Why entrepreneurs choose risky R&D projects - but still not risky enough

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Abstract

Entrepreneurs face higher commercialization costs than incumbents. We show that this implies that entrepreneurs will choose more risky projects than incumbents, aiming to reduce their high expected marginal commercialization cost. However, entrepreneurs may select too safe projects from a social point of view, since they do not internalize the business stealing effect. We also show that commercialization support induces entrepreneurship but may lead to mediocre entrepreneurship by inducing entrepreneurs to choose less risky projects, whereas R&D support encourages entrepreneurship without affecting the type of entrepreneurship. Using Swedish patent citation data, we find empirical support for predictions of the model.

1. Introduction

Entrepreneurs are important for economic progress as providers of "breakthrough" inventions. As Scherer and Ross (1990) point out, "new entrants without a commitment to accepted technologies have been responsible for a substantial share of the really revolutionary new industrial products and processes". Along these lines, Baumol (2004) documents that in the US small entrepreneurial firms have created a large share of breakthrough inventions whereas large established firms have provided more routinized R&D. Further, Cohen (2010), in a review of the empirical literature on firm size and innovative activity, concludes that "[t]he key findings are that larger, incumbent firms tend to pursue relatively more incremental and relatively more process innovation than smaller firms"[1]

[1] Prusa and Schmitz (1991) provide evidence from the personal computer software industry that new firms tend to create new software categories, while established firms tend to develop improvements in existing categories. Henkel, Rønde and Wagner (2010), on the other hand, undertake a qualitative empirical study of the electronic design automation (EDA) industry, concluding that start-ups opt for R&D projects characterized by high risk and return.

These observations raises some important questions. (i) Why do small independent firms (entrepreneurs) embark on radical R&D projects characterized by great uncertainties but high value in case of success? (ii) Do the projects chosen by the entrepreneurs differ from the optimal research projects from a social point of view?, and (iii) What are the expected induced effects of policies towards entrepreneurship which have been used in practice? These issues are addressed in this paper.

The starting point of the paper is that small independent firms have no complementary assets nor any experience when commercializing and, therefore, face much higher costs of commercializing an invention than incumbents do. As highlighted by Gans and Stern (2003, p. 333), "a key management challenge is how to translate promising technologies into a stream of economic returns for their founders, investors and employees. In other words, the main problem is not so much invention but commercialization."

We develop a model where an incumbent and an entrepreneur both invest in R&D that might lead to the creation of an invention. There are different types of R&D projects to choose among where a project with a lower probability of success is associated with a higher payoff if it succeeds. A key feature of the model is that if the entrepreneur turns out to be successful with her chosen research project, she will face a commercialization cost. However, the incumbent is already active in the market and, therefore, will not have to pay any cost to commercialize an invention.

We first establish that the entrepreneur will choose a project with a lower probability of success than that of the incumbent. There are two effects which explain this result. Firstly, the *entrepreneurship hurdle effect*: The higher commercialization cost for the entrepreneur implies that the entrepreneur opts for a project that involves more risk since by so doing it reduces the expected commercialization cost (since the commersialization cost is only paid when the project succeeds). Secondly, the *entry deterring effect*: being successful with a minor invention the incumbent might be able to block entry by an entrepreneur. Thus, for an incumbent, a succesful innovation not only gives rise to cost savings but also entry deterrence and, therefore, the incumbent will go more safe.

How does the optimal project chosen by the entrepreneur relate to the socially optimal research project? There are two important externalities involved in the entrepreneur's choice of project. When the entrepreneur innovates, she does not internalize the expected profit stealing (the entry deterring value from the perspective of the incumbent) which hurts the incumbents. The expected profit stealing increases when projects become more certain since entry hurts rivals per se. This implies that the entre preneur tends to choose too safe an R&D project from a social point of view. However, there is also an expected consumer surplus gain from entry, which increases the safer the project becomes, since entry per se benefits consumers. Consequently, the social planner would, in the latter respect, prefer the entrepreneur to choose projects with less risk (thus, entering with higher probability).

We show that in a model with symmetric firms and homogeneous goods, the profit stealing effect outweighs the increase in consumers surplus. Hence, the entrepreneur tends to choose *too safe* a project from a social perspective. Moreover, in a model with differentiated goods, we show that this finding holds unless the products are sufficiently differentiated. If the products are sufficiently differentiated, the increase in the consumer surplus might outweigh the profit stealing effect (entry deterring effect) and, consequently, the entrepreneur will then choose *too risky* a project from a social perspective.

In the last few decades, entrepreneurship has emerged as a key issue on the policy arena.[2] In addition, governments and policy makers have been playing a key role as facilitators of innovations by firms. An important policy debate regards the optimal design of government policies to facilitate and stimulate R&D and entrepreneurship. This paper will contribute to this debate by investigating the induced effects of the two following types of policies which have been used in practice: (*i*) R&D support and (*ii*) commercialization support.

First, a typical example of a pro-entrepreneurial policy is that of R&D subsidies targeted to small and medium sized enterprises (SMEs). According to a report by the OECD (OECD (2007)), in the year 2007 several countries offered tax subsidies for R&D targeted specifically at SMEs. Examples are: the UK, Canada, Japan, the Netherlands, Norway and Poland. In our proposed theoretical model, a tax subsidy for R&D reduces the R&D cost paid ex ante, before the outcome of the R&D project has been realized.

Second, government policy can also be geared towards supporting the commercialization of inventions that have already been developed. Examples of this type of policy are financial support for incubators, and loans specifically designed to facilitate the commercialization process in new firms. Recently, there has been a substantial increase in spending on such policies. For example, in 2009, the US Small Business Administration had approved over $13 billion in loans and $2.7 billion in surety guarantees to small businesses in a year.[3] In our proposed model, this second type of pro-entrepreneurial policy corresponds to a decrease in the entry (commercialization) cost that an entrepreneur must pay (ex-post) in case it succeeds with its R&D project and decides to enter the market with its invention.

In this paper, we undertake a comparison of the impact of each of these policies on the type of R&D projects that the entrepreneur as well as the incumbent will choose. We show that subsidies for R&D can induce an increase in the amount of R&D, but the type of R&D project which is carried out by the entrepreneur remains unaffected. The reason is that the commercialization cost is unaffected.

As for commercialization support, we show that, following the decrease in the commercialization cost, the entrepreneur embarks on an R&D project with a higher probability of success and a lower payoff (less-breakthrough) since the entrepreneurship hurdle effect is reduced. Moreover, the incumbent's response to a decrease in the entrepreneur's commercialization cost is to also choose projects with a higher probability of success. We then show that if the profit shifting effect of entry dominates the consumer effect, both agents will choose too safe projects and the optimal policy is to subsidize R&D but tax entry.

A main finding in the paper is the entrepreneurship hurdle effect described above. But how robust is this finding? We generalize this result to a model with marginal cost reductions and relax some of the assumptions made in the benchmark model. Firstly, we analyze the case when the entrepreneur can enter the market and both firms succeed. Secondly, we consider the cases

[2] *The Economist* (14th March 2009) published a special report on entrepreneurship, "Global Heroes", describing this phenomenon.

[3] Source: 2009 Summary of Performance and Financial Information, US Small Business Administration, 2009.

where a second entrepreneur or a second incumbent exist. Finally, we also allow the entrepreneur to commercialize its invention through sale to the incumbent, instead of entering with it into the product market. By so doing, we show that it is still true that as the commercialization cost increases, the entrepreneur has more incentives to embark on R&D projects with a low probability of success and a high payoff (innovations with high quality, i.e. breakthrough innovations).

We also examine empirical predictions of the entrepreneurship hurdle effect: (i) higher entry costs should result in more entrepreneurial failures, since when entry barriers are high, the entrepreneur opts for an R&D project with a lower probability of success; (ii) as a low success probability project is associated with a higher payoff in case of success, if the project succeeds, the invention will be "larger" or of a higher quality, and finally, (iii) the average (expected) quality should be lower for entrepreneurs with higher entry costs, since their choices are further away from the choice maximizing the expected quality. To analyze these three predictions, we use detailed data on patents granted to small firms and individual inventors in Sweden. This data is unique in the sense that it contains detailed information about initial patent holders characteristics at the point in time when the patent was applied for. As a comparison, the NBER Patent Citation Data File[4] contains the full names and addresses of inventors listed in each patent, but the type of information we use in this paper has to our knowledge not yet been collected. And it is through this additional information that we can examine how the incidence of breakthrough inventions (as measured by forward citations) is related to the costs of commercializing the invention, i.e., the hurdle effect.

To give brief a summary of our empirical results, Figure 1.1 plots the non-parametric kernel density of patent citations for the group, denoted L, of inventors that owned a firm at the application date (and, hence, had low commercialization costs) and the group, denoted H, that did not own a firm at the application date (thus facing high commercialization costs).[5]

This figure gives graphical support to prediction (i) by showing that the group of inventors facing higher commercialization costs indeed seem to generate more failures (which we assume to be associated with zero patent citations as measured by the $x-$axis in the figure). Visually, this is seen from that the density function characterizing the high-cost group have a larger point mass at zero. More formally, we formulate a statistical decision hypothesis to test whether data satisfies prediction (i). Specifically, the null in this hypothesis is that there is an equal probability of failure in the two groups whereas the alternative says that there is a larger probability of failure in the group of inventors facing higher commercialization costs, where the alternative then corresponds to prediction (i). Our results reveal that the data show strong empirical evidence that patents in the high-cost group are associated with a larger probability of failure, thereby supporting the prediction from the hurdle effect.

As further seen from Figure 1.1, the density function characterizing the high-cost group seems to have a fatter and longer tail than the density function of the low-cost group. This

[4] See Hall, Jaffe and Trajtenberg (2001) for a detailed description of the NBER Patent Citation Data.

[5] The data is described in more detail in Section 7. Technical details of how the kernel densities were estimated are given in footnote 29 in that section.

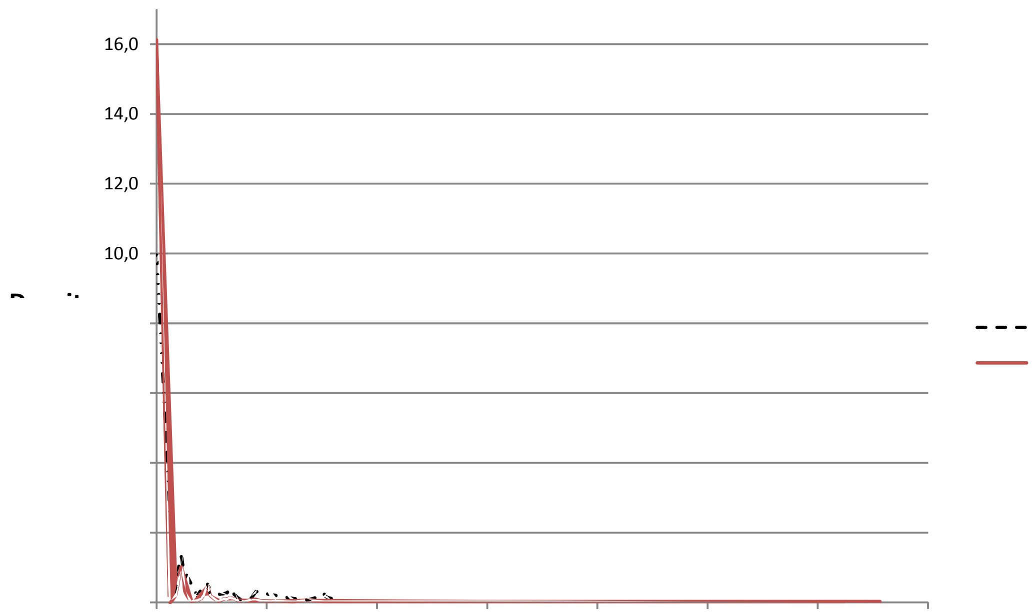

Figure 1.1: Explain

means that the group of inventors facing higher commercialization costs appear to generate more breakthrough inventions (i.e. has a higher number of citations), which corresponds to prediction (ii). To statistically test this prediction, we suggest comparing the tail-fatness of the distributions for the two groups.[6] The intuition behind this is that a fatter and longer tail puts more probability mass in the tail, meaning that there is a higher probability for a larger number of citations in the high-cost group (characterized by the fatter-tailed distribution) than in the low-cost group (characterized by the thinner-tailed distribution). The empirical results provide strong evidence that our data supports prediction (ii).

Finally, prediction (iii) says that entrepreneurs with higher entry costs should be associated with patents of a lower expected quality than patents from entrepreneurs facing lower entry-costs, which, however, is difficult to visually infer from Figure 1.1. We propose a statistical test of this prediction by formulating a statistical decision hypothesis of the null that the expected number of citations are equal in the two groups against the alternative that the expected number of citations is lower in the high-entry cost group, where the alternative then corresponds to prediction (iii). Our empirical results show that the data supports prediction (iii), but that it does so more weakly than the other two predictions. Summarizing the main conclusions from our empirical analysis of the three predictions, we find that the results are overall consistent with the identified entrepreneurship hurdle effects in the theoretical analysis.

In addition, we provide sensitivity analysis, which, for example, shows that our empirical results are robust to excluding what could be regarded as outliers in the data. On a more conceptual level, a potential issue with the current setup concerns the difficulty of identifying

[6] The tail-fatness of the densities is estimated using the modified Hill estimator proposed by Huisman, Koedijk, Kool and Palm (2001).

the effect of commercialization costs on the R&D outcome of entrepreneurship, i.e., how the outcome of the R&D project will affect the entrepreneur's choice of organizational form (starting a firm or being self employed). However, since our data is about firms' size at the application date when the commercial value of the invention should still be highly uncertain, we believe this problem to be limited.

Another potential concern is that there may be other underlying factors for why some inventors do not want to start larger firms which might explain why they behave in a more risky way in R&D (resulting in a sort of omitted variables problem). The sensitivity analysis, however, shows that this does not seem to be the case for our data. Finally, a potential limitation with our data is that R&D projects which do not even result in a patent are not included in our dataset. In our empirical analysis, we make the identifying assumption that a patent with zero citations is a failure. We believe that this is a reasonable assumption for many types of research projects where it is relatively easy to get a patent from the patent office but rather difficult to produce a patent that is cited. The large over-representation of zero citation patents in the data seems to support this view (See the frequency distributions in Table 2 in Section 7).[7]

The rest of the paper is organized as follows. In Section 2, we discuss related literature. In Section 3, we present the theoretical model and characterize the equilibrium research projects chosen by the entrepreneur and the incumbent. Section 4 establishes why entrepreneurs choose risky R&D projects – but still not risky enough. In Section 5, we use our model to investigate the effects of pro-entrepreneurial policies on the firms' choices of research projects. In Section 6 we examine the robustness of our main result, i.e. the entrepreneurship hurdle effect, considering scenarios which allow for commercialization by sale, several incumbent firms or several outsider entrepreneurs. Then in Section 7 we provide empirical support for the entrepreneurship hurdle effect. Section 8 concludes the paper. Further, in the Appendix, we extend the model to allow for innovation that improves product quality or reduces the variable costs of production, and we show that in a linear Cournot model, the main mechanisms of the model hold good.

2. Related literature

This paper is related to the literature on R&D and market structure.[8] There are several papers studying the type of R&D project to undertake.[9] To our knowledge, however, there are only a few papers considering asymmetries between firms in such a context. Cohen and Klepper (1996 a,b) put forward (and test empirically) a model where differences in R&D behavior stems from that larger firms have larger output over which they can apply their innovation results. This then imply that large firms have a relative advantage to pursue process innovation over product innovation since process innovations easier could directly be used in existing business.[10] Rosen

[7] An analogy to research in economics is that the almost all research projects lead to publications but only the successful projects leads to publications generating many citations.

[8] For a survey, see Gilbert (2006). See also Vives (1998) for a theoretical model examining whether competitive pressure fosters product or process innovation, whose results shed light on empirical strategies to evaluate the impact of competition on innovation.

[9] See, for instance, Bhattachrya and Mookherjee (1986).

[10] Using a duopoly model of multiproduct firms Yin and Zuscovitch (1998) show that large firms tend to invest more in process innovation and small firms invest more in a search for new products.

(1991) and Cabral (2003) show in oligopolistic settings that small firms may have an incentive chooses the risky strategy due to strategic output effects in the product market, i.e. small firms do not take on low risk-return project since they cannot exploit the improvements over large output. In these papers, the difference in R&D behavior between small and large firm stems from difference in post innovation outputs in the product market. This is distinct from our paper where the difference stems from the fact that the entrepreneur have not yet sunk a large part of its entry (commercialization) costs before the outcome of the R&D process is determined. The key difference can be illustrated in a simple example: consider a situation where there are two research projects firms can choose among. Project A has an associated payoff of 20 with probability 0.5 and 0 with probability 0.5. Project B, has an associated payoff of 10 with probability 1. An incumbent facing zero entry cost is indifferent between the projects A and B. This irrespective if it is small or large. Now consider an entrepreneur that faces an entry cost of 1 if she decides to commercialize the invention. The entrepreneur then prefers the risky project A over B. This follows from the fact that $(20-1)\times 0.5+0\times 0.5>10-1$. Using this distinction between entrepreneurship and incumbency we add to the literature by showing that entrepreneurs have an incentive to choose risky R&D projects in order to optimize on expected entry (commercialization) costs (the hurdle effect). Moreover, we show that incumbents have an incentive to choose safe R&D project in order to increase expected hurdle costs for the entrepreneur, i.e. optimize on entry deterring.[11]

This paper can also be seen as a contribution to the literature on entrepreneurship (entry) and the product market (e.g. Gans and Stern (2000, 2003) and von Weizsacker (1980)). Our paper is closest in spirit to that of Mankiw and Whinston (1986) who show that if an entrant causes incumbents to reduce output in a homogenous Cournot model (i.e. the business effect is positive), entry is more desirable to the entrant than it is to society in a free entry setting, whereas there can be insufficient entry in a differentiated product model, due to a positive product variety effect of entry. Examining the probability of entry, we add to this literature by showing that entrants choose too safe projects from a social perspective if entry generates a larger profit reduction for incumbents than it increases the consumer surplus, which can be shown to hold if the products are not too differentiated. Thus, we add to this by showing that less frequent but high quality entry is preferred to more frequent and mediocre entry.

