 + S_0 + B_0, & if\ succeed\ with\ a\ probability\ of\ r_0 \\ I_0 + S_0 - L_0, & if\ fails\ with\ a\ probability\ of\ (1 - r_0) \end{cases} \tag{3.2.1}$$

The expected cash flow of the project, Π, is now:

$$\Pi = r_0 * E(I_0 + S_0 + B_0) + (1 - r_0) * E(I_0 + S_0 - L_0)$$

$$= I_0 + S_0 + r_0 * E(B_0) - (1 - r_0) * E(L_0) \tag{3.2.2}$$

Similarly, assume that the project will be carried out only when the expected net cash flow is at least equal or greater than the opportunity cost. With the rate of return of the forgone project at i_0, we can write the conditions under which the project will be carried out as:

$$I_0 + S_0 + r_0 * E(B_0) - (1 - r_0) * E(L_0) \geq (1 + i_0)I_0 \tag{3.2.3}$$

Or

$$E(B_0) \geq \frac{(1-r_0)}{r_0} * E(L_0) + \frac{1}{r_0}(i_0 * I_0 - S_0) \tag{3.2.4}$$

With the line of boundary condition C_0':

$$C_0': \quad E(B_0) = \frac{(1-r_0)}{r_0} * E(L_0) + \frac{1}{r_0}(i_0 * I_0 - S_0) \tag{3.2.5}$$

Observe that the deadweight loss is now reduced as a portion of the deadweight loss is absorbed by the government subsidies ($\frac{S_0}{r_0}$). In practice, government subsidies are often costless but not re-deployable for the firms. Therefore, the portion of the project funded by government subsidies has practically zero opportunity cost for the firm. A portion of the uncertainty is thus transferred from the firm to the public through the provision of government subsidies. Moreover, the risk-sharing capacity of government subsidies ($\frac{S_0}{r_0}$) is determined by the size of the subsidies and the perceived success rate of the project. A higher success rate will reduce the deadweight loss but also reduce the risk-sharing capacity of the subsidy.

Proposition 3: Government subsidies function as a risk-sharing vehicle to transfer a portion of the opportunity costs to the public. The risk-sharing capacity of the subsidies is determined by the size of the subsidies and the potential success rate of the project.

Note that the slope of the boundary condition, $\frac{(1-r_0)}{r_0}$, does not change because the risk-reward condition is not changed by the subsidy. The risk-sharing function of government subsidies is illustrated in Figure 4.

[Insert Figure 4 Here]

From equation (3.2.4) we can predict whether subsidizing a potential research project will lead to positive additionalities in private R&D investment. Assume that a project P_1 exist which, given $E(\tilde{B}_1)$, $E(\tilde{L}_1)$, $\tilde{I}_1$ and $\tilde{r}_1$, the net expected benefit of the project meets the following condition:

$$\frac{i_0}{\tilde{r}_1} * \tilde{I}_1 - \frac{S_0}{\tilde{r}_1} < \tilde{r}_1 * E(\tilde{B}_1) - (1 - \tilde{r}_1) * E(\tilde{L}_1) < \frac{i_0}{\tilde{r}_1} * \tilde{I}_1 \qquad (3.2.6)$$

This means that the expected risk-reward condition of the project is lower than the expected opportunity cost, given a predetermined initial investment $\tilde{I}_1$, but higher than the difference between the expected opportunity cost and the risk-sharing capacity of government subsidies. As shown in Figure 4, the project P_1 falls between the two boundary lines. Since the net benefit is less than the weighted deadweight loss, the project will not be carried out without government subsidies. With government subsidies, the project becomes profitable because a portion of the deadweight loss is transferred to the public so that the net benefit is higher than the reduced deadweight loss. In the sense of Carboni (2017), and Bronzini and Iachini (2014), this is an example of a ***marginal project*** with negative net cash flow for the firm but the potential to become a positive net present value project if funded. The project will not be carried out without public subsidies because the deadweight loss is greater than the expected net benefit of the project. Therefore, if the project is subsidized the firm's private R&D investment will increase and the social benefit will increase, i.e., a crowding-in effect.

Assume that another project P_2 exist for which, given $E(\tilde{B}_2)$, $E(\tilde{L}_2)$, $\tilde{I}_2$ and $\tilde{r}_2$, the net benefit meets the following condition:

$$\tilde{r}_2 * E(\tilde{B}_2) - (1 - \tilde{r}_2) * E(\tilde{L}_2) > \frac{i_0}{\tilde{r}_2} * \tilde{I}_2 \qquad (3.2.7)$$

This means that the expected risk-reward condition of the project is higher than the expected opportunity cost given a predetermined initial investment $\tilde{I}_2$. Then, assuming that the firm is not financially constrained, the project will be carried out with or without government subsidies. This represents an ***inframarginal project*** in the sense of Wallsten (2000), and Bronzini and Iachini (2014). The provision of subsidies will just crowd-out private R&D investment as a cheaper source of finance, where $I_2 = \widetilde{I_2} - S$. The government subsidies substitute private R&D investment, and the total social R&D expenditure does not change.

Lastly, the project P_3 follows the following condition:

$$\tilde{r}_3 * E(\tilde{B}_3) - (1 - \tilde{r}_3) * E(\tilde{L}_3) < \frac{i_0}{\tilde{r}_3} * \tilde{I}_3 - \frac{S_0}{\tilde{r}_3} \qquad (3.2.8)$$

The project will not be funded regardless of whether the subsidies are provided or not because the size of the subsidies is not significant enough to offset the high opportunity cost due to the low success rate of the project. In other words, the risk-reward condition for this project is low enough that the given budget of government subsidies S_0 is not enough to offset the difference between the net cash flow and the opportunity cost. We can define these projects as ***supramarginal projects***.

Proposition 4: The provision of government subsidies to inframarginal projects,

meaning projects with a self-sustainable profit schedule, will not lead to positive additionalities in private R&D investment.

Proposition 5: When the project does not have a self-sustainable profit schedule, given a finite budget of government subsidy, the provision of government subsidies will only create positive additionality in private R&D investment when the risk-sharing capacity of the subsidies is higher than the net shortage in cash flow.

Important guidance to policymakers in government subsidies is that, when the applicants are not under financial constraints, government agencies should not "pick the winner" in terms of the potential profitability of the projects. Rather, the agencies should evaluate the rationale for the application for subsidies. To create positive additionality in private R&D investment, the funding should be given to projects that are not self-sustainable in profitability if not funded. Moreover, to ensure the crowding-in effect, the agencies should evaluate the size of the subsidy, and choose candidates whose demand for risk-sharing is within the capabilities of the government subsidies given the budget of the subsidies and the perceived probability of success of the project.

Government subsidies and absorptive capacity of the firm

Until now we have assumed that government subsidies do not change the risk-reward condition of the firm, meaning that the provision of subsidies does not create any additional knowledge for the firm, nor does it transfer existing knowledge from one project to another. This means that both the success rate, r_0, and the potential benefit/loss from the project, $r_0 * E(B_0) - (1 - r_0) * E(L_0)$, are independent of the provision of government subsidy. However, neither assumption is likely to be realistic. For example, with additional funds available at zero cost, the firm may be able to purchase better equipment or hire more qualified R&D personnel so that the success rate may increase. The R&D personnel may also acquire more experience and develop better research skills from additional training and from using better equipment. The skills and knowledge can be transferred to other R&D projects of the firm, creating an internal spillover effect.

The absorptive capacity theory (Cohen & Levinthal, 1989) defines two types of knowledge creation ability: assimilation capability, the ability to assimilate new or existing knowledge into the current process and create benefit, and transformation capability, the ability to assimilate and transform new or existing knowledge and apply the new knowledge to new projects with commercial ends (Todorova & Durisin, 2007; Zahra & George, 2002). The assimilation capability enables a firm to learn from internal and external sources and directly interpret knowledge into current research context, and the transformation capability allows the firm to transform tacit, sometimes unfit, knowledge into explicit, re-deployable knowledge (Todorova & Durisin, 2007; Zahra & George, 2002). In the next two subsections, we relax the assumptions that government subsidies do not influence the project success rate, reflecting consideration of assimilation capability, and that subsidies do not generate re-deployable knowledge, reflecting consideration of transformation capability.

Government subsidies and firm assimilation capability

Let's first relax the assumption that the provision of government subsidies does not impact the success rate of the firm. We also allow for idiosyncratic assimilation capabilities so that the provision of additional funding through government subsidies creates different levels of assimilable knowledge for different firms. To achieve this, we assume that the project success rate is a function of the size of the subsidy:

$$r_1 = r_0 + r(S_0) \tag{4.1.1}$$

where

$$0 \leq r(S_0) < 1 \qquad (4.1.2)$$

r_0 is the portion of the success rate that is determined by the risk-reward condition of the project, i.e., the nature of the project, the initial available funding, and the capabilities of the innovators and managers involved, etc. The variable portion, $r(.)$, represents the non-negative assimilation capability of the firm and is a function of the size of the government subsidy. It represents a firm's ability to change additional knowledge into productivity. Insert equation (3.1.1) into (2.2.2), we can rewrite the expected cash flow as follows:

$$\Pi = I_0 + S_0 + r_1 * E(B_0) - (1 - r_1) * E(L_0)$$

$$= I_0 + S_0 + r_0 * E(B_0) - (1 - r_0) * E(L_0) + r(S_0) * K \qquad (4.1.3)$$

where $K = E[P(B_0)] + E[P(L_0)]>0$ is the risk-reward condition amplifier. It means that the change in expected success rate will change the proportional influence of both the expected benefit and the expected loss on the cash flow of the project. If the success rate increases, the influence of expected benefit on the net cash flow will increase, as well the influence of expected loss on the net cash flow will decrease proportionately. Assume that the company can effectively predict the risk-reward condition of the project so that the expected cash flow without government subsidies is known to the firm. In this case, the expected cash flow with government subsidies is a function of the size of the subsidies and is determined by the assimilation capability of the firm. To see why this is the case, we can rewrite equation (3.1.2) as:

$$\Pi = \Pi_0 + S_0 + r(S_0) * K \qquad (4.1.4)$$

where Π_0 is the expected cash flow of the project without government subsidies, K is the risk-reward condition amplifier of the project. Therefore, it is easy to derive that the shape and characteristics of the function $\Pi(S_0)$ is determined by the assimilation capability $r(S_0)$. For example, if $r(S_0)$ is a concave quadratic function, meaning that a firm's marginal ability to assimilate additional knowledge is on a decreasing scale as the availability of additional cost-free funding increases, then the relationship between the expected cash flow of the project and government subsidies is also a concave quadratic function.