The paper is also related to the literature on financial structure and firm behavior. There, it has been shown that increased debt levels should make firms undertake more risky investments (e.g. Stiglitz and Weiss (1981)) and more risky product market decisions (Brander and Lewis (1986) and Maksimovic and Zechner (1991)). Our results concerning R&D project type and commercialization costs are conceptually similar. Increasing the commercialization cost in our set-up (corresponding to increased debt or interest rate in that literature) implies that a larger

[11] There are some recent papers studying what type of R&D projects entrepreneurs choose in situations where innovation for sale is an option. Henkel, Rønde and Wagner (2011) show that independent entrepreneurs which innovate for sale choose R&D projects with a higher risk than incumbents, since incumbents have an incentive to opt for safer R&D projects so as to improve their bargaining power in subsequent acquisitions. Haufler, Norbäck and Persson (2011) show that the limited loss offset feature of the tax system reduces the incentive for entrepreneurs to choose risky R&D projects. We differ from these studies by focusing on the importance of the commercialization cost, the strategic interaction between the R&D choices by the entrepreneur and the incumbent, and by undertaking a welfare analysis. This enables us to show that, due to the entrepreneurship hurdle effect and the business stealing effect, entrepreneurs choose risky R&D projects – but still not risky enough.

amount of the low risk projects have negative returns which implies that the entrepreneur will put more weight on high risk projects. However, our mechanism is distinct by not relying on asymmetric information problems, but rather on the fact that the outcome of the uncertain decision is realized before some of the costs of exploiting the investment are taken. Moreover, we differ from this literature by also examining how (innovation) policy affects the riskiness of the (R&D) projects undertaken, taking into account the interaction between entrepreneurs and incumbents and undertaking a welfare analysis taking into account market power effects. This enables us to show that R&D support can be preferred to commercialization support since it stimulates the amount of entrepreneurship but does not distort the type of entrepreneurship.

3. The Model

Consider a market with a unique incumbent firm. Outside this market there is an entrepreneur which can potentially enter the market. The sequence of events is shown in Figure 3.1.

In stage 1, both firms can invest in an R&D project at a cost R which, if it is successful, generates an invention. The invention can take several forms, which all increase the possessors profits: it can be a new product, a product of higher quality or a new or improved production process. To highlight our mechanism of interest, namely how commercialization costs affect the type of R&D conducted by firms, we will use a model where the innovation reduces the fixed cost of production, denoted $\overline{F}$, which is identical for the entrepreneur and for the incumbent. In the Section 6 we generalize the model to allow for innovations that improve product quality or reduce the variable costs of production.[12]

Each agent can choose among an infinite number of independent R&D projects. There is a cost of running a project and, to capture this, we assume that each firm can only undertake one project.[13] Each project (say, project l) is characterized by a certain probability of success, denoted p_l, and a corresponding reduction in the fixed cost $\Gamma(p_l)$, where $\Gamma_l'(p_l) < 0, p_l \in (0, 1)$. Along the technological frontier, the agents face a choice between projects that have a high probability of success but deliver a small reduction in fixed costs in case of success, and projects that are more risky but also have a higher associated payoff if successful.[14] Omitting the project index, the fixed cost reduction $\Gamma(p)$ is illustrated in Figure 3.2(i). As shown in Figure 3.2(ii) and (iii), the expected fixed cost reduction $p\Gamma(p)$ is then assumed to be strictly concave in p with a unique project $\hat{p}$ maximizing expected fixed cost reduction, $\hat{p} = \arg\max_p p\Gamma(p)$. The expected fixed production costs is the equal to $F(p) = \overline{F} - p\Gamma(p)$.

In stage 2, the outcomes of the agents R&D projects p_j are revealed. Since a project either succeeds or fails, there are two symmetric outcomes, $\{p_i$ fail, p_e fail$\}$ and $\{p_i$ succeed, p_e succeed$\}$ and two asymmetric outcomes, $\{p_i$ fail, p_e succeed$\}$ and $\{p_i$ succeed, p_e fail$\}$.

In stage 3, given the outcome of the R&D projects, the entrepreneur makes a decision regarding whether to enter the market at a fixed commercialization cost G (already sunk by the

[12] In addition, Section 6 adds additional entrepreneurs and incumbents and relaxes a simplifying assumption regarding the entry process.

[13] See Gilbert (2006) for a motivation.

[14] An interesting avenue for further research would be to investigate a setting in which the incumbent and the entrepreneur could have access to different pools of available projects to choose from (say, different technological frontiers). This is, however, outside the scope of the present paper.

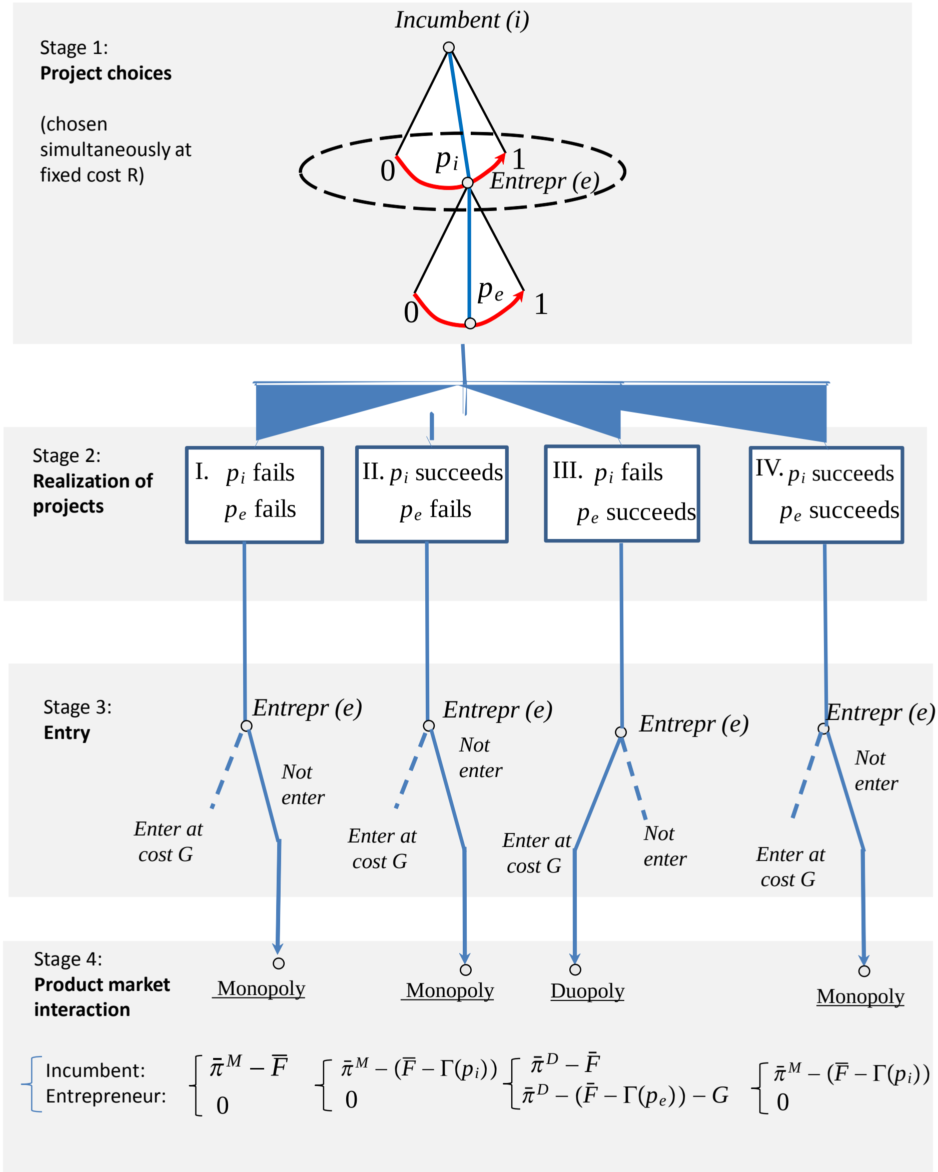

Figure 3.1: The structure of the model.

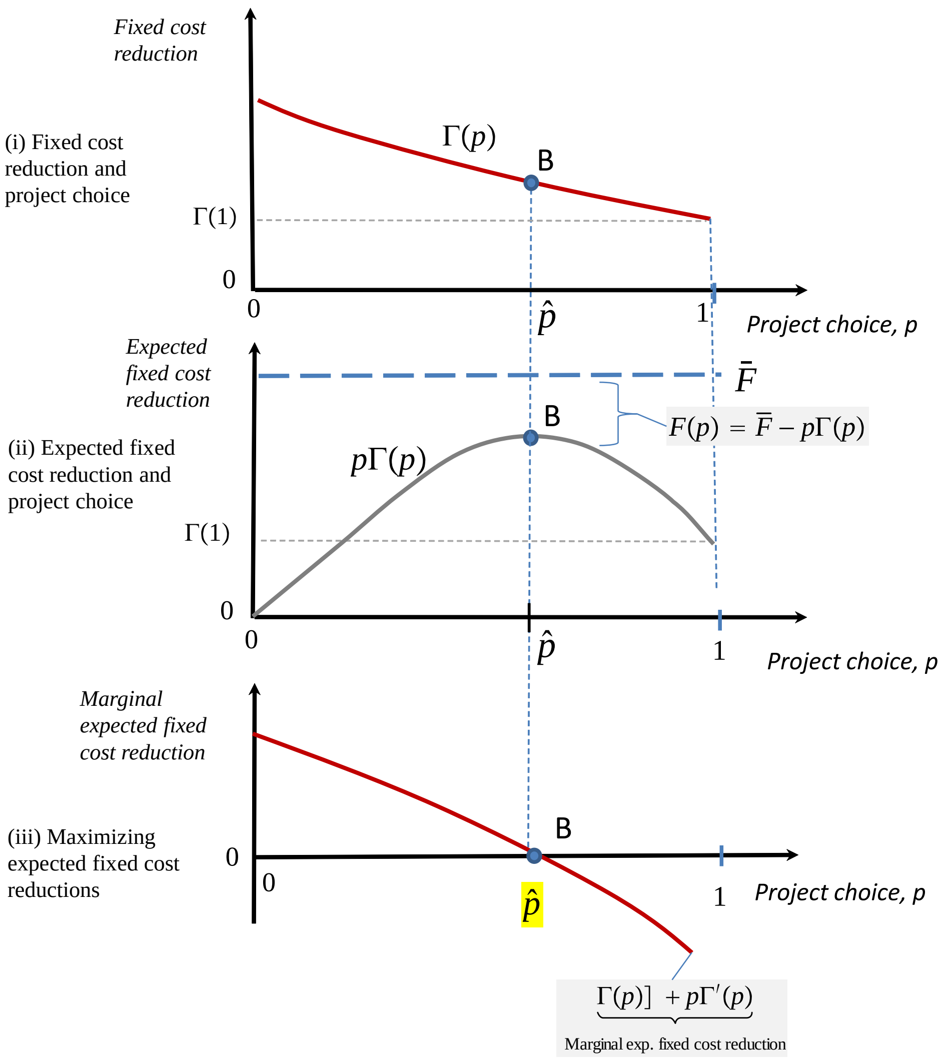

Figure 3.2: The fixed cost saving model: R&D projects and fixed cost reduction.

incumbent). Finally, in stage 4, the product market interaction takes place where competition may be in quantities or in prices. The product market profit will then depend on whether the entrepreneur enters the market, on whether the firm succeeds with its selected project, and on the type of project undertaken.

In what follows, we analyze the equilibrium of the proposed game, following the usual backward induction procedure.

3.1. Stage 4: product market interaction

Let $\pi_j(x_j, x_{-j}) - F_j$ be the product market profit of firm $j = \{i, e\}$ net of fixed costs $F_j = F(p_j)$, which result from the outcome of in stage 2. The product market profit $\pi_j(x_j, x_{-j})$ depends on the action taken by firm j, x_j, and the action taken by its opponent, x_{-j}. We then assume the existence of a unique Nash equilibrium, $\{x_j^*, x_{-j}^*\}$, defined from the condition:

$$\pi_j(x_j^*, x_{-j}^*) \geq \pi_j(x_j, x_{-j}^*), \tag{3.1}$$

for all $x_j \neq x_j^*$, which is unaffected by fixed costs $F(p_j)$. Since firms are symmetric, the reduced-form product market profit of each firm is $\bar{\pi}^D = \pi_j(x_j^*, x_{-j}^*)$ under entry by the entrepreneur. If the entrepreneur does not enter and the incumbent acts a monopolist, the reduced-form product market profit is $\bar{\pi}^M = \pi_i(x_i^M, 0)$. We take the usual assumption that profits decrease in the number of firms and that consumers are better off when entry occurs, i.e. $\bar{\pi}^M > \bar{\pi}^D$ and $CS^D > CS^M$ where CS denotes the consumer surplus. An example which fulfils these assumptions is the model involving quantity competition in a differentiated products market proposed by Singh and Vives (1994). This model is described in detail in the Appendix.

3.2. Stage 3: Entry by the entrepreneur

At this stage, given the outcome of the projects, the entrepreneur chooses whether or not to enter the market. We assume that in the no innovation benchmark situation, the entrant has no incentives to enter the market.

Assumption A1: When there is no innovation (or if innovation fails), the net profit from entry by the entrepreneur is negative, $\bar{\pi}^D - \bar{F} - G < 0$, where $\bar{\pi}^D - \overline{F} > 0$.

As illustrated in Stage 3 in Figure 3.1(iii), since $\bar{\pi}^D - \overline{F} - G < 0$, the entrepreneur will not enter the market if its R&D project fails. In addition, the fact that $\bar{\pi}^D - \overline{F} > 0$ implies that the incumbent will not exit market even if its R&D project fails.

As also shown in Stage 3 in Figure 3.1, we further assume that the entrepreneur can only enter when its R&D project is successful and the incumbent's project has failed.[15] This mirrors the fact that one major benefit for incumbents from innovating is that a successful innovation often serves as an entry deterring activity (see Crampes and Langinier (2002) and Gilbert and Newbery (1982)). In particular, being successful in innovating implies that the incumbent gains technical experience which makes it more likely to succeed in copying the entrepreneur's

[15] In Section 6 we extend the analysis so as to allow the entrepreneur to enter when it succeeds with the selected R&D project.

innovation, or reliably threatens to do so, and thereby reduces the likelihood of entry by the entrepreneur. Moreover, even if the entrepreneur has patented its product, high legal costs and limited access to financing may deter the entrepreneur from suing for infringement.[16]

3.3. Stage 2: Uncertain projects revealed

At this stage, the incumbent's and the entrepreneur's projects outcomes are revealed. Again, since each agent can succeed or fail, there are four outcomes to consider.

3.4. Stage 1: Project choices

We now examine the project choices of the agents. We start with the entrepreneur.

The entrepreneur's optimal R&D project As explained above, the entrepreneur will only enter at stage 3 (upon payment of the fixed entry cost, G) if its selected R&D project turns out to be successful in stage 2 while the incumbent's project fails. This outcome occurs with probability $p_e(1-p_i)$ and generates the net profit $\bar{\pi}^D - \left(\overline{F} - \Gamma(p_e)\right) - G$ for the entrepreneur. In addition, there is a fixed cost R of conducting R&D which has to be paid irrespective of whether the entrepreneur succeeds or not.

The entrepreneur's expected profit is therefore given by:

$$\mathrm{E}[\Pi_e] = p_e(1-p_i)[\bar{\pi}^D - \left(\overline{F} - \Gamma(p_e)\right) - G] - R. \tag{3.2}$$

The corresponding first-order condition, $dE[\Pi_e]/dp_e = 0$, is

$$(1-p_i)[\bar{\pi}^D - \left(\overline{F} - \Gamma(p_e^*)\right) - G] + (1-p_i)p_e^*\Gamma'(p_e^*) = 0. \tag{3.3}$$

The first term gives the increase in expected profit from choosing a marginally safer project. The second term, on the other hand, represents the reduction in expected profit from choosing a safer project since, if successful, the safer project will provide a smaller fixed cost reduction. It will be convenient to rewrite this first-order condition as follows:

$$\Gamma(p_e^*)] + p_e^*\Gamma'(p_e^*) = \underbrace{G - \underbrace{(\bar{\pi}^D - \overline{F})}_{(+)}}_{\substack{(+)\\ \text{Hurdle effect}}} > 0. \tag{3.4}$$

As illustrated in Figure 3.3, the left-hand side represents the increase in profits resulting from a lower expected fixed cost from choosing a marginally safer project. Then, turn to the right-hand side. From Assumption A1, $G - (\bar{\pi}^D - \overline{F}) > 0$. So, the entrepreneur faces a loss if entering without the invention. We label this the (entrepreneurship) hurdle effect. Note that because of the hurdle effect the entrepreneur will always choose a project which is riskier than the project $\hat{p}$ maximizing expected fixed cost reductions, i.e. $p_e^* < \hat{p} = \arg\max_p p\Gamma(p)$. To see

[16] We can incorporate this formally by assuming that the incumbent infringes on the entrepreneur's patent, and suing for infringement involves legal costs, L. Then, we can find an L such that $\bar{\pi}^D - \left(\overline{F} - \Gamma(p_e^*)\right) - G - L < 0$, whereas $\bar{\pi}^D - \left(\overline{F} - \Gamma(p_i^*)\right) - L > 0$, since $G > 0$. For expositional reasons, however, we do not pursue this here.

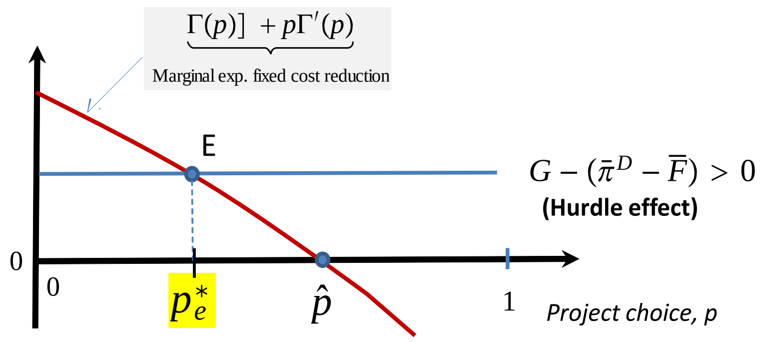

Figure 3.3: The entrepeneur's optimal project (p_e^*).

why, suppose that the entrepreneur would choose $\hat{p}$. From (3.2), this cannot be optimal since by marginally reducing the probability of success from $\hat{p}$, the entrepreneur would trade off a first-order reduction of the expected net cost of commercialization, $(1-p_i)\hat{p}[G-(\bar{\pi}^D-\overline{F})]$, against a second-order reduction of the expected fixed-cost reduction $(1-p_i)\hat{p}\Gamma(\hat{p})$.

Hence, by choosing a riskier project than $\hat{p}$ the entrepreneur can increase her expected profit by lowering the expected commercialization cost. As shown by Figure 3.2(ii), at an increasing distance from the cost-efficient project $\hat{p}$, the loss in profits from lower expected fixed cost reductions will increase in size. At the optimum $p_e^* < \hat{p}$ (point E in Figure 3.3), the implied loss in expected profits from a lower expected fixed cost reduction and the increase in expected profits from lower expected (net) commercialization costs then balance each other out.

What happens if the entry hurdle is increased? Differentiating (3.4) in p_e and G, we obtain

$$\frac{dp_e^*}{dG} = \frac{1}{2\Gamma'(p_e^*) + p_e^*\Gamma''(p_e^*)} < 0 \tag{3.5}$$

where $2\Gamma'(p_e^*) + p_i^*\Gamma''(p_e^*) < 0$ by our assumption that the expected fixed cost reduction $p\Gamma(p)$ is strictly concave in p. If the entry cost G increases, the entrepreneur will choose a riskier project. This can be seen in Figure 3.3 by shifting the locus for the hurdle effect $G-(\bar{\pi}^D-\overline{F})$ upwards and noting that p_e^* must then decrease. We thus have the following proposition:

Proposition 1. *If the entry cost G increases, the entrepreneur chooses an R&D project with a lower probability of success and a higher payoff if successful (a "breakthrough" invention of higher quality).*

To sum up, the commercialization cost is paid ex-post (in stage 3), conditional upon the success of its selected R&D project (in stage 2). The entrepreneur therefore responds to the increase in the entry cost by choosing a project with a lower probability of success in order to reduce the expected net commercialization cost.

The incumbent's optimal R&D project Let us now examine the choice of the incumbent. The expected incumbent's profit is

$$\mathrm{E}[\Pi_i] = p_i[\bar{\pi}^M - \left(\overline{F} - \Gamma(p_i)\right)] + (1-p_i)\{p_e\left(\bar{\pi}^D - \overline{F}\right) + (1-p_e)\left(\bar{\pi}^M - \overline{F}\right)\} - R. \tag{3.6}$$

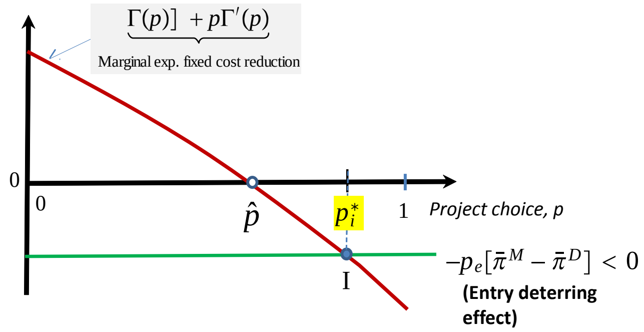

Figure 3.4: The incubent's optimal project (p_i^*).

Consider again Figure 3.1. The incumbent's R&D project will succeed with probability p_i, in which case it earns a monopoly profit $\bar{\pi}^M$ and incurs a fixed production cost equal to $\overline{F} - \Gamma(p_i)$. Recall that, by assumption, the entrepreneur cannot enter when the incumbent succeeds. This payoff is therefore independent of p_e. With probability $(1-p_i)$, the incumbent's R&D project fails. Then, if the entrepreneur's project has succeeded, the incumbent obtains a duopoly profit $\bar{\pi}^D$ and incurs a fixed production cost $\overline{F}$. If instead the entrepreneur's project has also failed, the incumbent earns a monopoly profit $\bar{\pi}^M$ and still incurs a fixed production cost $\overline{F}$. In addition, the fixed cost of R&D, paid ex-ante, is R.

The corresponding first-order condition, $dE[\Pi_i]/dp_i = 0$, is given by

$$\bar{\pi}^M - \left(\overline{F} - \Gamma(p_i)\right) + p_i \Gamma\prime(p_i) - \left\{p_e\left(\bar{\pi}^D - \overline{F}\right) + (1-p_e)\left(\bar{\pi}^M - \overline{F}\right)\right\} = 0. \tag{3.7}$$

The first term shows the increase in the incumbent's expected profit from choosing a safer project, where $\bar{\pi}^M - \left(\overline{F} - \Gamma(p_i)\right)$ is the net profit and $p_i\Gamma\prime(p_i) < 0$ represents the decrease in the expected fixed cost reduction. As usual, the incumbent also has to consider a "replacement effect". If the incumbent fails, its expected profit is $p_e\left(\bar{\pi}^D - \overline{F}\right) + (1-p_e)\left(\bar{\pi}^M - \overline{F}\right)$ where this profit depends on whether the entrepreneur fails or not. Choosing a marginally safer project implies a higher probability of this profit being replaced, which explains the second term in (3.7).

It is once more convenient to rewrite (3.7) as follows:

$$\Gamma(p_i^*) + p_i^* \Gamma'(p_i^*) = -p_e \underbrace{\left[\bar{\pi}^M - \bar{\pi}^D\right]}_{\substack{(+) \\ \text{Entry Deterring}}} < 0 \tag{3.8}$$

This condition is illustrated in Figure 3.4. The left hand side is again the marginal expected fixed cost reduction. The term $\bar{\pi}^M - \bar{\pi}^D > 0$ on the right hand side mirrors the fact that the monopolist will lose its monopoly position if the entrepreneur succeeds and enters the market. We denote this the entry deterring effect. Note that because of the entry deterring effect the incumbent will choose a project which is safer than the project $\hat{p}$ maximizing expected fixed cost reductions, i.e. $p_i^* > \hat{p} = \arg\max_p p\Gamma(p)$. To see why, suppose that the incumbent would instead choose $\hat{p}$. This cannot be optimal since by marginally increasing the probability of success from

$\hat{p}$, the incumbent would trade off a first-order reduction in the expected loss from entry by the entrepreneur, $(1-\hat{p})p_e[\bar{\pi}^M - \bar{\pi}^D]$, against a second-order reduction of the expected fixed-cost reduction $(1-p_i)\hat{p}\Gamma(\hat{p})$.

So, by choosing a marginally safer project than $\hat{p}$ the incumbent can increase its expected profit by lowering the expected loss from entry (since the entrepreneur cannot enter if the incumbent succeeds). But yet again, as shown by Figure 3.2(ii), at an increasing distance from the cost-efficient project $\hat{p}$, the loss in profits from lower expected fixed cost reductions will increase in size. At the optimum $p_i^* > \hat{p}$ (point I in Figure 3.4), the implied loss in expected profits from a lower expected fixed cost reduction and the increase in expected profits from lower expected loss from entry, balance each other out.

The Nash equilibrium in project choices Let us now characterize the market solution in terms of the Nash-equilibrium in project choices. From (3.4) the entrepreneur's choice of project is independent of the incumbent's choice. Thus, the reaction function of the entrepreneur is simply $R_e = p_e^*$. This is depicted as the vertical line in Figure 3.5 (ii).

The reaction function of the incumbent $R_i(p_e)$ is implicitly given by eq. (3.8). Differentiating it in p_e and p_i, we obtain the corresponding slope $R_i'(p_e)$:

$$\frac{dp_i^*}{dp_e} = \mathcal{R}_i'(p_e) = -\frac{(\bar{\pi}^M - \bar{\pi}^D)}{2\Gamma'(p_i^*) + p_i^*\Gamma''(p_i^*)} > 0 \tag{3.9}$$

where once more $2\Gamma'(p_i^*) + p_i^*\Gamma''(p_i^*) < 0$ by our assumption that $p\Gamma(p)$ is strictly concave in p.

We can then formulate the following proposition:

Proposition 2. *For the incumbent, the two firms' probabilities of success are strategic complements: $R_i'(p_e) > 0$.*

The intuition for this result is already apparent from (3.8): if the entrepreneur chooses a higher probability of success, this increases the expected entry deterring effect, which induces the incumbent to choose a higher probability of success so as to avoid losing its monopoly position.

The reaction function of the incumbent $R_i(p_e)$ is depicted as the upward-sloping solid line in Figure 3.5 starting from the cost-efficient project, $\hat{p}$, which can be obtained by substituting $p_e = 0$ into (3.8). The unique Nash-equilibrium $\{p_e^*, p_i^*\}$ is then represented by point N where the reaction functions $R_i(p_e)$ and R_e intersect. Note that the Nash-equilibrium N is located to the north of the 45 degree line, implying that the entrepreneur chooses a riskier R&D project, $p_e^* < p_i^*$.

We can then formulate the following proposition:

Proposition 3. *Entrepreneurs carry out more risky innovations than in case of success: $p_e^* < p_i^*$ and, subsequently, $\Gamma(p_e^*) > \Gamma(p_i^*)$.*

The proof of the previous proposition directly follows from Figures 3.3 and 3.4: Through the existence of entry costs, the hurdle effect $(G - (\bar{\pi}^D - \overline{F}) > 0)$ induces the entrepreneur to choose a project with lower probability than the cost-efficient project $p_e^* < \hat{p}$, in order to

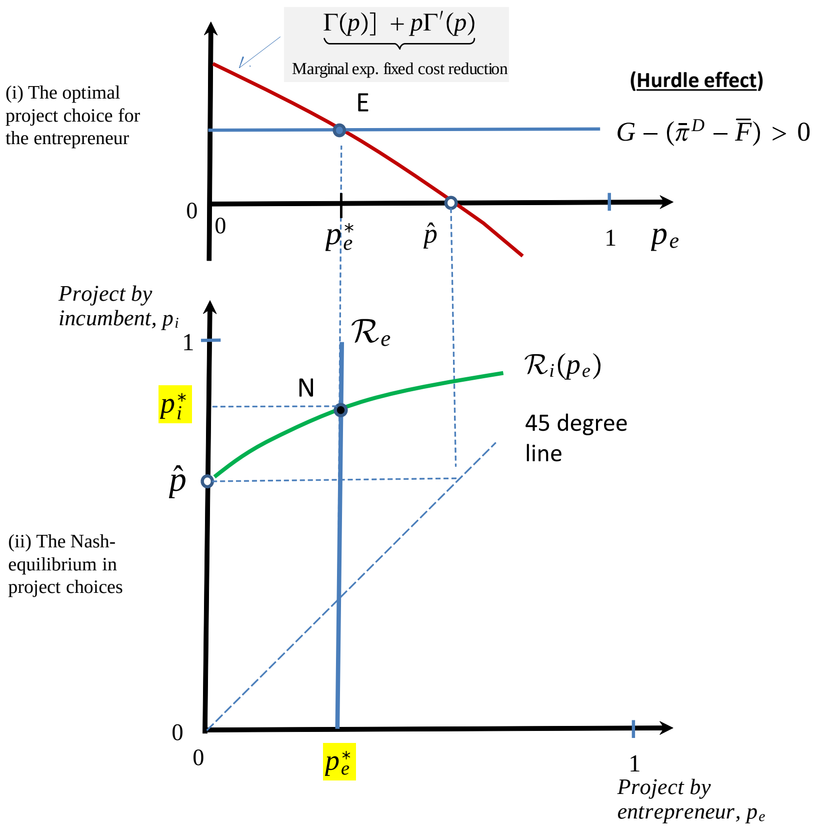

Figure 3.5: Deriving the Nash-equilibrium in project choices (N).

decrease the expected net entry cost. The incumbent, on the other hand, faces no cost of entry. Instead, through the entry deterring effect $(-p_e^* \left[\bar{\pi}^M - \bar{\pi}^D\right] < 0)$, it takes into account the risks of losing the monopoly profit if its R&D project fails and that of the entrepreneur succeeds - this induces the incumbent to choose a project with a higher probability of success than the cost-efficient project, $p_e^* > \hat{p}$. Since $p_e^* < p_i^*$, it also follows that, in case of success, the entrepreneur's selected project contains a larger fixed cost reduction than the incumbent's selected project, $\Gamma(p_e^*) > \Gamma(p_i^*)$.

4. Why entrepreneurs choose risky R&D projects – but still not risky enough

Let us now compare the market solution to the first-best solution chosen by a social planner. We define welfare under the assumption of partial equilibrium and consider the expected total surplus. We can then think of the social planner in a stage 0 calculating the expected total surplus taking into account how the game evolves given the R&D outcomes shown in Figure 3.1.

Thus, let $\bar{W}^M$ be the total surplus when no firm's R&D project succeeds, where superscript M denotes monopoly. In this case, the incumbent earns net profits equal to $\bar{\pi}^M - \overline{F}$, consumers enjoy a surplus equal to CS^M and total R&D costs equal $2R$. Let $W^M(p_i)$ be the total surplus when the incumbent succeeds with project p_i. Now, the incumbent earns net profits equal to $\bar{\pi}^M - \left(\overline{F} - \Gamma(p_i)\right)$, the consumer surplus is CS^M and total R&D costs equal $2R$. Finally, let

$W^D(p_e)$ be the total surplus when the entrepreneur succeeds with project p_e and the incumbent's project fails, where superscript D denotes duopoly. The entrepreneur then earns net profit $\bar{\pi}^D - \left(\overline{F} - \Gamma(p_e)\right) - G$, the incumbent earns net profit $\bar{\pi}^D - \overline{F}$, the consumer surplus is CS^D and the total R&D costs equal $2R$. As noted in Section 3.1, increased competition in the market is assumed to increase the consumer surplus, $CS^D > CS^M$. Finally, there are positive (exogenous) externalities from research, ξ. To incorporate these spillovers of R&D in a simplified way, let the spillovers from R&D accrue across sectors in the economy and across time. Spillovers are also assumed independent of the probabilities of success. We then want to capture spillovers that the research process generates in terms of knowledge, the gains of research per se, which arise irrespective of the outcome of the particular project.

Formally, we define the total surpluses for the different outcomes as

$$\begin{cases} \bar{W}^M = \bar{\pi}^M - \overline{F} + CS^M - 2R + 2\xi, \\ W^M(p_i) = \bar{\pi}^M - \left(\overline{F} - \Gamma(p_i)\right) + CS^M - 2R + 2\xi, \\ W^D(p_e) = \bar{\pi}^D - \left(\overline{F} - \Gamma(p_e)\right) - G + \bar{\pi}^D - \overline{F} + CS^D - 2R + 2\xi. \end{cases} \tag{4.1}$$

First, we note that $W^M(p_i) - \bar{W}^M = \Gamma(p_i)$: if the incumbent innovates successfully, there is no increase in the consumer surplus, the only effect is a decrease in the incumbent's fixed cost of production. Consequently, there are no positive externalities benefiting the consumers resulting from innovation by the incumbent. Second, $W^D(p_e) - \bar{W}^M = \left[CS^D - CS^M\right] + \bar{\pi}^D - \overline{F} - G - \left[\bar{\pi}^M - \bar{\pi}^D\right]$: if the entrepreneur innovates, there is an increase in the consumer surplus equal to $CS^D - CS^M$, in addition to the effects on the two firms' profits. Hence, innovation by the entrepreneur confers a positive externality on consumers, which the social planner takes into account.

The expected total surplus when both firms invest in R&D is then:

$$E[W(p_i, p_e)] = p_i W^M(p_i) + (1 - p_i)\{p_e W^D(p_e) + (1 - p_e)\bar{W}^M\} \tag{4.2}$$

where the first term is the total surplus if the incumbent succeeds and the second term is the total surplus if the incumbent fails. The second term is composed of two parts: $(1-p_i)p_e W^D(p_e)$ is the surplus if the entrepreneur succeeds whereas $(1-p_i)(1-p_e)\bar{W}^M$ is the status quo surplus when neither firm succeeds.

In what follows, we will assume that the externalities from research ξ are such that the social planner prefers that both the incumbent and the entrepreneur invest in R&D. Let $E\left[W(p_i)\right] = p_i W^M(p_i) + (1 - p_i)\bar{W}^M$ be the expected welfare when only the incumbent does R&D. Then:

Assumption A2: $E[W(p_i, p_e)] > E[W(p_i, 0)]$

4.1. First-best choice for the entrepreneur

Let us start with the first-best choice of probability of success for the entrepreneur. It is given from the first-order condition $dE[W(p_i, p_e)]/dp_e = 0$. Using (4.2), this condition becomes

$$W^D(p_e) + p_e W^{D\prime}(p_e) = \bar{W}^M \tag{4.3}$$

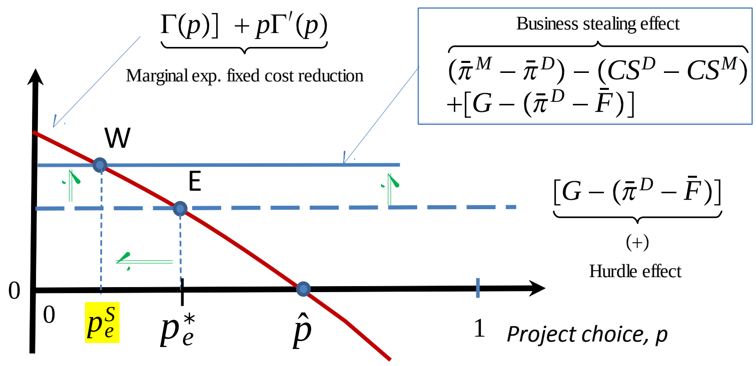

Figure 4.1: Comparing the first-best project (p_e^S) and the privately optimal project (p_e^*) for the entrepeneneur when the business stealing affect is positive, $\pi^M - \pi^D > CS^D - CS^M$.

where the left-hand side is the expected increase in the total surplus when the entrepreneur chooses a marginally safer project and the right-hand side is the cost in terms of replacing the status quo total surplus. Using the expressions for total surplus in (4.1), we can rewrite (4.3) as follows

$$\Gamma(p_e^S) + p_e^S \Gamma'(p_e^S) = \underbrace{[G - (\bar{\pi}^D - \overline{F})]}_{\substack{(+) \\ \text{Hurdle effect}}} + \underbrace{(\bar{\pi}^M - \bar{\pi}^D) - (CS^D - CS^M)}_{\substack{(?) \\ \text{Business stealing effect}}} \tag{4.4}$$

where p_e^S is the optimal choice of probability of success from a social point of view. Comparing (3.4) and (4.4), we see that whether or not the entrepreneur chooses a too safe or a too risky project depends on the second term in (4.4), labelled the business stealing effect. The first component of this business stealing effect, $(\pi^M - \pi^D)$, is the entry deterring effect. The second component, $CS^D - CS^M$, represents the increase in the consumer surplus that occurs when the market goes from monopoly to duopoly. If the incumbent loses more from entry than what consumers gain, $\pi^M - \pi^D > CS^D - CS^M$, the business stealing effect is positive and the entrepreneur ends up choosing too safe a project from a first-best perspective, $p_e^S < p_e^*$. This case is illustrated in Figure 4.1.