Inserting equation (4.1.1) into (3.2.3), we get the positive net cash flow condition as:

$$E(B_0) \geq \frac{[1-r_0-r(S_0)]}{r_0+r(S_0)} * E(L_0) + \frac{1}{r_0+r(S_0)} * (i_0 * I_0 - S_0) \quad (4.1.5)$$

With the line of the boundary condition, C_1 being:

$$C_1: \quad E(B_0) = \frac{[1-r_0-r(S_0)]}{r_0+r(S_0)} * E(L_0) + \frac{1}{r_0+r(S_0)} * (i_0 * I_0 - S_0) \quad (4.1.6)$$

Note that for (4.1.6) both the slope and the deadweight loss depend on the level of $r(.)$. If $r(.)$ increases, the slope $\frac{[1-r_0-r(S_0)]}{r_0+r(S_0)}$ decreases and the deadweight loss $\frac{1}{r_0+r(S_0)} * (i_0 * I_0 - S_0)$ decreases. Therefore, a non-negative assimilation capability $r(S_0)$ functions as an amplifier to both improve the success rate and reduce the opportunity cost of the project. Figure 5 shows the change in boundary conditions when the success rate is considered as a function of the initial success rate due to the risk-reward condition of the project and the assimilation capability of the firm.

[Insert Figure 5 Here]

From equation (4.1.5) we can also predict when the crowding-in effect will happen. Assume that there exists a project P_1 with a given condition of $\tilde{B}_1$, $\tilde{L}_1$, $\tilde{I}_1$, $\tilde{r}_1$, $\tilde{r}(S_0)$ and S_0. We can predict that for the government subsidies to create crowding-in effects, the net benefit of the project without the subsidies needs to meet the following condition:

$$\frac{i_0}{\tilde{r}_1} * \tilde{I}_1 - \frac{S_0}{\tilde{r}_1} - \tilde{r}(S_0) * K < \tilde{r}_1 * E(\tilde{B}_1) - (1-\tilde{r}_1) * E(\tilde{L}_1) < \frac{i_0}{\tilde{r}_1} * \tilde{I}_1 \quad (4.1.7)$$

where $K > 0$ is the risk-reward condition amplifier. Therefore, a non-negative $\tilde{r}(S_0)$ will amplify the risk-sharing capability of the subsidies so that the subsidies can make up a bigger difference between the net benefit of the project and the deadweight loss. In other words, a higher assimilation capability changes more supramarginal projects into marginal projects as shown in Figure 5.

Proposition 6: The risk-sharing ability of government subsidies depends on the assimilation capability of the firm so that with a higher assimilation capability, a finite budget of government subsidies can help the firm accept projects with lower expected risk-reward conditions.

Government subsidies and firm transformation capability

Knowledge can only be transferred from one project to another when the right elements to assimilate and transform knowledge are in place (Garicano & Wu, 2012; March, 1991). Therefore, a significant component of a firm's absorptive capacity is its ability to transform tacit knowledge into assimilable knowledge and transfer knowledge within the organization (Todorova & Durisin, 2007; Zahra & George, 2002). This creates an internal spillover effect of the firm's R&D investment and provides an indirect benefit for the firm from its R&D activities (Cohen & Levinthal, 1990). In the risk-sharing model, the transformation capability can be seen as a function of an additional benefit beyond the original risk-reward condition of the project.

Assume that a total internal spillover benefit $B(S_0)$ is created during the process and can be realized at t_1 regardless of whether the project succeeds or fails. For example, with the provision of a cost-free subsidy, the firm's R&D personnel can learn new skills from the addition of equipment or training. These skills are transferable to other projects regardless of whether the focal project succeeds or fails. At t_1 period, the probable benefit and loss can be expressed as:

$$\begin{cases} B_1 = B_0 + B(S_0) & if\ succeeds \\ L_1 = L_0 - B(S_0) & if\ fails \end{cases} \quad (4.2.1)$$

where the function $B(.)$ represents the internal spillover effect determined by the firm's transformation capability. This means that if the project succeeds, the total benefits a firm receives is the benefit of the project, B_0, and the benefit from the internal spillover effect, $B(S_0)$; whereas if the project fails, the total loss for the firm is the loss due to the failure of the project L_0 minus the internal spillover effect that the firm can still enjoy on other R&D adventures.

The expected cash flow can be re-written as:

$$\Pi = r_0 * E(I_0 + S_0 + B_1) + (1 - r_0) * E(I_0 + S_0 - L_1)$$

$$= I_0 + S_0 + B(S_0) + r_0 * E(B_0) - (1 - r_0) * E(L_0) \quad (4.2.2)$$

Assume that the same rate of opportunity cost $(1 + i_0)$ applies, and the firm is not financially constrained. The project will still need to have a positive net cash flow to be carried out, so the expected cash flow still needs to be at least equal to the opportunity cost. We can have the non-negative cash flow condition as:

$$E(B_0) \geq \frac{(1-r_0)}{r_0} * E(L_0) + \frac{1}{r_0}[i_0 * I_0 - S_0 - B(S_0)] \quad (4.2.3)$$

Given a non-negative $\tilde{B}(S_0)$, the condition under which subsidizing a project will lead to positive additionality on private R&D investment can now be written as follows:

$$\frac{i_0}{\tilde{r}_1} * \tilde{I}_1 - \frac{S_0}{\tilde{r}_1} - \frac{\tilde{B}(S_0)}{\tilde{r}_1} < \tilde{r}_1 * E(\tilde{B}_1) - (1 - \tilde{r}_1) * E(\tilde{L}_1) < \frac{i_0}{\tilde{r}_1} * \tilde{I}_1 \quad (4.2.4)$$

Note that the spillover effect works as an addition to the government subsidies. In this case, the risk of bearing the deadweight loss $\frac{i_0}{r_0} * I_0$ is reduced by the public subsidies, $\frac{S_0}{r_0}$, and a firm's transformation capability as a function of the additional financing through the subsidies $\frac{B(S_0)}{r_0}$. In a sense, the risk-sharing effect of government subsidies is amplified by the transformation capability of the firm, as shown in Figure 6.