Proposition 4. *For any p_i, if the business stealing effect is positive, i.e if $\pi^M - \pi^D > \left(CS^D - CS^M\right)$, the entrepreneur chooses too safe projects from a social point of view: $p_e^S < p_e^*$.*

If the business stealing effect is positive, the costs of entry in terms of lost profit for the incumbent outweigh the benefits to consumers and a social planner would prefer the entrepreneur to take more risk and enter the market less often. Conversely, if the business stealing effect is negative, the benefits of entrepreneurial entry outweigh the costs in terms of lost profit for the incumbent and a social planner would prefer the entrepreneur to enter the market more often, which corresponds to choosing a higher probability of success.

4.2. First-best for incumbent

Let us now examine the first-best choice of the incumbent, which results from the first-order condition $dE[W(p_i, p_e)]/dp_i = 0$. Using (4.2), this condition becomes

$$W^M(p_i) + p_i W^{M\prime}(p_i) = p_e W^D(p_e) + (1 - p_e)\bar{W}^M \tag{4.5}$$

where the left-hand side is the expected increase in welfare when the incumbent chooses a marginally safer project and the right-hand side is a weighted replacement cost, where $p_e W^D(p_e)$ is the expected total surplus under entry and $(1 - p_e)\bar{W}^M$ is the expected total surplus under status quo.

Using the expressions for total surplus in (4.1), it will be useful to write (4.5) as follows

$$\Gamma(p_i^S) + p_i^S \Gamma'(p_i^S) = -p_e \underbrace{(\bar{\pi}^M - \bar{\pi}^D)}_{\text{Entry deterring}} + \underbrace{p_e[\underbrace{\bar{\pi}^D - \left(\overline{F} - \Gamma(p_e)\right) - G}_{\text{Entrant's profit}} + \underbrace{CS^D - CS^M}_{\text{Consumer gain}}]}_{\text{Entry effect }(+)} \tag{4.6}$$

In eq. (4.6), we denote the second part of the right-hand side the entry effect. It consists of the induced effect of entry by the entrepreneur on: (*i*) the entrepreneur's profit and (*ii*) the consumer surplus. Even though effects (*i*) and (*ii*) are considered by the social planner in order to determine the optimal probability of success for the incumbent, these effects are, however, not taken into account by the incumbent who only considers the first part of the right-hand side of (4.6), namely the business stealing effect.

If we examine the terms comprising the entry effect, it is clear that the first part, namely $\bar{\pi}^D - \left(\overline{F} - \Gamma(p_e)\right) - G$, is positive. If it were not, the entrepreneur would not enter the market. The second part, $CS^D - CS^M$, is also positive. Thus, comparing (3.8) to (4.6), it is clear that for the same level of $p_{e,}$ it must be the case that the incumbent chooses projects with a higher probability of success than what would the social planner. We can then formulate the following proposition:

Proposition 5. *For any given $p_e > 0$, the incumbent chooses too safe projects: $p_i^S < p_i^*$*

The intuition from this result is the following. There are no positive effects on consumers from innovation by the incumbent. On the contrary, since the entrepreneur can only enter in case the incumbent's project fails, innovation by the incumbent precludes entrepreneurial entry, which has a positive effect on consumers. Therefore, for a given value of p_e, such that $p_e > 0$, the social planner prefers the incumbent to choose riskier projects which succeed less often.

It will also be useful examine the incumbent's reaction function in the first best solution. Define this optimal probability of success for the incumbent as $p_i^S = \Psi_i(p_e)$. To examine the shape of $\Psi_i(p_e)$, first note that from (4.6), $\Psi_i(0) = R_i(0)$: the first best choice of the incumbent's project coincides with the market solution p_i^* if $p_e = 0$. Then, note that for $p_e > 0$, Proposition 5 implies that $\Psi_i(p_e) < R_i(p_e)$: for a given value of p_e, by ignoring the entry effect the incumbent chooses too safe a project from the social planner's point of view. Differentiating (4.6) in p_e

and p_i, we can also obtain an expression for the slope of the first-best choice

$$\frac{dp_i^S}{dp_e} = \Psi_i'(p_e) = \frac{\pi^D - \left(\overline{F} - \Gamma(p_e)\right) - G + p_e\Gamma'(p_e) - \{(\pi^M - \pi^D) - \left(CS^D - CS^M\right)\}}{2\Gamma'(p_i^*) + p_i^*\Gamma''(p_i^*)}.$$

Now, from (3.4), $\Psi_i'(p_e)$ can be re-written making use of the the first-order condition for the entrepreneur's project

$$\frac{dp_i^S}{dp_e} = \Psi_i'(p_e) = \frac{dE[W]/dp_e}{\left[2\Gamma'(p_i^*) + p_i^*\Gamma''(p_i^*)\right](1 - p_i^*)}. \tag{4.7}$$

Then, as shown in Figure 4.2, it follows from (3.4) and (4.7) that $\Psi_i(p_e)$ is U-shaped and reaches a minimum for $\Psi_e = p_e^S$. The properties of the function for the social planner's optimal choice of p_i^S can be summarized as follows:

Lemma 1. *(i) $\Psi_i(0) = R_i(0) = \hat{p}$, (ii) for $p_e > 0$, $\Psi_i(p_e) < R_i(p_e)$ and (iii) $\Psi_i(p_e)$ is U-shaped with $\Psi_i'(0) < 0$, $\Psi_i'(p_e^S) = 0$ and $\Psi_i'(p_e) > 0$ for $p_e > p_e^S$.*

4.3. When does the market provide too safe projects?

Next, we turn to the equilibrium outcomes, comparing $\{p_e^*, p_i^*\}$ chosen by the firms to $\{p_e^S, p_i^S\}$ chosen by the social planner. Proposition 4 shows that two cases can be identified, depending on whether the business stealing effect is positive or negative.

Suppose first that the business stealing effect is positive. From Proposition 4, we have that $p_e^S < p_e^*$. Together with Proposition 5, which shows that $p_i^S < p_i^*$, we find that the market solution implies that both the entrepreneur and the incumbent choose projects with too low risk. This case is shown in Figure 4.2. The first-best solution $\{p_e^S, p_i^S\}$ is given by the intersection of the vertical line Ψ_e, which defines the social planner's optimal choice of p_e^S, and the U-shaped function $\Psi_i(p_e)$, which occurs at point W in Figure 4.2. The market solution $\{p_e^*, p_i^*\}$, on the other hand, is once more given from the intersection of the reaction functions $R_i(p_e)$ and R_e, which occurs at point N. By construction, it must be the case that the first-best solution W is located south-west of the market solution N.

We can formulate the following Corollary:

Corollary 1. *If the business stealing effect is positive, $\pi^M - \pi^D - \left(CS^D - CS^M\right) > 0$, the market solution provides projects with too little risk, $p_e^S < p_e^*$ and $p_i^S < p_i^*$.*

If the business stealing effect is positive, the entrepreneur takes too little risk, from a social planner point of view, since it does not take into account that its entry into the market reduces the incumbent's profits. In addition, from Proposition 5, we have that the incumbent takes too little risk from a social planner point of view, since there are no benefits to consumers from innovation by the incumbent and, in addition, innovation precludes entrepreneurial entry. Hence, if the business stealing effect is positive, the market solution will provide projects with too little risk.

Suppose now that the business stealing effect is negative, such that $p_e^S > p_e^*$. Now, the market solution implies that the incumbent takes too little risk while the entrepreneur takes

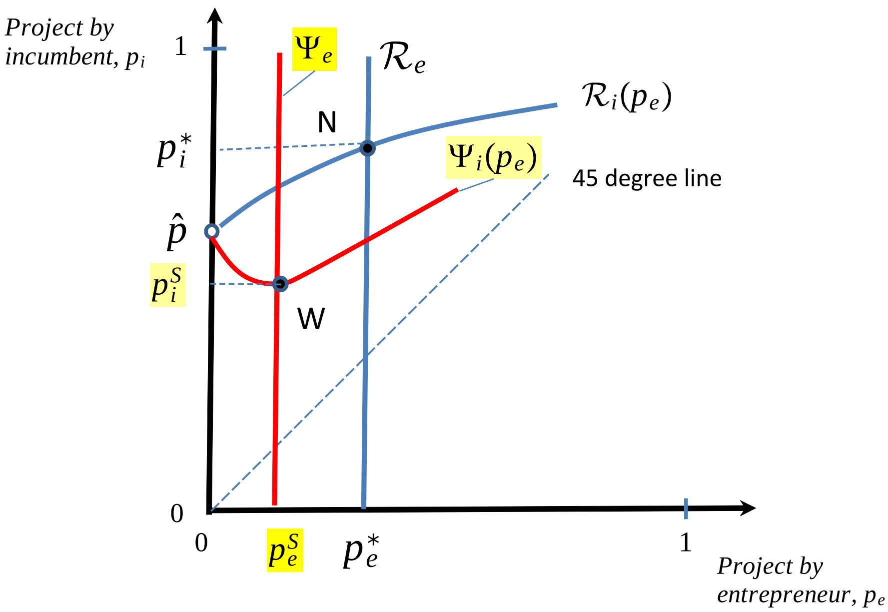

Figure 4.2: Comparing the first-best project choices (W) and Nash-equilibrium project choices (N) when the business stealing affect is positive, $\pi^M - \pi^D > CS^D - CS^M$.

too much risk and the net effect is ambiguous. To explore the scenario where the market provides too little risk in more detail, we will in the following example use a linear Cournot model which can give closed form expressions for the business stealing effect. Following Singh and Vives (1984), let us assume that the utility of a consumer is given by:

$$U(q_e, q_i, I) = aQ - \frac{1}{2}\left[q_i^2 + 2\gamma q_i q_e + q_e^2\right] + I \tag{4.8}$$

where q_i is the output of the incumbent, q_e is the output of the entrepreneur, $Q = q_e + q_i$ denotes total output, I is a composite good of other goods and a is a constant. The parameter γ measures the substitutability between products. If $\gamma = 0$, each firm has monopolistic power, whereas if $\gamma = 1$, the products are perfect substitutes. Firms have identical marginal costs c. We then show in the Appendix that the following Proposition applies:

Proposition 6. *In the Singh and Vives' (1984) model of Cournot competition with differentiated goods: (i) when goods are not too differentiated, i.e. if $\gamma \in (\frac{2}{3}, 1]$, the business stealing effect is positive, $\pi^M - \pi^D - (CS^D - CS^M) > 0$. As a result, the entrepreneur chooses too safe a research project, $p_e^S < p_e^*$, as does the incumbent, $p_i^S < p_i^*$. (ii) When goods are sufficiently differentiated, i.e. if $\gamma \in (0, \frac{2}{3})$, the business stealing effect is negative, $\pi^M - \pi^D - (CS^D - CS^M) < 0$, implying that the entrepreneur chooses too risky projects, $p_e^S > p_e^*$, while the incumbent chooses projects with too little risk $p_i^S < p_i^*$.*

In this example, entry will increase total output, while the incumbent will contract its output to dampen the reduction in product market price. The consumer surplus will then increase by adding consumers with decreasing willingness to pay, whereas the loss for the incumbent contracting its sales will occur at a constant price cost margin. In the homogenous goods case, this will cause the business stealing effect to be positive and, from Proposition 1, the market will provide projects with too little risk. However, when product differentiation increases, the entrepreneur steals less of the incumbent's profits upon entry and, in addition, creates a larger increase in the consumer surplus, implying that the business stealing effect is negative. Consequently, when goods are sufficiently differentiated, the business stealing effect becomes negative and the social planner prefers that the entrepreneur takes less risk. However, the incumbent still takes too little risk from a social welfare perspective.

A broader treatment of the conditions under which more break-through projects have smaller business stealing effects could be interesting avenue for future research. Some natural properties pointing in this direction are the fact that as a project succeeds more it reduces more the quantity of the rival and its mark-up, thus making the next marginal unit of profit shifting smaller. Another way would be to consider situations where more break-through projects are more differentiated, thereby generating less profit shifting while creating larger consumer surplus.

5. Entrepreneurial policies

In the last few decades, entrepreneurship has emerged as a key issue in the policy arena.[17] This marks a distinct break against traditional industrial policy which has focused on large established firms. An example of more pro-entrepreneurial policies is that of R&D subsidies targeted to small and medium sized enterprises, SMEs.[18] Other government policies are more geared towards supporting the commercialization of the invention. Examples of this type of policy are financial support for incubators, and loans specifically designed to facilitate the commercialization process in new firms.[19] In this section, we will use our model to examine these types polices affect the agents' R&D projects. We then turn to the policy chosen by the social planner.

Let us add a stage zero where the entrepreneur can decide to conduct R&D or abstain from doing R&D. From Assumption A2, the social planner wants the entrepreneur to conduct R&D, and enter the market if it succeeds. In addition, the planner can affect the entrepreneur's decisions by subsidizing the fixed R&D cost R by an amount r and/or the commercialization cost G by an amount s. We then assume that a subsidy is a lump-sum transfer between the government and the entrepreneur. The first best solution is therefore not altered. We can then write the reduced-form expected profit for the entrepreneur as follows:

$$E[\Pi_e(p_e^*, p_i^*)] = (1 - p_i^*)p_e^*[\pi^D - \left(\overline{F} - \Gamma(p_e^*)\right) - (G - s)] - (R - r) \tag{5.1}$$

In order to induce the entrepreneur to conduct R&D and enter when successful, it must be that entry is profitable in stage 3. Thus, the commercialization cost must fulfil:

[17] Recall footnote 2 in the Introduction that *The Economist* (14th March 2009) recently published a special report describing this phenomenon.

[18] A report by OECD (2007) shows that, in the year 2007, several countries offered tax subsidies for R&D targeted specifically at SMEs. Examples are: the UK, Canada, Japan, the Netherlands, Norway and Poland.

[19] Recently, there has been a substantial increase in spending on such policies. For example, in 2009, the US Small Business Administration had approved over $13 billion in loans and $2.7 billion in surety to small businesses in a year. (Summary of Performance and Financial Information, US Small Business Administration, 2009).

$$G \leq \bar{G}(s) = \pi^D - \left(\overline{F} - \Gamma(p_e^*)\right) + s. \tag{5.2}$$

Furthermore, it must be profitable for the entrepreneur to take on the investment cost R. From (5.1) and (5.2), the R&D cost must fulfil:

$$R \leq \bar{R}_E(r, s) = p_e^*(1 - p_i^*)[\underbrace{\pi^D - \left(\overline{F} - \Gamma(p_e^*)\right) + s}_{\bar{G}(s)} - G] + r. \tag{5.3}$$

Let us then assume that the entrepreneurial R&D is not profitable without subsidies, while the incumbent always conducts R&D:

Assumption A3: $R > \bar{R}_E(0, 0)$ and $G < \bar{G}(0)$

Under Assumption A3, only the incumbent does R&D. From (3.8), the incumbent's will then choose the cost-efficient project, $p_i^* = R_i(0) = \hat{p}$.

R&D subsidies Let us first examine subsidies to R&D. An R&D subsidy r paid before the project choice in stage 1 then implies that the entrepreneur starts to invest in R&D, $R < \bar{R}_E(r, 0)$, choosing the project p_e^*, given from (3.4). Since projects are strategic complements for the incumbent $R_i'(p_e) > 0$ as shown in Proposition 2, this will induce the incumbent to choose a safer project, $p_i^* > \hat{p}$. From the entry-deterring effect, the incumbent can increase its expected profit when choosing a safer project as this reduces the expected loss from entry.

We have the following Lemma.

Lemma 2. *Let $R > \bar{R}_E(0, 0)$ so that only the incumbent innovates, $p_i^* = \hat{p}$. Then, when the entrepreneur has been subsidized by an amount r such that $R < \bar{R}_E(r, 0)$, it will start undertaking R&D choosing the project p_e^* , and the incumbent responds to the entrepreneur's R&D investment by choosing an R&D project with a higher probability of success, $p_i^* > \hat{p} > p_e^*$.*

Commercialization subsidies Let us now examine subsidizing commercialization though a subsidy s to the entry cost G in stage 3. As this policy implies that $R < \bar{R}_E(0, s)$, the same outcome is reached: the entrepreneur invests into R&D. Proposition 1 then tells us that the entrepreneur will respond by choosing a safer project (a project with less breakthrough potential in terms of lower quality) and from Proposition 2 the incumbent will respond by also choosing a project with a lower level of risk. Thus, compared to the policy subsidizing R&D, the commercialization subsidy will induce both the entrepreneur as well as the incumbent to choose safer projects.

Thus, we can state the following Lemma:

Lemma 3. *Suppose an R&D subsidy r or that a commercialization subsidy s can induce the entrepreneur to invest into R&D, $R < \bar{R}_E(r, 0)$ and $R < \bar{R}_E(0, s)$. Then, both agents will choose safer projects (with less potential quality if they succeed) under the subsidy to commercialization as compared to when the R&D subsidy is used, $p_h^*|_{r>0=s} < p_h^*|_{s>0=r}$ for $h = \{e, i\}$.*

In sum, subsidy policies can be used to induce the entrepreneur to conduct R&D which will increase welfare from Assumption A2. However, this will also influence the project choice by the incumbent. When a policy aimed at subsidizing entry costs is used, it will affect the type of R&D project chosen by the entrepreneur which in turn affects the project that the incumbent firm chooses. We will now use these results to make some observations on optimal policy.