[Insert Figure 6 Here]

Therefore, an important indirect effect of government subsidies is to provide additional resources to create internal spillovers of knowledge, so as to increase the innovation and R&D capabilities of the firm. To achieve positive additionalities to social benefit, government subsidies should be given to firms with a high transformation capability.

Proposition 8: Government subsidies are more likely to create positive additionality in private R&D investment when it is given to firms with high capability to transform project-specific knowledge into assimilable knowledge, i.e., firms with a high transformation capability.

Cohen and Levinthal (1989) argue that firms invest in R&D projects not only to develop new knowledge through innovation but also to improve their transformation and assimilation capabilities. The two-faced objectives for innovation enable the provision of government subsidies to create transformable knowledge within the firms. However, the level of transformable knowledge created by different types of R&D projects differs. For example, Fabrizio (2009) argues that basic research (research-centric R&D projects) are absorptive capacity-building research activities. Therefore, firms that perform more in-house basic research will have an advantage in searching for new R&D inventions. Therefore, in order to create additionalities in private R&D expenditure, subsidies should be given to projects with higher transformation capability, such as research-centric innovation projects. This ensures that the provision of subsidies creates more positive spillovers of knowledge within the organization. This point has been empirically tested and proved by previous research. For example, Clausen

(2009) found that “research” subsidies, i.e., subsidies provided to R&D projects that are “far from the market”, help stimulate R&D spending within the firms, while “development” subsidies, i.e., subsidies provided to projects that are “close to the market”, substitutes such spending. Therefore, important guidance to the policymakers is that subsidies may be better given to support research-centric projects than application-centric projects.

Government subsidies and asset specificity

Another important consideration of the risk-sharing effect of government subsidies is the level of asset specificity. A higher asset specificity reflects a lower re-deployability of the assets which indicates a higher cost of the project (Williamson, 1979,1981). Project-specific assets, such as unique data, equipment that are not re-deployable, and project-specific training, increases the loss of the project if it fails.

So far, we have assumed that the use of government subsidies creates homogeneous outcomes for the firm, meaning that the entire subsidies are used for the same purpose. However, in reality, the provision of government subsidies often comes with restrictions on how the subsidies should be used. For example, a common restriction of government subsidies is that a certain percentage of the subsidies needs to be used to purchase equipment, and a certain percentage can be used to pay for R&D personnel. The different usage of the funding may create divergent risk-sharing capabilities.

Assume that the subsidies are used in two separate parts:

$$S_0 = S_1 + S_2 \tag{5.1}$$

where S_1 is the portion used on assets that cannot be re-deployed, such as research specific equipment, and S_2 is the portion used on re-deployable assets, such as general-purpose R&D equipment. Therefore, if the project fails, S_1 will not be a part of the residual cash flow due to its lack of re-deployability, and the level of residual cash flow of S_2 depends on the re-deployability of the assets purchased. A firm's risk-reward condition is now a function of the re-deployability of S, as shown below:

$$\begin{cases} I_0 + S_1 + g(S_2) + B_0, & if\ succeeds\ with\ a\ probability\ of\ r_0 \\ I_0 + g(S_2) - L_0, & if\ fails\ with\ a\ probability\ of\ (1 - r_0) \end{cases} \quad (5.2)$$

where $g(.)$ is the function that represents the level of re-deployability of the assets.

$$g(S_2) \in (0, S_2) \quad (5.3)$$

Inserting equation (5.1) into (3.2.2), we can re-write the expected cash flow of the project as follows:

$$\Pi = r_0 * E[I_0 + S_1 + g(S_2) + B_0] + (1 - r_0) * E[I_0 + g(S_2) - L_0]$$

$$= I_0 + r_0 * S_1 + g(S_2) + r_0 * E(B_0) - (1 - r_0) * E(L_0) \quad (5.4)$$

The non-negative cash flow condition can now be expressed as:

$$E(B_0) \geq \frac{(1-r_0)}{r_0} * E(L_0) + \frac{i_0}{r_0} * I_0 - [S_1 + \frac{g(S_2)}{r_0}] \quad (5.5)$$

Note that, given (5.1) and (5.3), the new risk-sharing effect of the government subsidies follows the condition:

$$S_1 + \frac{g(S_2)}{r_0} < \frac{S_0}{r_0} \quad (5.6)$$

This means that the risk-sharing effect of government subsidies is reduced due to asset specificity, as shown in Figure 7. This is because a portion of the deadweight loss that would have been absorbed by the risk-sharing capability of the subsidies, is now born by the firm due to asset specificity.

[Insert Figure 7 Here]

The condition for subsidies to provide positive additionality in R&D investment is now a function of the asset specificity. A marginal project, P_1, now needs to meet the following condition:

$$\frac{i_0}{r_0} * \tilde{I}_1 - [S_1 + \frac{g(S_2)}{r_0}] < \tilde{r}_1 * E(\tilde{B}_1) - (1 - \tilde{r}_1) * E(\tilde{L}_1) < \frac{i_0}{\tilde{r}_1} * \tilde{I}_1 \qquad (5.7)$$

Note that project P_2 is now a supra-marginal project, even though its net cash flow is within the risk-sharing capability of the government subsidies without considering asset specificity. In other words, many projects that would have been marginal projects given the finite size of the subsidies are now supra-marginal projects. Guidance to policymakers is when distributing the subsidy, the agency should regulate the usage of the funding so that the money is not spent on assets that are not re-deployable.

Proposition 9: Government subsidies are more likely to create positive additionality in private R&D investment when it is used on assets with high re-deployability.