5.1. When should entrepreneurial R&D be subsidized and entry taxed

From Proposition 4, we know that how the market outcome $\{p_e^*, p_i^*\}$ differs from the first best first-best $\{p_e^S, p_i^S\}$ will depend on the effect that entry by the entrepreneur has on consumers surplus and on the incumbent's profit, as measured by the aggregate business stealing effect, $\pi^M - \pi^D - \left(CS^D - CS^M\right)$.

Suppose that the business stealing effect is positive. As shown in the Appendix, this may arise when the incumbent's and the entrant's products are close substitutes, generating a tough product market competition. Corollary 1 then shows that the entrepreneur - as well as the incumbent - will choose too safe projects from a social point of view. The planner should then tax entry. To see this, define the axillary variable $\tilde{G} = G - s$. Then, differentiating the expected welfare and evaluating at the Nash-equilibrium $\{p_e^*, p_i^*\}$ (and making use of eqs. (3.5), (3.9) , (4.4), (4.6) and (5.1)), yields:

$$\frac{dE[W(p_e^*, p_i^*)]}{ds} = \left[\underbrace{\frac{\partial E[W(p_e^*, p_i^*)]}{\partial p_e}}_{\text{(-)}} + \underbrace{\frac{\partial E[W(p_e^*, p_i^*)]}{\partial p_i}}_{\text{(-)}} \underbrace{\mathcal{R}_i'(p_e^*)}_{(+)}\right] \underbrace{\frac{dp_e^*}{dG}}_{(-)} \underbrace{\frac{d\tilde{G}}{ds}}_{(-)} < 0 \tag{5.4}$$

The optimal entry tax $s^S < 0$ is then given from $\frac{dE[W(p_e^*, p_i^*)]}{dt} = 0$, given $G < \bar{G}(s^S)$, otherwise the tax $s < 0$ should be set such that $G = \bar{G}(s)$. Figure 5.1 illustrates this graphically: In Figure 5.1(i), a tax ($t = -s > 0$) on entry increases the hurdle effect, inducing the entrepreneur to choose higher risk. Then, as shown in Figure 5.1(ii), the incumbent will react by choosing a more risky project as well, and the market outcome will shift from point N to Ñ, which is closer to the first-best solution W (which is unaffected by a subsidy). A subsidy to entry, on the other hand, will take the market solution further away from the first best solution; moving point N further to the north-east which increases the distance from the first-best solution W.

In order to have the entrepreneur conducting R&D, the planner will complement the entry tax $s < 0$ with an R&D subsidy $r > 0$ such that $R < \bar{R}_E(r, s)$. We can now formulate this result as follows:

Proposition 7. *Suppose that Assumption A3 holds and $R > \bar{R}_E(0, 0)$. If the aggregate business stealing effect is positive $\pi^M - \pi^D - \left(CS^D - CS^M\right) > 0$, the optimal policy is to subsidize R&D by the entrepreneur by an amount $r > 0$ and tax entry $t = -s > 0$ such that $R < \bar{R}_E(r, s)$.*

On a final note, even if the entrepreneur would conduct R&D without a subsidy r, if the aggregate business stealing effect is positive, the planner will always want tax entry in order to have the private incentives regarding project choices in line with social incentives.

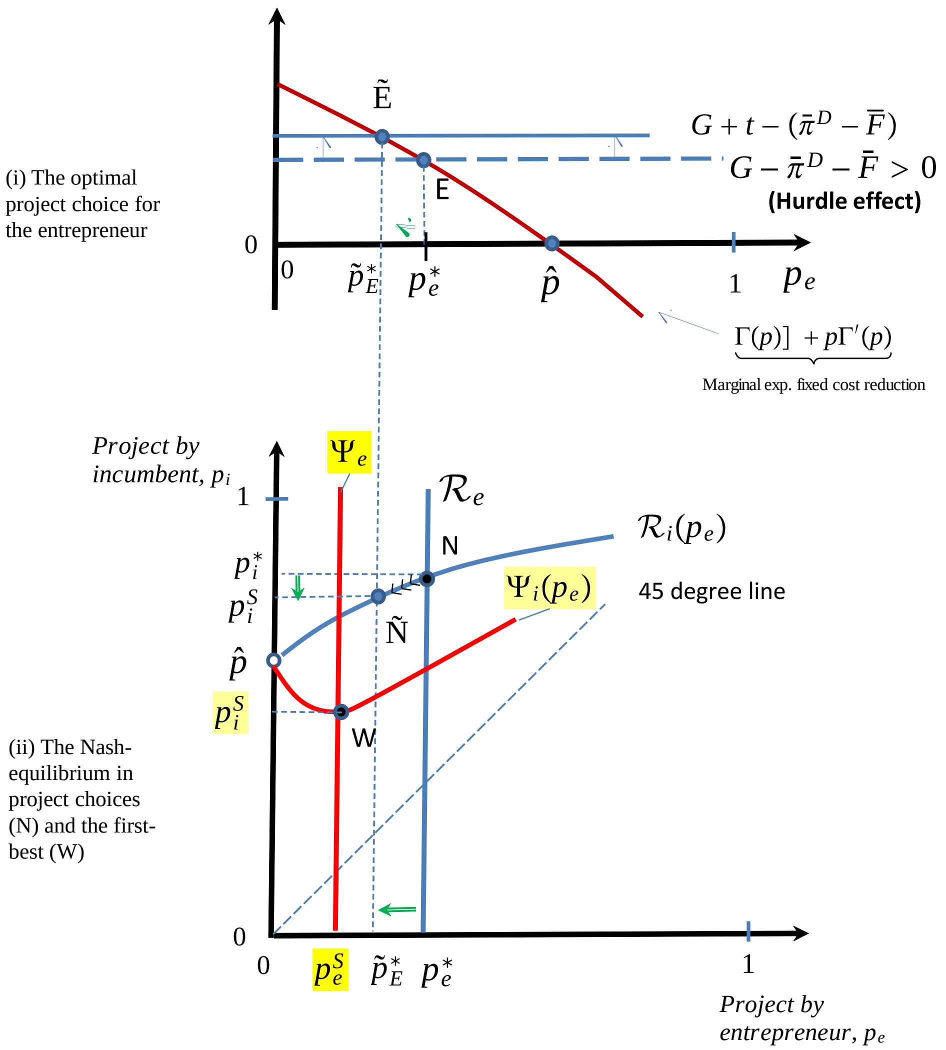

Figure 5.1: Asmall tax on entry will increase welfare when the business stealing affect is positive, $\pi^M - \pi^D > CS^D - CS^M$.

Summing up, the social planner takes the externalities ξ from research into account and, therefore, finds it optimal to subsidize the fixed cost of R&D. However, if the business stealing effect is positive, the social planner wants the entrepreneur to conduct R&D, which generates positive effects for society as a whole, but also to choose more risky projects, implying that the entrepreneur will actually enter the market less often.

6. Robustness of the hurdle effect

A main finding in this paper is the entrepreneurship hurdle effect: Entrepreneurs choose more risky R&D projects than incumbents since they then reduce the expected net commercialization costs.

In this section, we generalize this result to a model with marginal cost reductions and relax some of the assumptions made in the benchmark model. Firstly, we analyze the case when the entrepreneur can enter the market and both firms succeed. Secondly, we consider the cases where a second entrepreneur or a second incumbent exist. Finally, we also allow the entrepreneur to commercialize its invention through sale to the incumbent, instead of entering with it into the product market. By so doing, we show that it is still true that as the commercialization cost increases, the entrepreneur has more incentives to embark on R&D projects with a low probability of success and a high payoff (innovations with high quality, i.e. breakthrough innovations).

6.1. Generalization

Let us now use a more general formulation of R&D projects, where an invention can take several forms, which all increase the firm profits: it can be a new product, a product of higher quality or a new or improved production process. As before, each project is characterized by a probability of success $p_l \in (0,1)$. Let $k_l = k(p_l)$ denote the corresponding project quality, where a higher quality increases the pay-off associated with a successful invention $\frac{d\pi}{dk_l} > 0$ but project quality and probability of success are inversely related, $\frac{dk}{dp_l} < 0$. Hence, a project with a lower probability of success is then associated with a higher quality and a higher payoff, whereas a project with a higher probability of success is associated with a lower quality and a lower payoff. That is, the more profitable is an invention, the more difficult it is to develop, $\frac{d\pi(p_l)}{dp_l} = \frac{d\pi}{dk}\frac{dk}{dp_l} < 0$. We define a reduced-form pay-off function as $\pi(p_l) \equiv \pi\left(k(p_l)\right)$. In addition, in order to have a well-behaved model, we will assume that the profit function has the following properties:

Assumption A4: Monopoly profits. (i) $\pi(p_l) \in (\bar{\pi}, \infty)$, (ii) $\pi'(p_l) < 0$ and $\pi'(p_l) > -\infty$, and (iii) $\frac{d^2(p_l\pi(p_l))}{dp_l^2} = 2\pi'(p_l) + p_l\pi''(p_l) < 0$

Assumption A4(i) states that a successful project always gives a higher profit than the incumbent's status-quo profit, while the profit is bounded from infinity. Assumption A4(ii) states that a project with a higher probability of success has a corresponding lower profit. Finally, Assumption A4(iii) states that the expected pay-off function $p_l\pi(p_l)$ is strictly concave, implying that $p_l^* = \arg max_{p_l} p_l\pi(p_l) \in (0,1)$.

We define the duopoly profits as follows: $\pi_i^D(p_e)$ is the incumbent's duopoly profit, and $\pi_e^D(p_e)$ is the entrepreneur's duopoly profit, where the superscript D denotes duopoly. Note that the duopoly profits are independent of p_i, since the duopoly competition occurs only if the incumbent's R&D project has failed. Moreover, we make the following assumption about duopoly profits:

Assumption A5: Duopoly profits. (i) $\pi_i^D(p_e) \in (0, \bar{\pi})$, (ii) $\frac{d\pi_i^D(p_e)}{dp_e} = \pi_i^{D\prime}(p_e) \in (0, \infty)$, and (iii) $\frac{d^2(p_e\pi_e^D(p_e))}{dp_e^2} = 2\pi_e^{D\prime}(p_e) + p_e\pi_e^{D\prime\prime}(p_e) < 0$.

Assumption A5(i) states that the incumbent's profit is reduced by entry, but it is positive. Assumption A5(ii) states that the incumbent's profit increases when the entrepreneur chooses a project that is more likely to succeed (since the associated quality is lower). Finally, Assumption A5(iii) states that the expected duopoly profit for the entrepreneur is strictly concave.

In what follows, we characterize the firm's optimal behavior in this extended setting.

6.2. The entrepreneur's optimal R&D project

The entrepreneur's expected payoff is given by:

$$\mathrm{E}[\Pi_e] = p_e(1 - p_i)[\pi_e^D(p_e) - G] - R \tag{6.1}$$

which is identical to (3.2), apart from the formulation of profits from a successful invention. The first-order condition, $dE[\Pi_e]/dp_e = 0$, is then:

$$\pi_e^D(p_e^*) + p_e^*\pi_e^{D\prime}(p_e^*) = G \tag{6.2}$$

which differs from (3.4) only by the constant terms $\bar{\pi}^D$ and $\overline{F}$.

Differentiating (6.2) in p_e and G, we obtain $\frac{dp_e^*}{dG} < 0$ just as in the benchmark model with fixed cost innovation.

6.3. The incumbent's optimal R&D project

Turning to the incumbent, we have that the incumbent's expected payoff is given by:

$$\mathrm{E}[\Pi_i] = p_i\pi(p_i) + (1 - p_i)[p_e\pi_i^D(p_e)(1 - p_e)\bar{\pi}] - R \tag{6.3}$$

which is once more identical to (3.6), apart from the formulation of profits from a successful invention. The corresponding first-order condition, $dE[\Pi_i]/dp_i = 0$, is

$$\pi(p_i^*) + p_i^*\pi'(p_i^*) = \bar{\pi} - p_e[\bar{\pi} - \pi_i^D(p_e)]. \tag{6.4}$$

Compared to the expression in (3.8), the term on the r.h.s now contains two terms: (i) the loss of the status quo profit $\bar{\pi}$ which we denote the monopoly replacement effect; and (ii) the duopoly profit (when the entrepreneur succeeds and the incumbent fails) $\pi_i^D(p_e)$, which we denote the duopoly replacement effect, where the first effect is absent in the fixed cost model, since the incumbent's invention only affects the fixed cost of production and not the good sold.

In the main model, Proposition 3 shows that $p_e^* < p_i^*$. In this case, comparing the first-order condition for the entrepreneur and that of the incumbent, (6.2) and (6.3), we note that the left-hand side of the expressions is strictly decreasing in p_l, $l \in \{e, i\}$. Turning to the right-hand sides, we cannot determine whether $p_e^* < p_i^*$ or not. The intuition is that the incumbent now takes into account that by innovating, he will to some extent replace his own profits, which may make him choose a project with a higher risk than that of the entrepreneur. However, we have that $\lim_{F \to \pi_e^D(0)} p_e^*(G) = 0$. When the entry cost for the entrepreneur G approaches $\pi_e^D(0)$, the project chosen by the entrepreneur approaches $p_e^* = 0$. In the limit, the incumbent acts as a monopolist, choosing the success probability $p_i^M > 0$. Consequently, we can show that when $F \to \pi_e^D(0)$, then $p_i^* > p_e^*$.

The entrepreneur's reaction function $R_e = p_e^*$ is then given from equation (6.2), while equation (3.8) implicitly defines the incumbent's reaction function $R_i(p_e)$, whose slope is given by:

$$\mathcal{R}_i'(p_e) = -\frac{\bar{\pi} - \pi_i^D(p_e) - p_e \pi_i^{D'}(p_e)}{2\pi'(p_i^*) + p_i^* \pi''(p_i^*)} \tag{6.5}$$

and comparing it to (3.9), we see that the sign of the reaction function is now ambiguous.

Turning to the analysis of socially optimal project choices, expected welfare is

$$E[W] = p_i W(p_i) + (1 - p_i)[p_e W^D(p_e) + (1 - p_e)\bar{W}] \tag{6.6}$$

where $\bar{W} = \bar{C}S + \bar{\pi} - 2R + 2\xi$, $W(p_i) = CS(p_i) + \pi(p_i) - 2R + 2\xi$ and $W^D(p_e) = CS^D(p_e) + \pi_e^D(p_e) - G + \pi_i^D(p_e) - 2R + 2\xi$. The first-order condition $dE[W]/dp_i = 0$ then determines the incumbent's first best project choice $p_i^S = \Psi_i(p_e)$ and, $dE[W]/dp_e = 0$, determines the entrepreneur's first-best project choice p_e^S.

In order to show the coherence between the model with fixed cost innovation and this more general one, we use the linear Cournot model with homogenous goods, i.e. let $\gamma = 1$ in eq. (8.1) in the Appendix. Then, assume that a successful invention leads to a reduction in the marginal cost level. Making a distinction between firm types, we then have:

$$c_i^{Nosucc} = c, \qquad c_i^{Succ} = c - (1 - p_i), \qquad c_e^{Succ} = c - (1 - p_e) \tag{6.7}$$

where we once more note the trade-off faced by firms: choosing a safer project reduces the marginal cost less. Reduced-form profits are once more quadratic in output, $\pi_j = \left[q_j^*\right]^2$ and the optimal quantities are given by $\bar{q} = \frac{\Lambda}{2}$, $q_i^*(p_i) = \frac{\Lambda+1-p_i}{2}$, $q_i^D(p_e) = \frac{\Lambda-(1-p_e)}{3}$, and $q_e^D(p_e) = \frac{\Lambda+2(1-p_e)}{3}$, where $\Lambda = a - c > 1$. Inserting these profits into (6.2) and (6.4), we obtain

$$p_e^*(\Lambda, G) = \tfrac{\Lambda+2}{3} - \tfrac{\sqrt{\Lambda^2+4\Lambda+27G+4}}{6}, \;\; p_i^*(\Lambda, G) = \tfrac{2\Lambda+2}{3} - \tfrac{\sqrt{\Lambda^2+2\Lambda+12\Phi(\Lambda,G)+11}}{3} \tag{6.8}$$

where $\Phi(\Lambda, G) = p_e^*(\Lambda, G)\left(\frac{\Lambda-(1-p_e^*(\Lambda,G))}{3}\right)^2 + (1 - p_e^*(\Lambda, G))\left(\frac{\Lambda}{2}\right)^2$.

We can then derive the following results:

Lemma 4. *In the Cournot model described with homogenous goods, (i) $p_e^* < p_i^*$, (ii) if $\Lambda = a - c > 8/5$, $R_i'(p_e) > 0$, (iii) if $\Lambda = a - c \geq 2$, $p_e^S < p_e^*$.*

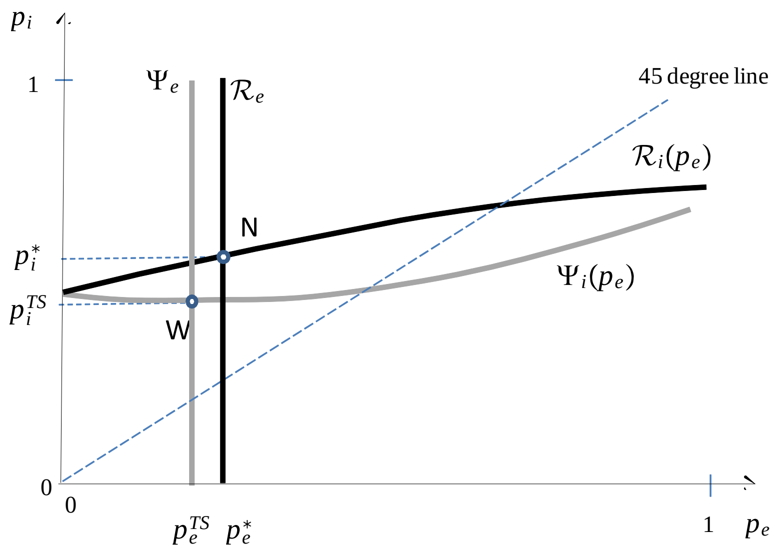

Figure 6.1: The variable cost saving model. The Nash equilibrium is given in point N and the first best solution is given in point S. Parameter values: $\Lambda = a - c = 2, G = 1$.

Hence, if the net willingness to pay $\Lambda = a - c$ is not too low (which implies that we are not too close to monopoly), the entrepreneur will undertake a project with higher risk than that chosen by the incumbent, and the two firms' success probabilities are strategic complements. In addition, the entrepreneur chooses too little risk from society's point of view; $p_e^S < p_e^*$. That is, the central results in Propositions 2 and 3, which were derived for the benchmark model where an innovation consists of a fixed cost reduction, also hold in this model. In addition, we can show that with homogeneous goods, the business stealing effect is positive and the result regarding the entrepreneur's project choice in Corollary 5 holds; $p_e^S < p_e^*$. An illustration is given in Figure 6.1. Consequently, the main mechanisms in the model with fixed cost innovation remain valid when innovations lead to variable cost reductions in a linear Cournot model.

6.4. Commercialization through sale

Hitherto, we have assumed that the entrepreneur can only commercialize her invention through entry into the product market. However, an alternative is to sell the invention to the incumbent. If the entrepreneur faces a transaction cost associated with a sale, then the entrepreneurial commercialization hurdle effect remains. We can show that in response to an increase in the transaction cost, the entrepreneur chooses an R&D project with a higher probability of success and a lower payoff. Suppose now that if the entrepreneur's research project succeeds, the invention can only be implemented if it is sold to the incumbent firm. In this scenario, the commercialization cost takes the form of a fixed transaction cost $T \geq 0$ that the entrepreneur has to pay in case of sale. If both firms are successful, it is assumed that the incumbent always chooses to implement its own invention and, consequently, the entrepreneur's profit is zero. Hence, the entrepreneur can earn a positive profit if her selected research project is the only one that succeeds, but not otherwise. The firms are assumed to share the surplus created by the invention according to the Nash Bargaining solution, where the incumbent and the entrepreneur have bargaining strengths θ and $1-\theta$, respectively, $\theta \in (0,1)$. The incumbent's status-quo profit, $\bar{\pi}$, is its outside option in the bargaining. To make the problem interesting, we assume that the profit net of transaction costs is higher than the status-quo profit: $\pi(p_n) - T > \bar{\pi}, n \in \{i, e\}$. The entrepreneur's outside option is zero.

The entrepreneur's expected payoff when playing this game is given by:

$$\mathrm{E}[\Pi_e] = p_e(1-p_i)\,(1-\theta)\,(\pi(p_e) - T - \bar{\pi}) - R_S. \tag{6.9}$$

If the entrepreneur succeeds and the incumbent fails, the incumbent will acquire the entrepreneur's invention and obtain the profit $\pi(p_e)$ from selling it on the market. The entrepreneur gets a share $(1-\theta)$ of the surplus created by the invention net of transaction costs and the incumbent's outside option, which is $\pi(p_e) - T - \bar{\pi}$. The entrepreneur pays a fixed R&D cost R_S in order to start a project. Let us define a function $R_S^* \equiv f(p_i, p_e, \pi(p_e), T, \bar{\pi})$, where the subscript S denotes sale, such that for $R_S = R_S^*$, $E[\Pi_e] = 0$. Then, two different regimes might arise in equilibrium. If $R_S \geq R_S^*$, the entrepreneur chooses not to perform any R&D. If instead $R_S < R_S^*$, then it is optimal for the entrepreneur to choose an equilibrium value for p_e, p_e^*, implicitly defined by the following first-order condition:

$$\frac{\partial \mathrm{E}[\Pi_e]}{\partial p_e} = \pi(p_e^*) - T - \bar{\pi} + p_e^* \pi'(p_e^*) = 0, \tag{6.10}$$

where the first three terms capture the direct effect on the expected surplus, $\pi(p_e) - T - \bar{\pi}$, of choosing a project with a different probability of success. The fourth term captures the indirect effect on the expected surplus of choosing a project with a different payoff. Differentiating the entrepreneur's first-order condition in p_e and T, it may be concluded that:

$$\frac{dp_e^*}{dT} = \frac{1}{2\pi'(p_e^*) + p_e^* \pi''(p_e^*)} < 0, \tag{6.11}$$

where $2\pi'(p_e^*) + p_e^* \pi''(p_e^*) < 0$ as a result of Assumption A1. If T increases, the entrepreneur will reduce its equilibrium success probability p_e^* since this reduces the expected transaction cost $p_e(1-p_i)\,(1-\theta)\,T$ and, at the same time, increases the payoff $\pi(p_e)$ of its research project if it succeeds. Consequently, our result that the entrepreneur chooses an R&D project with a lower probability of success and higher payoff if the commercialization cost increases continues to hold if the entrepreneur commercializes the invention through sale instead of entry.

6.5. The entrepreneur always enters if it succeeds

In the baseline model, it is assumed that there is only room for the entrepreneur in the market in case the incumbent's research project has failed. Now, we examine the case when the entrepreneur always enters the market if it succeeds. The entrepreneur's expected payoff is then given by:

$$\mathrm{E}[\Pi_e] = p_e(1-p_i)[\pi_e^D(p_e) - F] + p_e p_i[\pi_e^D(p_e, p_i) - F] - R_E \tag{6.12}$$

where the corresponding first-order condition is given by:

$$\pi_e^D(p_e^*) - F + p_e^*\pi_e^{D\prime}(p_e^*) + p_i\{\pi_e^D(p_e,p_i) - \pi_e^D(p_e) + p_e[\pi_{e,p_e}^{D\prime}(p_e^*,p_i) - \pi_e^{D\prime}(p_e^*)]\} = 0. \quad (6.13)$$

From (6.13) it follows directly that $\frac{dp_e^*}{dF} < 0$. Note also that:

$$\lim_{F\to\pi_e^D(p_e,p_i)} \mathrm{E}[\Pi_e] = p_e(1-p_i)[\pi_e^D(p_e) - F] - R.$$

So with F approaching $\pi_e^D(p_e,p_i)$ the previous analysis applies. The incumbent's expected payoff is given by:

$$\begin{aligned} \mathrm{E}[\Pi_i] &= p_i(1-p_e)\pi(p_i) + p_e(1-p_i)\pi_i^D(p_e) \\ &\quad + p_i p_e \pi_i^D(p_i,p_e) + (1-p_i)(1-p_e)\bar{\pi} \end{aligned} \quad (6.14)$$

with the first-order condition

$$(1-p_e)\left[\pi(p_i^*) + p_i^*\pi'(p_i^*) - \bar{\pi}\right] + p_e\left[\pi_i^D(p_i,p_e) + p_i\pi_{i,p_i}^{D\prime}(p_i^*,p_e) - \pi_i^D(p_e)\right] = 0. \quad (6.15)$$

Note that since $\frac{dp_e^*}{dF} < 0$ there must exist an F such that $\lim_{F\to\pi_e^D(p_e,p_i)} p_e^*(F) = 0$. But then (6.15) becomes:

$$\pi(p_i^*) + p_i^*\pi'(p_i^*) - \bar{\pi} = 0 \quad (6.16)$$

Thus, when the entry costs are sufficiently high, the entrepreneur will choose more risky projects (higher quality) than the incumbent.

6.6. Adding an entrepreneur

Let us now examine the case with one incumbent and two entrepreneurs, where the entrepreneurs both face an entry cost F if they enter the market. Let us retain the assumption that if both entrepreneurs are successful with their R&D projects while the incumbent fails, the triopoly expected profits an entrant would obtain are not sufficient to compensate for the fixed cost F. Further assume that entrepreneurs cannot enter if the incumbent is successful and that there is a lottery with equal probability of entry if both entrepreneurs succeed when the incumbent fails.

Then, the expected profit for an entrepreneur (for entrepreneur 1, e_1, say) is:

$$\mathrm{E}[\Pi_{e_1}] = (1 - \frac{1}{2}p_{e_2})(1-p_i)p_{e_1}[\pi_e^D(p_{e_1}) - F]. \quad (6.17)$$

Note that the success probability associated with the optimal project is $p_{e_1}^* = \arg\max_{p_{e_1}}[(1 - \frac{1}{2}p_{e_2})(1-p_i)p_{e_1}[\pi_e^D(p_{e_1}) - F]$ which is equal to p_e^* where $p_e^* = \arg\max_{p_e}[(1-p_i)p_e[\pi_e^D(p_e) - F]$.

The incumbent's expected profit is:

$$\begin{aligned} \mathrm{E}[\Pi_i] &= p_i(1-p_{e_1})(1-p_{e_2})\pi(p_i) + (1-p_i)\left[p_{e_1}(1-p_{e_2})\pi_i^D(p_{e_1}) + p_{e_2}(1-p_{e_1})\pi_i^D(p_{e_2})\right] \\ &\quad + p_i\left[p_{e_1}p_{e_2} + p_{e_1}(1-p_{e_2}) + p_{e_2}(1-p_{e_1})\right]\pi(p_i) \qquad (6.18) \\ &\quad + (1-p_i)(1-p_{e_1})(1-p_{e_2})\bar{\pi}. \end{aligned}$$

For a sufficiently high F, both entrepreneurs will choose a project with very high quality, i.e. $\lim_{F\to\pi_e^D(p_{e_v})} p_{e_v}^*(F) = 0$, $v \in \{1,2\}$. The incumbent's project is then given as $p_i^* = \arg\max_{p_i} E[\Pi_i] = \arg\max_{p_i}[p_i\pi(p_i) + (1-p_i)\bar{\pi}]$, where we once more have $p_i^* > 0$. Thus $p_i^* > p_{e_v}$, and it follows that for a sufficiently large F, the entrepreneurs choose more breakthrough inventions than the incumbent.

6.7. Adding an incumbent

Let us now add another incumbent, so that the market consists of two incumbents and one entrepreneur. The entrepreneur faces an entry cost F if it enters the market. Let p_{i_j} denote the success probability corresponding to the research project selected by the incumbent j, $j = 1,2$. In line with the previous analysis, we will assume that the entrepreneur only enters the market in case it is successful with the chosen research project while both incumbents fail. When this is the case, $\pi_e^T(p_e)$ denotes the entrepreneur's triopoly profit. As before, this (triopoly) profit is independent of the incumbents' success probabilities since oligopoly competition only occurs when incumbents' R&D projects have failed. The entrepreneur's expected profit is then given by

$$\mathrm{E}[\Pi_e] = p_e(1-p_{i_1})(1-p_{i_2})[\pi_e^T(p_e) - F] - R_F. \qquad (6.19)$$

So, if R_F is sufficiently small that the entrepreneur chooses to invest, it will choose an equilibrium value for p_e, p_e^*, implicitly defined by the following first-order condition:

$$\frac{\partial \mathrm{E}[\Pi_e]}{\partial p_e} = \pi_e^T(p_e^*) - F + p_e^*\pi_e^{T\prime}(p_e^*) = 0. \qquad (6.20)$$

Now, differentiating the previous first-order condition in p_e and F, it may be concluded that:

$$\frac{dp_e^*}{dF} = \frac{1}{2\pi_e^{T\prime}(p_e^*) + p_e^*\pi_e^{T\prime\prime}(p_e^*)} \qquad (6.21)$$

which turns out to be negative since $2\pi_e^{T\prime}(p_e^*)+p_e^*\pi_e^{T\prime\prime}(p_e^*) < 0$ (Assumption A4 holds for $\pi_e^T(p_e^*)$). Hence, the commercialization hurdle effect remains when we extend the model to encompass more than one incumbent. Moreover, it remains true that high fixed costs F will force the entrepreneur to choose a very risky strategy, $\lim_{F\to\pi_e^T(p_e)} p_e^*(F) = 0$.

7. Empirical evidence of the hurdle effect

We now turn to providing empirical evidence for the entrepreneurial hurdle effect. The empirical predictions from the hurdle effect are illustrated in Figure 7.1 using, for illustrative convenience, the benchmark fixed cost savings model.

Figure 7.1(iii) shows the effect on the optimal project choice of the entrepreneur resulting from an increase in the commercialization cost. From Proposition 1, the entrepreneur responds to an increase in the entry cost to $\tilde{G} > G$ by choosing a project with a lower probability of success, $\tilde{p}_E^* < p_E^*$, as shown by points E and Ẽ. A lower success probability then reduces the net expected commercialization cost (the hurdle effect).

Figure 7.1(ii) then shows that the expected fixed cost reduction will decrease when the entrepreneur is induced to choose a more uncertain project: as shown by points E and Ẽ, $\tilde{p}_E^*\Gamma(\tilde{p}_E^*) < p_E^*\Gamma(p_E^*)$. Intuitively, when faced with a stronger hurdle effect the entrepreneur's optimal project $\tilde{p}_E^*$ is now further away from the cost-efficient project, $\hat{p} = \arg\max_p p\Gamma(p)$.

Finally, Figure 7.1(i) shows that - conditional on succeeding - the increase in the entry (commercialization) cost will create a larger fixed cost reduction, i.e. $\Gamma(\tilde{p}_E^*) > \Gamma(p_E^*)$. As shown by points E and Ẽ, this follows from the fact that projects which are less likely to succeed provide larger fixed cost reduction if they do succeed, since $\Gamma'(p) < 0$.

To take the model to the data, let us think of the amount of fixed cost reductions, or the amount of marginal cost reductions, that a successful innovation brings as the quality of the innovation, k. For instance, in the fixed costs savings model, $k(p) = \Gamma(p)$. We assume that $k = 0$ when an innovation fails, $k'(p) < 0$ when it succeeds and that the expected quality $E[k] = pk(p)$ is strictly concave in project choice p. Under these assumptions in the fixed cost savings model, we summarize the empirical predictions of the hurdle effect in the following proposition.

Proposition 8. *Let the quality of an innovation be $k(p)$ with $k'(p) < 0$ and $k = 0$ when an innovation fails. In addition, let $pk(p)$ be strictly concave in p. Suppose that Proposition 1 holds. Then, when the entry cost G increases:*

(i) the probability of success p_E^*, decreases.

(ii) the quality given that the innovation is successful $k(p_E^*)$, increases.

(iii) the expected quality of the invention, $E[k(p)] = p_E^* k(p_E^*)$, decreases.

7.1. Data and variable definitions

Data To investigate whether observed patent data satisfies the predictions set forth in Proposition 8, we use data collected from a survey of Swedish patents granted to small firms and individual inventors in 1998.[20] In that year, 1082 patents were given to small (less than 1000 employees) Swedish firms and individuals.[21] Information about inventors, applying firms, their addresses and the application date for each patent was obtained from the Swedish Patent and

[20] A further description of the data can be found at http://www.ifn.se/web/Databases_9.aspx and in Svensson (2007).

[21] In 1998, there were in total 2760 patents granted in Sweden - 776 of these to foreign firms, 902 to large Swedish firms with more than 1000 employees and 1082 to Swedish individuals and firms with less than 1000 employees.

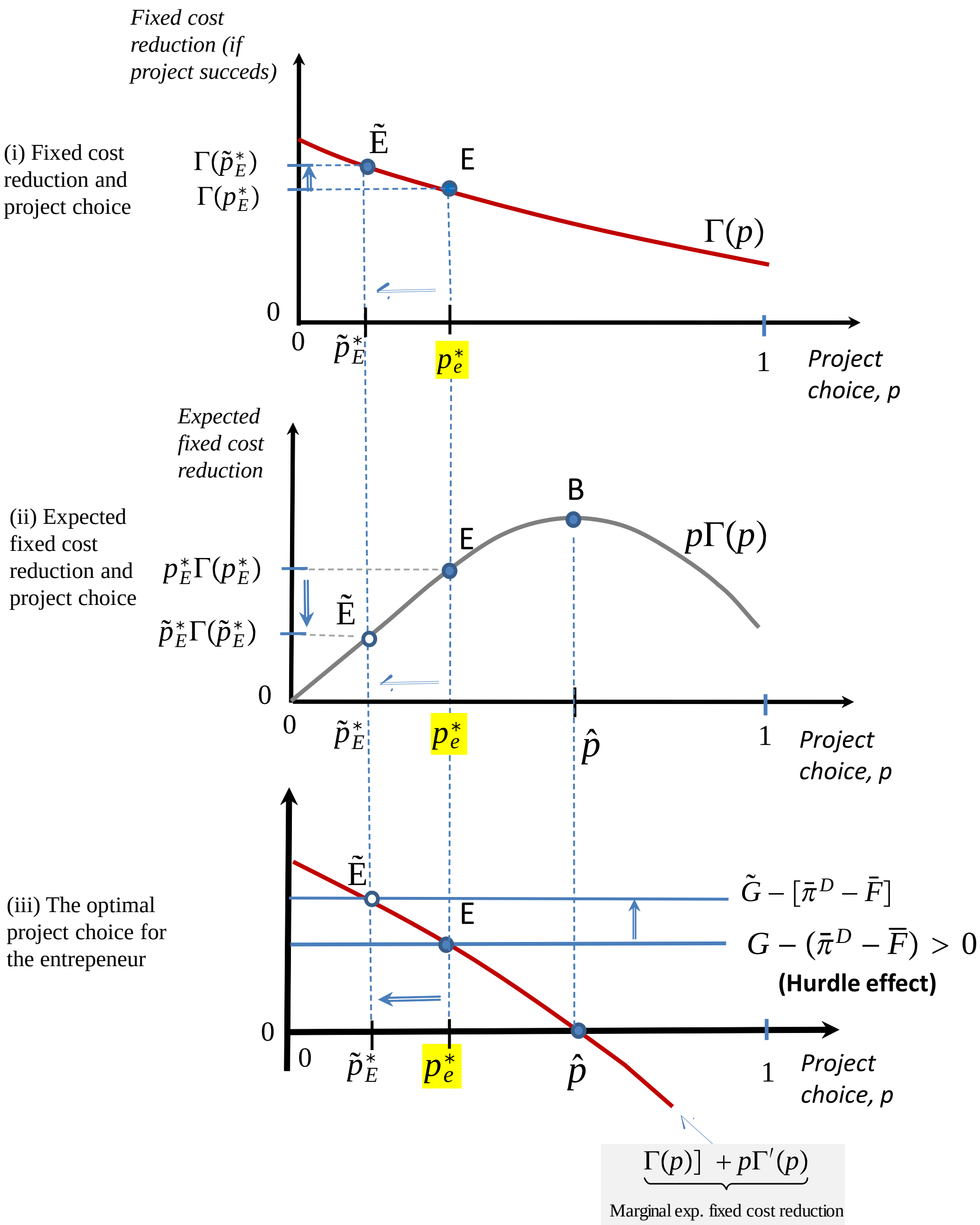

Figure 7.1: **Here we need to fill in.**

Registration Office (PRV, www.prv.se). Thereafter, a questionnaire was sent out to the inventors of the patents in 2004.[22] The inventors were asked where the invention was created, if and when the invention had been commercialized, which kind of commercialization mode was chosen, type of financing, etc. 867 out of 1082 inventors (∼80%) filled out and returned the questionnaire.[23] From these 867, we focus on the 624 patents where the inventor has some ownership of the invention.[24]

The entry cost variable, G As a proxy for the costs of entry into the product market G in Proposition 8, we use a variable indicating whether the inventor owned a firm at the application date or not. Firms that already have marketing, manufacturing and financial resources in-house should have lower costs of entering the market for a new product. To capture this effect from the behavior of the entrepreneurs, we exclude 97 patents that belong to firms with more than 11 employees from our sample of 624 patents. Thus, our empirical analysis is based on data from a set of 527 patents.