Conclusion

In this paper, we aim to build a theoretical model that explains the impact of government subsidies on private R&D investment. Using a simple risk-reward model for the expected cash flow of R&D projects, we treat government subsidies as a risk-sharing vehicle. We argue that government subsidies are needed for many R&D projects because the risk-reward conditions of the R&D projects are imbalanced compared to alternative investment opportunities due to inappropriable external spillover of knowledge (Arrow, 1962; Lundvall & Borrás, 2005). In other words, the companies bear the uncertainty of R&D investment, but the society shares the rent from their success at zero cost. We consider the imbalanced risk-reward conditions as the deadweight loss of the R&D project. We argue that the main function of government subsidies is to transfer a portion of the deadweight loss to the public to compensate for the rent acquired by the society. In this case, the government subsidies function as a risk-sharing vehicle.

The paper contributes the arguments about the effect of sunk and fixed costs as binding obstacles for innovation (e.g., Arqué‐Castells & Mohnen, 2015; Kaplan, Luski & Wettstein, 2003; Manez, Rochina‐Barrachina, Sanchis & Sanchis, 2009). As suggested by Arqué‐Castells and Mohnen (2015), both sunk costs and fixed R&D costs act as deterrents to engage in R&D activities. While sunk costs might act as a barrier to entry into R&D for some firms, fixed costs will be the binding obstacle for many more firms, in particular for SMEs and young firms (Bellucci, Pennacchio & Zazzaro, 2019; Radicic & Djalilov, 2019). Therefore, public subsidies are necessary to increase the pool of R&D performers, and that sustained subsidization is needed to foster R&D performance, in particular, to address the binding obstacle from fixed costs (Arqué‐Castells & Mohnen, 2015). We extend this argument by building a theoretical model that explains why government subsidies can help solve binding obstacles from fixed costs while other types of financing may not be able to. The advantage of treating sunk and fixed costs of innovation as opportunity costs is that opportunity costs explain the irremediability nature of such costs from the risk-sharing perspective. Since firms cannot exploit enough rent from R&D to off-set the sunk and fixed costs due to inappropriable external spillover (Arrow, 1962), such sunk and fixed costs will always generate irremediable opportunity costs. Government subsidies, in contrast to costly financing, bears virtually no opportunity costs and, therefore, can function as a risk-sharing vehicle to reduce the binding obstacles of innovation.

Treating government subsidies as a risk-sharing vehicle enables us to build a theoretical model to explain when positive additionalities will be created by the subsidies, and what factors may influence the creation of additionalities. Given the size of the subsidies and the expected probability of success, the risk-sharing capability of the government subsidies is not limitless. We argue that the positive additionality in private R&D investment can only be created when the shortfall between the expected net benefit of the project and the opportunity costs is remediable by the risk-sharing capability of the subsidy. In other words, given the limited size of government subsidies, only a finite range of potential projects can be considered as “marginal projects” in the sense of Carboni (2017), and Bronzini and Iachini (2014). In order to increase the risk-sharing capabilities of the subsidies, government agencies can either increase the size of the subsidies or help firms increase the success rate of the project. For example, empirical works suggest that providing advisory services together with the financial subsidies can help increase the success rate, since firms might be better prepared to conduct the funded R&D projects (Sawang, Parker & Hine, 2016; Shapira & Youtie, 2016). Our model did not consider the extension on the potential to increase absorptive capabilities after the reception of advisory services per se. However, following Cohen and Levinthal (1990), we considered the increase of absorptive capabilities due to the engagement in innovation activities.

An important contribution of this paper is the theoretical explanation of how a firm’s absorptive capacity and asset specificity influence the risk-sharing capabilities of the government subsidies. We argue that higher absorptive capacity reflects a firm’s competitive capability in assimilating and transforming new knowledge into a better risk-reward condition of the project. Therefore, the risk-sharing capacity of the subsidies is amplified by a high level of absorptive capacity. Guidance to government subsidies policymakers is that the subsidies are better granted to research-centric projects rather than application-centric projects (Clausen, 2009; Fabrizio, 2009) and to firms with better R&D capability.

The funding can be invested in assets with different re-deployability. If the subsidies are invested in highly re-deployable assets, such as general equipment and basic knowledge training, the risk-sharing capacity is relatively high; whereas if the funding is dedicated to less re-deployable assets, such as project-specific equipment, the risk-sharing capacity of the subsidies is discounted. Therefore, to create higher positive additionalities, the subsidies should be invested in assets with a high salvage value even if the project fails. This provides an explanation of why using subsidies to increase the salaries of R&D personnel is an inefficient use of government resources (Goolsbee, 1998).

This paper should be considered as the initial attempt in creating a theoretical model for the impact assessment of government subsidies. We offer an alternative explanation to the inconsistent empirical findings and provide guidance to policymakers on the allocation of government subsidies. Our proposed risk-sharing model seeks to contribute to the discussion of crowding in, and future extensions from this model can include further discussions for situations of crowding out. Subsidy allocation decisions follow, in general, a detailed evaluation process that seeks to lower the risk of allocating public resources to private firms. However, one needs to consider the problems of information asymmetries faced by the government agencies and the potential that these information asymmetries might lead to suboptimal allocation of resources. Future research can be done to extend the theoretical framework to firm strategic choices and test the reliability and validity of the predictions of this research.

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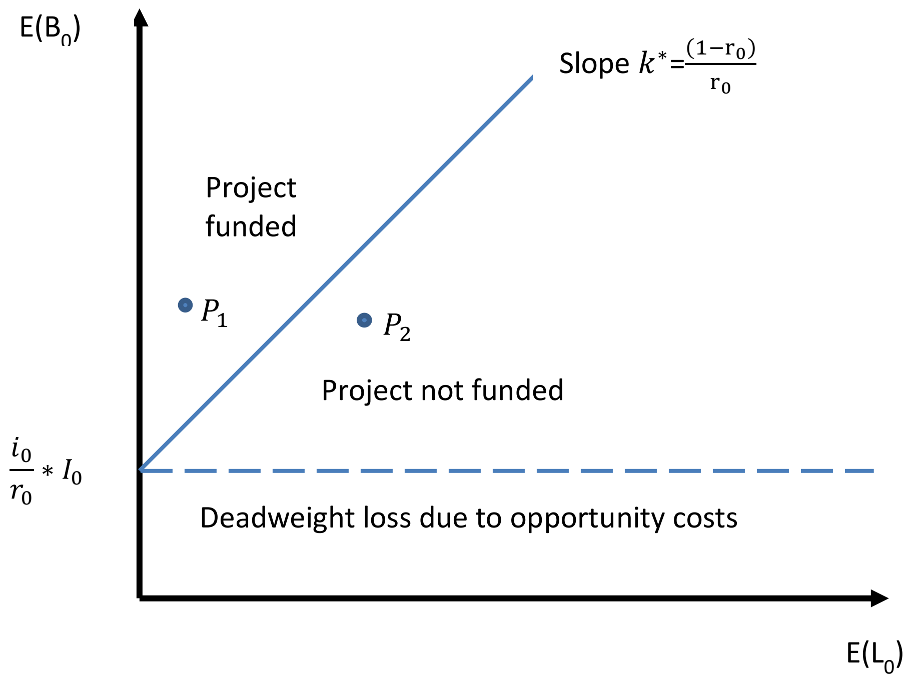


Figure 1. Boundary condition of the decision to invest in an R&D project

Figure 2. Effect of change in the probability of success on the boundary condition

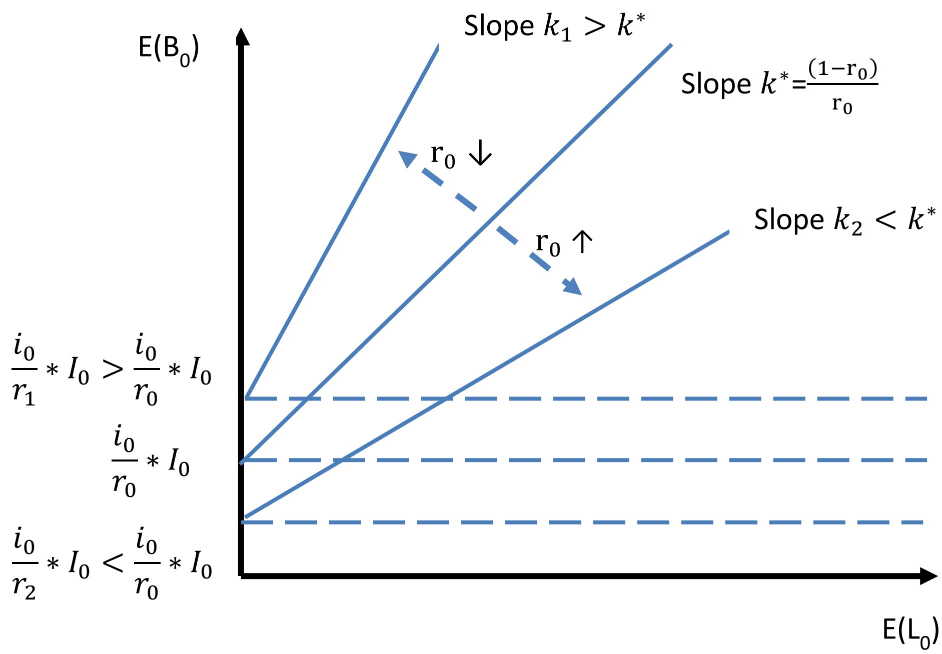


Figure 3. The success rate of the R&D project as a function of the initial R&D budget