Next, we divide this sample of 527 patents into two sub groups. The first group consists of the 122 patents that are held by inventors who are the owners or joint owners of micro companies with 2-10 employees. The second sub group consists of the 405 patents held by inventors who are self-employed. Our empirical analysis is aimed at comparing the characteristics of these two groups. In doing so, recall that the hurdle effect is $G - (\bar{\pi}^D - \bar{F})$. Consequently, self-employed inventors may not only have higher entry costs G than micro firms but also lower product market profits. This would then reinforce the difference between firm types in the two groups.

The quality variable, k To measure the quality of the entrepreneur's invention k in Proposition 8, we use forward citations (excluding self-citations) that a patent received from the application date until November 2007. Forward citations are regarded as the most important quality indicator of patents in the literature (Harhoff et al., 1999; Lanjouw and Schankerman, 1999; Hall et al., 2005). Since patents have different application years, the length of the time period they can be cited differs. Therefore, we adjust our citation variable so that it measures the mean number of forward citations over a five-year period.[25] Specifically, the 624 patents in the original sample (before the exclusion of firms with more than 11 employees) together have: (i) 636 forward citations where the cited and citing patents have at least one common technology class at the four-digit ISIC-level and, (ii) 79 forward citations where they have no common

[22] Each patent always has at least one inventor and often an applying firm. The inventors or the applying firm can be the owner of the patent, but the inventors can also indirectly be owners of the patent, via the applying firm.

[23] In particular, the response rate was slightly above 80%. The 20% non-respondents did so in an unsystematic manner: 10% were due to the inventors having old addresses, 5% had correct addresses but was not possible to reach, and 5% who refused to reply. The only available information about the non-respondents is the IPC-class of the patent and the region of the inventors. For these variables, there was no systematic difference between respondents and non-respondents.

[24] It is interesting to note that 364 out of the 624 patents (∼58%) were commercialized, i.e., the holder received income from the patent.

[25] In doing so, we also follow the approach of Trajtenberg (1990) and weight the number of received patent citations by a linear time trend.

technology class at the four-digit ISIC-level. The mean number of citations is calculated over both within and across technology classes.

Let $\{m_i^L\}_{i=1}^{122}$ denote the mean number of citations for the 122 patents held by inventors who jointly or individually own firms with 2-10 employees and $\left\{m_j^H\right\}_{j=1}^{405}$ denote the mean number of citations for the 405 patents held by self-employed inventors. Let also $\{B_i^L\}_{i=1}^{122}$ and $\left\{B_j^H\right\}_{j=1}^{405}$ be binary variables taking on the value one if the patent receives any forward citations within the 5-year period, and zero if it doesn't,

$$B_i^L = \begin{cases} 1 & if \quad m_i^L > 0 \\ 0 & if \quad m_i^L \leq 0 \end{cases} \tag{7.1}$$

$$B_j^H = \begin{cases} 1 & if \quad m_j^H > 0 \\ 0 & if \quad m_j^H \leq 0 \end{cases} \tag{7.2}$$

Table 1 presents descriptive statistics for the series m^L, m^H, B^L and B^H.

Table 1. Descriptive statistics

Series	#Obs	Mean	Std. dev.	Median	Min	Max
m^L	122	0.5428	0.8143	0	0	3.3245
m^H	405	0.3526	0.9852	0	0	13.1275
B^L	122	0.4836	0.5018	0	0	1
B^H	405	0.2963	0.4572	0	0	1

To get an more balanced picture of the two series m^L and m^H and their characteristics, Table 2 gives the frequency distributions for these series (see also the kernel density plot in Figure 1.1).

Table 2. Frequency distributions of mean citations

Series	Range for mean number of citations							
	0	$(0,1)$	$[1,3)$	$[3,5)$	$[5,7)$	$[7,9)$	$[9,11)$	$[11,14)$
m^L	63	37	16	6	0	0	0	0
	(51.64%)	(30.33%)	(13.12%)	(4.92%)				
m^H	285	80	33	5	0	1	0	1
	(70.37%)	(19.75%)	(8.14%)	(1.25%)		(0.25%)		(0.25%)

Note: Percentage of total number of observations in the group is in parenthesis.

As seen from this table, the m^L series has a more even mass than m^H (as additionally seen from the kernel density plot in Figure 1.1) while the latter series seem to have a larger point mass at zero and could be regarded as having two outliers (given by the values 8.2 and 13.1). In the following analysis, we keep these two (extreme) observations in our data since they are predicted by the theory. Later on, however, we conduct sensitivity analysis and show that our conclusions still hold even with the outliers excluded from the data.

Finally, our analysis require that we can identify failed R&D projects. In particular, we use the following assumption to classify unsuccessful patents.

Assumption A6: Patents with zero citations, i.e., $m^L = 0$ and $m^H = 0$, identify failed R&D projects, that is, innovations for which $k = 0$.

We believe that this is a reasonable approximation for many types of research projects where it is relatively easy to get a patent from the patent office but rather difficult to have a patent that is actually being cited. In terms of the binary variables B^L and B^H, Assumption A6 implies that $B^L = B^H = 0$ represents unsuccessful patents.

7.2. Econometrical analysis and results

This section introduces the econometrical tools used to test the three predictions in Proposition 8, and also the results from applying these to our data. For this purpose, we need the following assumption.

Assumption B1: The observations $\{m_i^L\}_{i=1}^{122}$ and $\left\{m_j^H\right\}_{j=1}^{405}$ are realizations of the independent and identically distributed (i.i.d.) random variables L and H.

This assumption states that $\{m_i^L\}_{i=1}^{122}$ and $\left\{m_j^H\right\}_{j=1}^{405}$ are random samples drawn from the two groups L and H in a population. Let $f_L\left(m^L\right)$ and $f_H\left(m^H\right)$ denote the densities (pdfs) of the distributions of the i.i.d. variables L and H. We begin our analysis of checking whether the two groups L and H differ according to predictions (i)-(iii) in Proposition 8 by testing if $f_L\left(m^L\right)$ and $f_H\left(m^H\right)$ are (statistically) equivalent. This corresponds to testing the following statistical statistical hypothesis:

$$\begin{aligned} &H_0 : f_L\left(m^L\right) = f_H\left(m^H\right), \\ &H_1 : f_L\left(m^L\right) \neq f_H\left(m^H\right), \quad \textit{on a set of positive measures.} \end{aligned} \tag{HYP1}$$

Failing to reject H_0 implies that the data $\{m_i^L\}_{i=1}^{122}$ and $\left\{m_j^H\right\}_{j=1}^{405}$ are drawn from the same underlying distribution, which means that the two groups L and H cannot differ as suggested by Proposition 8. Hence, (HYP1) can be seen as a joint test of predictions (i)-(iii). On the other hand, rejecting H_0 in favor of H_1 means that the data $\{m_i^L\}_{i=1}^{122}$ and $\left\{m_j^H\right\}_{j=1}^{405}$ are samples drawn from different underlying distributions. However, the alternative, H_1, cannot identify the different characteristics of the distributions. Thus, rejecting H_0 simply says that the two groups are different but gives us no answer to *how* they in fact differ.

We use the non-parametric kernel-based test-procedure proposed by Li (1996,1999) to test (HYP1).[26] But applying this test to our data require some modifications.[27] Specifically, since the distributions C and E have bounded support, the standard kernel density estimator is inconsistent at the boundary which invalidates its use in the current context.[28] Instead, we employ the Schuster (1985) - Silverman (1986) reflection method yielding the following consistent density estimator:

$$\widehat{f}_l\left(m^l\right) = \begin{cases} \frac{1}{n^l h^l} \sum_{r=1}^{n^l} \left[K\left(\frac{m^l - m_r^l}{h^l}\right) + K\left(\frac{m^l + m_r^l}{h^l}\right)\right] & \text{if } m^l \geq 0, \quad \text{and,} \\ 0 & \text{if } m^l < 0, \quad \text{for } l = L, H. \end{cases} \tag{7.3}$$

n^l for $l = L, H$ refer to the number of observations in the sample.[29] K refer to the kernel function; here we choose K to be the standard second-order gaussian kernel. h^l for $l = L, H$ refer to the bandwidths, which we, for the reflected data samples $\left[m_1^l, ..., m_{n^l}^l, -m_1^l, ..., -m_{n^l}^l\right]$, calculate using the Sheater and Jones (1991) plug-in method.[30] In the Li-test we set the bandwidth equal to $\min\left\{h^L, h^H\right\}$. As recommended by Li (1999) and Li and Racine (2007), we calculate the $p-$value for the test statistic using the consistent bootstrap procedure described in Li (1999).[31]

Table 3 presents the results from the Li-test.

Table 3. Results from the Li-test.

Test statistic	$p-$value
13.9520	0.0002

This table shows that the Li-test strongly rejects H_0 that $f_L\left(m^L\right)$ and $f_H\left(m^H\right)$ are equal. In fact, the small $p-$value may be taken as rather strong evidence that $f_L\left(m^L\right)$ and $f_H\left(m^H\right)$ are different. However, as discussed above, we cannot tell from this result if the difference is due to the reasons predicted by Proposition 8 - we can merely conclude that there is a statistically significant difference. Therefore, we move on to analyze the three predictions separately.

Prediction (i) Prediction (i) in Proposition 8 suggests that if the group of innovators without a firm (denoted by L) has higher commercialization costs than the group with firms (denoted by H), then we should observe that the latter group have a lower success probability as measured

[26] Non-parametric in this sense means that the procedure does not require any parametric assumptions on the densities $f_L\left(m^L\right)$ and $f_H\left(m^H\right)$. See Li and Racine (2007) for a detailed overview of non-parametric econometrics.

[27] See Simar and Zelenyuk (2006) for a similar modification of the Li-test in the context of Data Envelopment Analysis (DEA).

[28] The bounded support follows because the number of citations is a non-negative value. The mean number of citations can therefore only take non-negative values, i.e., $(L, H) \in \mathbb{R}_+ \times \mathbb{R}_+$.

[29] Hence, $n^L = 122$ and $n^H = 405$.

[30] The kernel density plots in Figure 1.1 are also calculated using the bounded kernel estimator (7.3). When calculating these densities, we also chose K to be the standard gaussian kernel and used Sheater and Jones (1991) plug-in method to calculate the bandwidths, which yielded $h^L = 0.0414$ and $h^H = 0.0348$.

[31] The number of bootstrap replications was set to $5,000$ and we recalculated the bandwidths using the Sheater and Jones (1991) plug-in method for each bootstrap sample.

by the proportion of patents being cited (entrepreneurs without firms choose more risky projects to overcome the hurdle effect). Since unsuccessful projects are associated with zero citations, the econometrical interpretation of this prediction is that there is a higher probability of drawing the value zero in group H than in group L, so that H should contain a larger relative fraction of zero-valued observations. More formally, the pdf $f_H\left(m^H\right)$ should have a larger point mass at zero than $f_L\left(m^L\right)$. An informal indication that this is true for our data can be seen from the frequency distributions in Table 2, which shows that group H indeed has a larger relative fraction of zeros (H has $\sim 70\%$ zeros compared to $\sim 51\%$ in L).

A more formal (statistical) test of prediction (i) consists of applying a simple two-sample $Z-$test of equal proportions.[32] But before explaining how this test procedure is applied to our context, we need the following additional assumption.

Assumption B2: The binary variables B^L and B^H defined by (7.1) and (7.2) are Bernoulli distributed variables with success probabilities π^L and π^H, respectively.

This assumption gives B^L and B^H a stochastic interpretation.[33] Specifically, we assume that B^L and B^H are Bernoulli variables such that $\pi^L = P\left[B^L = 1\right] = P\left[m^L > 0\right]$ and $\pi^H = P\left[B^H = 1\right] = P\left[m^H > 0\right]$, where the second equality in these two relations follows from (7.1) and (7.2). Thus, π^L and π^H denote the probabilities of a patent being cited at least once during the five-year period in the two groups, or in other words, denote the probabilities that a R&D project is successful. The following hypothesis attaches a statistical decision rule in order to evaluate prediction (i).

$$\begin{array}{l} H_0 : \pi^H = \pi^L \Leftrightarrow \text{There is an equal probability that a R\&D project is a success in } L \text{ and } H. \\ H_1 : \pi^H < \pi^L \Leftrightarrow \text{There is a lower probability that a R\&D project is a success in } H. \end{array} \quad \text{(HYP2)}$$

This hypothesis is a test of the null that there is an equal probability of a patent receiving at least one citation over the 5-year period in groups L and H. The alternative, H_1, corresponds to prediction (i), which means that rejecting H_0 in favor of H_1 supports this prediction.

The statistical hypothesis (HYP2) is tested using a two-sample $Z-$test of equal proportions. Table 4 presents the results from applying this test to our data.

Table 4. Results from the two-sample $Z-$test of equal proportions.

Test statistic	$p-$value
-3.8296	0.00006417

This result shows that H_0 in (HYP2) can be strongly rejected in favor of H_1, i.e., the data show strong evidence that there is a lower probability of having a successful R&D project in the self-employed group, i.e, group H. Thus, this result supports prediction (i) in Proposition 8.

[32] The two-sample $Z-$test is a built-in procedure in many statistical softwares such as STATA, SPSS and SAS.

[33] Note here that the i.i.d. assumption (Assumption B1) of the random variables L and H implies that the Bernoulli variables B^L and B^H are also i.i.d.

Prediction (ii) We now turn to prediction (ii) in Proposition 8 which tells us that if the hurdle effect makes entrepreneurs choose more risky projects, the projects that succeed should attain higher quality. In other words, the hurdle effect predicts that we should see more extreme outcomes when entry is more costly. This means that the more risky group, H, should be assigned a larger probability of receiving more forward citations compared to the less risky group, L. Another way to interpret this is that the pdf, $f_H\left(m^H\right)$, characterizing group H should have a larger tail mass (i.e. a fatter and longer tail) than $f_L\left(m^L\right)$. To evaluate whether the data satisfies this prediction, we suggest to measure and compare the amount of tail-fatness of the two densities, $f_H\left(m^H\right)$ and $f_L\left(m^L\right)$. And if $f_H\left(m^H\right)$ is found to have a fatter tail this should be taken as evidence supporting prediction (ii).

We propose to measure the degree of tail-fatness using the modified Hill estimator introduced by Huisman, Koedijk, Kool and Palm (2001). The original Hill estimator (Hill, 1975) produces an index measure of the tail-fatness for the power-law family of distributions. This family covers a wide range of heavy-tailed distributions, which makes the Hill quasi-maximum likelihood estimator quite general in that it can measure the degree of tail-fatness for a wide range of underlying distributions. The modified Hill estimator we use here is a weighted average of Hill estimators for different threshold values that corrects for the small-sample bias which the original Hill estimator is known to suffer from. Monte Carlo studies conduced by Huismann et al. (2001) confirm that the modified Hill estimator outperforms the original estimator in a number of different cases, including many small-sized problems matching our sample sizes, n^L and n^H.

Table 5 presents the results from applying the modified Hill estimator to our data.[34] Note in this table that a lower estimated tail index value indicates a fatter tail.

Table 5. Results from the modified Hill estimator.

Distribution	Mod. Hill estimator
$f_L\left(m^L\right)$	4.9966
$f_H\left(m^H\right)$	1.9455

These results show that the distribution $f_H\left(m^H\right)$ has a considerable fatter and longer tail than $f_L\left(m^L\right)$ (i.e., $f_H\left(m^H\right)$ has a lower estimated tail index), which supports prediction (ii).[35] To get some intuition as to how much fatter the tail of $f_H\left(m^H\right)$ appear to be, we can relate our estimates in a parametric example. Suppose the data were drawn from $t-$distributions; that is, assume $f_L\left(m^L\right)$ and $f_H\left(m^H\right)$ to be the pdfs of $t-$distributions with different degrees of freedom. As such, the tail index estimates obtained from the modified Hill estimator is

[34] When calculating the modified Hill estimator, we use only positive-valued observations (i.e., we omit the zero-valued observations in our samples). Moreover, we follow Huisman et al. (2001) and choose the midpoint of the samples (excluding the zero-valued observations) as the threshold value.

[35] We also estimated the standard errors of the tail index estimates following Huisman et al. (2001). However, these standard errors should be taken with caution since they implicitly rely on the assumption that $f_L\left(m^L\right)$ and $f_H\left(m^H\right)$ are pdfs of the Pareto distribution (See Huisman et al. 2001, Appendix, for a detailed discussion). Nevertheless, the estimated standard errors were found to be less than 0.25 in both cases which may be taken as an indication that the tail indices are estimated quite precisely.

equal to the number of degrees of freedom. In this case, the difference in tail-fatness therefore corresponds to the difference between $t-$distributions with 2 and 5 degrees of freedom, which is quite a substantial difference. We view this example as supporting our claim that $f_H\left(m^H\right)$ has considerable fatter tails than $f_L\left(m^L\right)$.

A joint measure of predictions (i) and (ii) In this section, we argue that the kurtosis (i.e., the standardized fourth population moment about the mean) serves as a summary measure of predictions (i) and (ii). First, however, let us consider the following simple illustration of the concept of kurtosis: take two overlapping distributions, and assume that these are truncated from the left. Pressing the shoulder from the right hand side of one of the distributions so that it moves mass from the center of the distribution to the lower and upper parts of the distribution would, obviously, make this distribution more peaked and put more mass in the tail. As a result, the kurtosis for that distribution increases relative to the kurtosis for the other distribution the harder one presses the shoulder. The kurtosis can therefore be viewed as a joint measure of the tail-fatness and peakedness of a distribution.