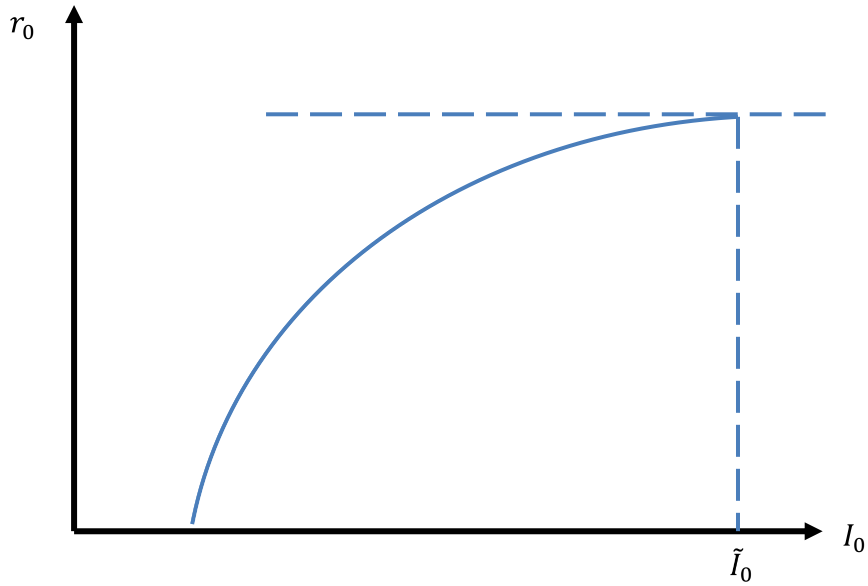


Figure 4. Government subsidies as a risk-sharing vehicle

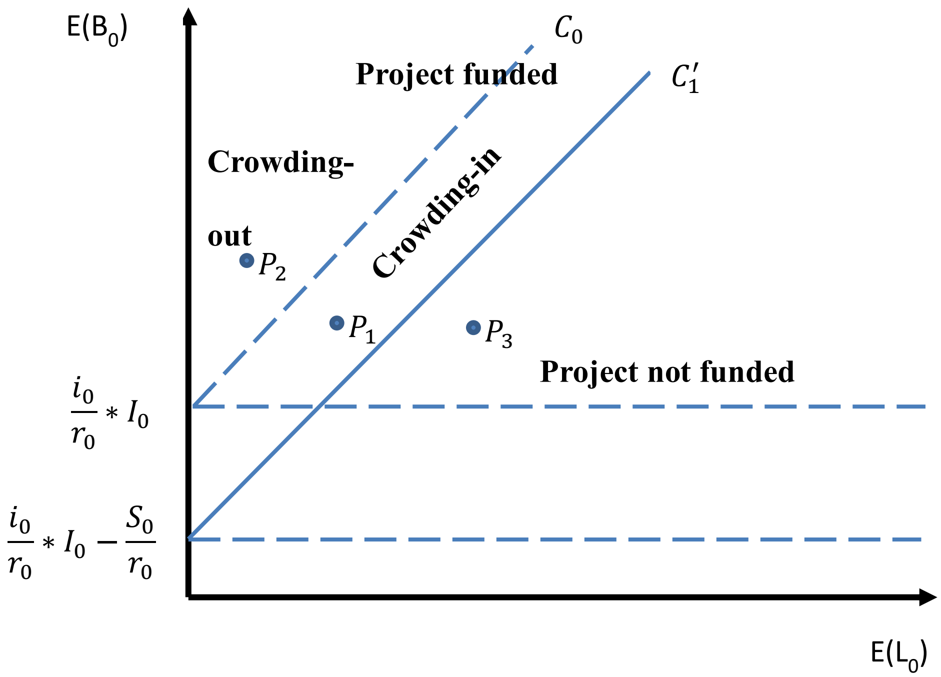


Figure 5. Change in boundary conditions due to assimilation capability.

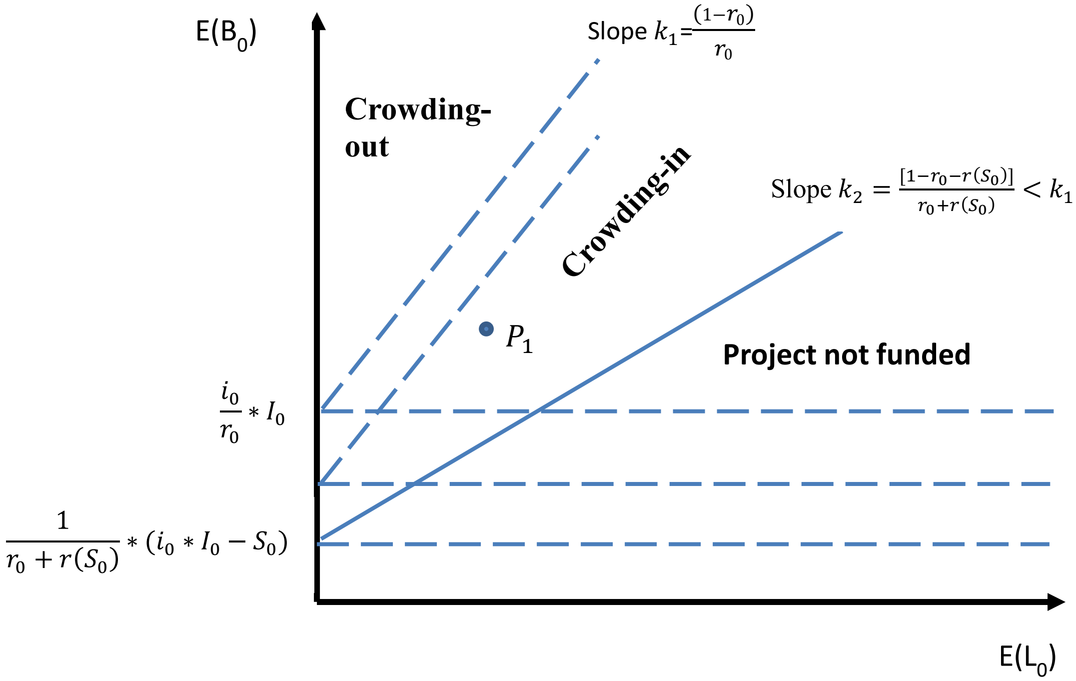


Figure 6. Change in boundary conditions due to transformation capability

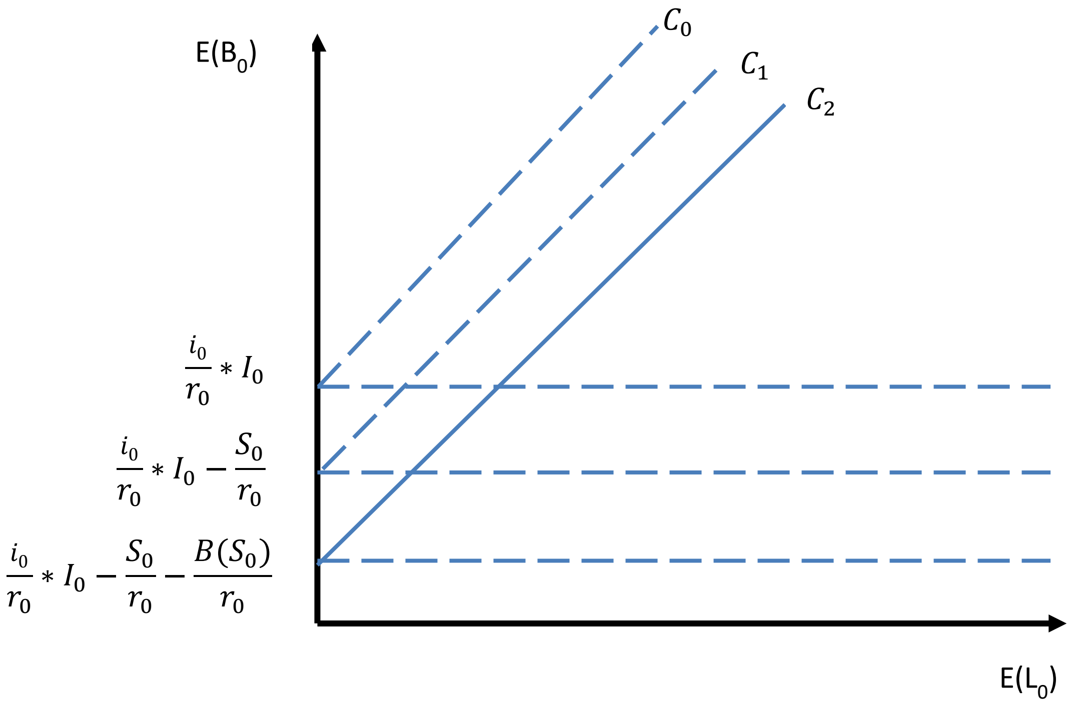
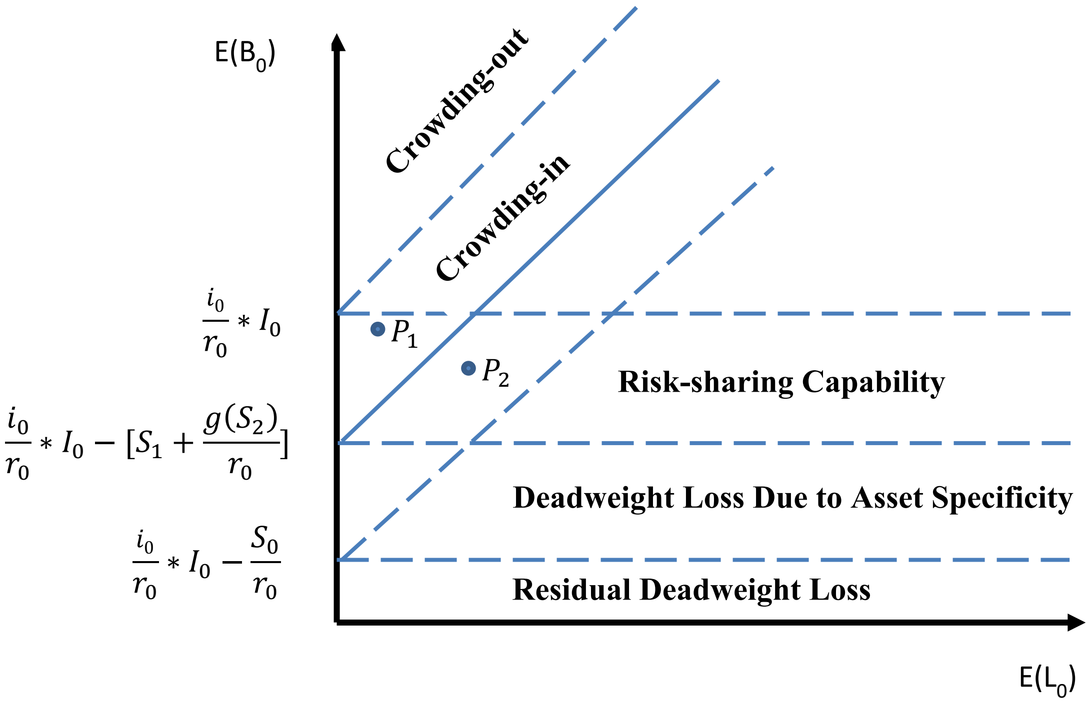


Figure 7. Subsidies with limited re-deployability.



Appendix 1: Link to The Marginal Model

To see how the concavity Π is determined by the relationship between r_0 and I_0, consider a simple equation where the marginal effect of I_0 on the success rate r_0 is a concave function:

$$r_0 = f(I_0) \tag{A1.1}$$

Where

$$f''(I_0) < 0 \tag{A1.2}$$

This means that an optimal initial R&D investment I_0^* exists at which point the project has the highest potential success rate.

Recall the equation for the expected cash flow of the project:

$$\Pi = I_0 + r_0 * E(B_0) - (1 - r_0) * E(L_0) \tag{A1.3}$$

Insert equation (A1.1) into the equation (A1.3), we get:

$$\Pi = I_0 + r_0 * E(B_0) - (1 - r_0) * E(L_0)$$
$$= I_0 + f(I_0) * K - E(L_0) \tag{A1.4}$$

where

$$K = E[P(B_0)] + E[P(L_0)] > 0 \tag{A1.5}$$

K is the risk-reward condition amplifier of the project. It means that if the success rate increases, the influence of expected benefit on the net cash flow will increase, as well the influence of expected loss on the net cash flow will decrease proportionately.

Therefore, the expected cash flow, Π, is also a function of initial R&D investment, such that:

$$\frac{d^2\Pi}{d{I_0}^2} = K * f''(I_0) \tag{A1.6}$$

Given (A1.2) and (A1.5),

$$\frac{d^2\Pi}{d{I_0}^2} < 0 \tag{A1.7}$$

Therefore, equation (A1.3) is also a concave function of I_0, and an equilibrium cash flow Π exists when $f'(I_0^*) = 0$.