Now, recall prediction (i) and the econometric interpretation of this prediction saying that $f_H\left(m^H\right)$ should have a larger point mass at zero than $f_L\left(m^L\right)$. As explained above, this means that $f_H\left(m^H\right)$ should be more peaked (at least at the point zero). Next, prediction (ii) states that $f_H\left(m^H\right)$ also should be characterized by a fatter tail than $f_L\left(m^L\right)$. These predictions taken together and in light of the previous illustration implies that $f_H\left(m^H\right)$ should have a larger kurtosis than $f_L\left(m^L\right)$. Table 6 reports the kurtosis of the distributions $f_H\left(m^H\right)$ and $f_L\left(m^L\right)$ calculated from our data.

Table 6. Kurtosis of distributions

Distribution	Kurtosis
$f_L\left(m^L\right)$	5.9492
$f_H\left(m^H\right)$	82.2611

As seen from this table, $f_H\left(m^H\right)$ has a higher kurtosis than $f_L\left(m^L\right)$ which jointly then supports predictions (i) and (ii). Note, however, that it is not possible from this analysis alone to identify whether the larger kurtosis arises because $f_H\left(m^H\right)$ is more peaked, has a fatter tail, or because of both.

Prediction (iii) Proposition 8(iii) implies that if the group of innovators without a firm has higher commercialization costs than the group with firms, we should observe that the latter group has a higher mean of total number of patent citations (entrepreneurs without firms choose more inefficiently risky projects to overcome the hurdle effect). That is, the expected number of mean citations for the high-cost group, H, should be lower than for the low-cost group, L.

To formulate a statistical decision hypothesis to this prediction, we let μ^L and μ^H denote the expected number of mean citations in the groups L and H, such that $\mu^L = E[L] =$

$\int_{\Omega} m^L f_L\left(m^L\right) dm^L$ and $\mu^H = E[H] = \int_{\Omega} m^H f_H\left(m^H\right) dm^H$, where Ω denotes the support of L and H. The following hypothesis attaches a decision rule to evaluate prediction (iii).

$$\begin{aligned} &H_0 : \mu^H = \mu^L \Leftrightarrow \text{The expected number of mean citations are equal in } L \text{ and } H. \\ &H_1 : \mu^H < \mu^L \Leftrightarrow \text{The expected number of mean citations is lower in } H. \end{aligned} \tag{HYP3}$$

This hypothesis is a test of the null that the expected number of mean citations are equal across the two groups. The alternative, H_1, stating that the expected number of citations is lower in the high-cost group, H, than in the low-cost group L, corresponds to prediction (iii), which means that rejecting H_0 in favor of H_1 supports this prediction.

The statistical hypothesis (HYP3) is tested using a simple Welch $t-$test.[36] Table 7 presents the results from applying this test to our data.

Table 7. Results from Welch $t-$test

Test statistic	$p-$value
-2.1488	0.0163

This result shows that H_0 in (HYP3) can be rejected at the 5% nominal significance (but not at the 1% level). As such, we take this as providing at least some support to that the expected number of mean citations is lower for the group with firms, H. Thus, it supports prediction (iii) in Proposition 8, but does so rather weakly.

Discussion and sensitivity analysis A possible concern with the above results is that they may be influenced by the two (largest) extreme observations in group H (See the frequency distributions in Table 2, and the discussion below the table). In particular, while the other patents in group H received less than 5 citations on average each year during the 5 year period, these two patents were on average cited 8.2 and 13.1 times each year. To investigate how sensitive our results are to the inclusion of these observations, we reran the above test procedures without the outliers. Table 8 reports the results from these tests.

Table 8. Results from sensitivity analysis

[36] The Welch $t-$test is a generalization of the standard Student's $t-$test for the case when the two samples have possibly unequal variances (as in our data). The test statistic in the Welch $t-$test is asymptotically $t-$distributed, and we used the Welch-Satterthwaite equation to approximate the degrees of freedom in the asymptotic $t-$distribution. We also calculated a $p-$value for the test statistic using bootstrapping but found this to be insignificant at the 5% nominal significance level, and consequently larger than the $p-$value from the asymptotic distribution.

Test procedure	Test statistic	$p-$value
Li-test	14.6602	< 0.0000
$Z-$test	-3.9059	0.00004639
Welch $t-$test	-2.9980	0.0016
Distribution	**Mod. Hill estimator**	**Kurtosis**
$f_L\left(m^L\right)$	4.9966	5.9492
$f_H\left(m^H\right)$	3.1222	13.8937

As seen from this table, our above conclusions hold true even with the outliers omitted from group H. The fraction of zero-valued observations in the group H increases which, of course, gives an even lower $p-$value in the two sample $Z-$test of equal proportions, as seen when comparing tables 4 and 8. More importantly, the lower tail index values (Mod. Hill estimator) in Table 8 show that the tail of the pdf $f_H\left(m^H\right)$ is still fatter than the tail of $f_L\left(m^L\right)$. In particular, although omitting the outliers increases the tail index from ~ 2 to ~ 3 for $f_H\left(m^H\right)$ it is still considerable lower than the tail index of $f_L\left(m^L\right)$ (given by ~ 5). As such, we argue that our results supporting prediction (ii) seem to be quite robust. From Table 8, we also note that even if the kurtosis of $f_H\left(m^H\right)$ decreases compared to Table 6 it is still considerable higher than the kurtosis of $f_L\left(m^L\right)$. In our view, this further supports our claim that the empirical evidence supporting predictions (i) and (ii) are quite robust. Finally, we see that the $p-$value from the Welch $t-$test becomes significant at the 1% when omitting the outliers (recall that it was significant at the 5% level but not at the 1% level above). Hence, excluding the outliers gives stronger support to prediction (iii) in Proposition 8 than before.

We end this section by discussing some potential concerns with the data at hand, and provide some further robustness checks to deal with these issues. First, a potential concern in identifying the effect of commercialization costs on the R&D outcome of entrepreneurship is reverse causality, i.e., that the outcome of the R&D project will affect the entrepreneur's choice of organization mode (firm or self employed). However, since our data is about firms' size at the application date when the commercialization value of the invention should still be highly uncertain, we believe this problem to be limited. On the other hand, we are more concerned with omitted variable problems. In particular, there might be underlying factors why some inventors do not want to start larger firms and that this might explain why they behave in a more risky way in R&D. To control for this omitted variable problem, we tested whether the densities of the two groups differ when excluding inventions made at a university, inventions made by women, and inventions made by non-Swedes without qualitative change of results. Moreover, in unreported regressions we found that the different propensity to cite patents between the two groups is significant when controlling for industry- and regional characteristics and whether the invention made at a university, or if the innovator was a women or an immigrant.

Finally, we should note that many R&D project that fail may not even result in a patent. By construction, these failures are not included in our dataset. However, the frequency distributions in Table 2 indicate that these failures are possibly more frequent in group H than in group L. We may then understate the effect of entry costs on the entrepreneurs' choices of R&D projects.

8. Concluding remarks

This paper shows that entrepreneurs have incentives to choose projects with high risk and a high potential in order to reduce expected commercialization costs. This finding is interesting in the light of the recent shift towards more pro-entrepreneurial policies all over the world as revealed in data from the World Bank Doing Business project. The cost of starting a new business declined by more than 6 percent per annum over the period 2003-08 and the decline among OECD countries has been even more dramatic. Our results suggest that this development is likely to lead to more entrepreneurial entry, but to less breakthrough inventions by entrepreneurs. In addition, incumbent firms are likely to respond to this development by (also) choosing R&D projects with lower risk.

We also find that the social planner may prefer both incumbent firms and entrepreneurs to embark on riskier R&D projects. Since entrepreneurial policies do not only increase entrepreneurial effort, but also affect the type of R&D projects chosen by entrepreneurs and the incumbent, this aspect should be taken into account when designing entrepreneurial R&D policies. Consequently, our findings suggest that policies designed to reduce commercialization costs could stimulate entrepreneurship, but also stimulate entrepreneurship that takes too little risk from a social point of view.

As emphasized by Gilbert (2006), innovation diversity is a characteristic of truly independent R&D. This paper makes an attempt to not only formally model innovation diversity, but also understand how this diversity is affected by entrepreneurial policy. We believe that this model can be used to study how different policies such as financial and educational policies affect the innovation diversity and the efficiency of the innovation market.

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Appendix: The linear Cournot model with differentiated goods

Following Singh and Vives (1984), assume the utility of a consumer to be given by:

$$U(\mathbf{q}, I) = aQ - \frac{1}{2}\left[q_i^2 + 2\gamma q_i q_e + q_e^2\right] + I \tag{8.1}$$

where q_i is the output of the incumbent, q_e is the output of the entrepreneur, $Q = q_e + q_i$ denotes total output, I is a composite good of other goods and a is a constant. The parameter γ measures the substitutability between products. If $\gamma = 0$, each firm has monopolistic power, whereas if $\gamma = 1$, the products are perfect substitutes.

Consumers maximize utility subject to the budget constraint $P_i q_i + P_e q_e + I \leq m$, where m denotes income and the price of the composite good is normalized to one, $P_I = 1$. The first-order condition for good j is $\frac{\partial U}{dq_j} = a - q_j - \gamma q_h - P_j = 0$ for $j \neq h$ which gives the inverse demand for firm j

$$P_j = a - q_j - \gamma q_h, \quad j \neq h \ . \tag{8.2}$$

The product market profit is given by $\pi_j = (P_j - c)q_j$, where c is a constant marginal cost, and the first-order condition in (3.1) becomes

$$\frac{\partial \pi_j}{\partial q_j} = P_j - c_j - q_j^* = 0 \tag{8.3}$$

which can be solved for the optimal quantities q^*. With symmetric firms $c_j = c$, defining $\Lambda = a - c$ gives:

$$q_i^M = \frac{\Lambda}{2} \text{ and } q_i^D = q_e^D = \frac{\Lambda}{2+\gamma}. \tag{8.4}$$

Noting that $\frac{\partial \pi_j}{\partial q_j} = 0$ implies $P_j - c_j = q_j^*$, the reduced-form equilibrium profits are then $\bar{\pi}_j^* = \left[q_j^*\right]^2$. From (8.2), prices are $P_i^m = a - q_i^M$ and $P_i^D = P_e^D = a - (1+\gamma)\, q^D$. We then have

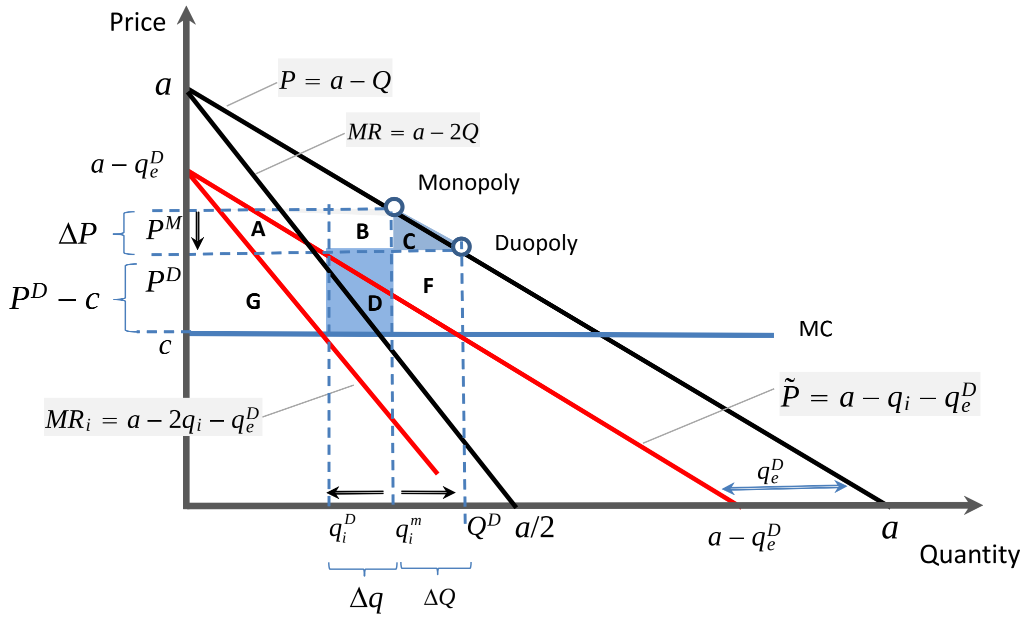

Figure 8.1: The business stealing effect in **a** Cournot model with homogenous goods is the area D-C.

that the consumer surplus in each market structure is given by

$$\begin{cases} CS^D = CS(\mathbf{q}^D) = aQ^D - \frac{1}{2}\left[\left(q_i^D\right)^2 + 2\gamma q_i^D q_e^D + \left(q_e^D\right)^2\right] - P_i^D q_i^D - P_e^D q_e^D \\ CS^M = CS(q_i^M) = aq_i^M - \frac{1}{2} q_i^M - P_i^M q_i^M. \end{cases} \tag{8.5}$$

Homogeneous goods Let us first examine entry when goods are perfect substitutes, $\gamma = 1$. We have that $CS^M = \frac{1}{2}\left[q_i^M\right]^2$ and $CS^D = \frac{1}{2}\left[Q^D\right]^2$. In addition, some algebra shows that in this case $\bar{\pi}^M - \bar{\pi}^D - \left[CS^D - CS^M\right] = \frac{1}{24}\Lambda^2 > 0$. This gives the following Lemma:

Lemma 5. *In the Linear-Cournot model with homogeneous goods, the business stealing effect is positive, $\pi^M - \pi^D - (CS^D - CS^M) > 0$. As a result, the entrepreneur chooses too safe a research project, $p_e^S < p_e^*$, as does the incumbent, $p_i^S < p_i^*$.*

This result is illustrated in Figure 8.1. The increase in the consumer surplus from entry $\Delta CS = CS^D - CS^M$ is given as the sum of areas A, B and C. Entry reduces the product market price by $\Delta P = P^M - P^D$, while consumption expands with $\Delta Q = Q^D - q_i^M$, where $Q^D = q_i^D + q_e^D$. Thus, consumers face a lower price on the the "old" monopoly consumption q_i^M, corresponding to the rectangles A and B. In addition, the consumer surplus also increases since output is higher in duopoly, corresponding to the triangle C.

The loss in profit for the incumbent, $\Delta\pi_i = \bar{\pi}^M - \bar{\pi}^D$, i.e. the entry deterring effect is represented by areas A, B and D. The incumbent faces profit losses since entry by the entrepreneur reduces the incumbent's output by $\Delta q = q_i^M - q_i^D$. The total loss on these units is $(P_i^m - c)\,\Delta q$ and is represented by areas B and D. In addition, the monopolist faces a reduction in price on the (new) duopoly output, leading to a loss of revenues $\Delta P q_i^D$ and shown by area A.

Areas A and B represent a transfer between the monopolist and the consumers, so the business stealing effect must be the rectangle D minus the triangle C. Note that with homogeneous goods, rectangle D must be larger than triangle C. This follows from the fact that expanding consumption ΔQ adds consumers with a decreasing willingness to pay, while the loss of business from entry for the incumbent, Δq, occurs at a constant price cost margin $P^D - c$. Thus, with homogeneous goods and symmetric firms, the business stealing effect is always positive. From a social planner's point of view, the entrepreneur then chooses R&D projects that are not risky enough. From Proposition 5, both firms then take on too little risk.

Differentiated goods Let us now examine entry with differentiated products, where $\gamma \in (0, 1)$. It is instructive to first evaluate the business stealing effect in the limiting case of $\gamma = 0$, i.e. when products are independent and each firm is a monopolist, $q^M = \{q_i^M, q_e^M\}$. Since entry does not imply any output reduction for the incumbent; $\Delta q = 0$, $\pi_i(q^M) = \pi_i(q_i^M)$ and $\Delta\pi_i = \pi_i(q_i^M) - \pi_i(q^M) = 0$. However, aggregate output increases, $\Delta Q = q_e^M > 0$, because of the introduction of a new variety and, as a result, the consumer surplus must increase. To see this, note that $CS(q^M) = CS(q_i^M) + CS(q_e^M)$ so that $\Delta CS = CS(q^M) - CS(q_i^M) = CS(q_e^M)$. Thus, in the limiting case of independent products, the business stealing effect is negative, $\Delta\pi_i - \Delta CS = -CS(q_e^M) < 0$.

Since we have shown that the business stealing effect is positive for the case of homogenous products ($\gamma = 1$) and negative for the case of independent products ($\gamma = 0$), then, by continuity, there must exist a cut-off differentiation such that the business stealing effect turns negative. To see this, first note that the consumer surplus under monopoly is $CS^M = \frac{1}{8}\Lambda^2$, and under duopoly it is $CS^D = \Lambda^2 \frac{\gamma+1}{(\gamma+2)^2}$. Note that $\frac{\partial CS^D}{\partial \gamma} < 0$, which implies that the consumer surplus in a duopoly market is increasing in product differentiation. Then, some algebra shows that

$$\pi^M - \pi^D - (CS^D - CS^M) = \frac{1}{8}\Lambda^2 \frac{3\gamma - 2}{\gamma + 2}. \tag{8.6}$$

From (8.6), we can solve for the level of $\tilde{\gamma}$ such that $(\pi^M - \pi^D) - (CS^D - CS^M) = 0$. Then, we can formulate the following Lemma:

Lemma 6. *In the Linear-Cournot model when goods are sufficiently differentiated, i.e. if $\gamma \in (0, \frac{2}{3})$, the business stealing effect is negative, $\pi^M - \pi^D - (CS^D - CS^M) < 0$, implying that the entrepreneur chooses too risky projects: $p_e^S > p_e^*$, while the incumbent chooses projects with to little risk $p_i^S < p_i^*$.*

If the parameter that determines product differentiation, γ, is sufficiently low so that $\gamma \in \left[0, \frac{2}{3}\right)$, the business stealing effect is negative. Consequently, if goods are sufficiently differentiated, the social planner prefers that the entrepreneur takes less risk. This is explained by the fact that as product differentiation increases, the entrepreneur steals less of the incumbent's profits upon entry and, in addition, creates a larger increase in the consumer surplus. Once more, since the incumbent does not internalize the entry effects in terms of the entrepreneur's profit, on the one hand, and on the consumer surplus, on the other, it ends up embarking on projects with too little risk from a social welfare perspective.