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

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Abstract

This paper examines how entrepreneurs and incumbents differ in R&D strategies. We show that entrepreneurs have incentives to choose projects with higher risk and a higher potential in order to reduce expected commercialization costs. However, entrepreneurs may still select too safe projects from a social point of view, since they do not internalize the business stealing effect. 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. We develop a regression framework to test empirical predictions of the model. Within our regression framework we derive and attach statistical decision hypotheses corresponding to each prediction. Using a unique data set of Swedish patents and innovators, we find strong empirical support for these predictions.

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1. Introduction

1.1. Motivation and contributions

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, in a review of the empirical literature on firm size and innovative activity, Cohen (2010) 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]

These observations raise 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 that 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 do incumbents. 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. First, 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 commercialization cost is only paid when the project succeeds). Second, 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

[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.

successful innovation does not only give rise to cost savings but also entry deterrence and, therefore, the incumbent will choose less risky projects.

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 entrepreneur 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 the consumer 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 (the entry deterring effect) and, consequently, the entrepreneur will 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 concerns 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 at 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.

[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.

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. Then, we 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. First, we analyze the case when the entrepreneur can enter the market and both firms succeed. Second, we consider the cases where a second entrepreneur or a second incumbent exists. Finally, we also allow the entrepreneur to commercialize its invention through sale to the incumbent, instead of entering with it into the product market. Thus, 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).

1.2. Empirical evidence

There are a number of empirical predictions emerging of the entrepreneurship hurdle effect. These predictions can be summarized as follows: (i) Higher entry costs results in more entrepreneurial failures, since high entry barriers implies that the entrepreneur opts for a R&D project with a lower probability of success; (ii) If the project succeeds, then it will be of a higher quality since a low success probability results in a higher payoff in case of success; (iii) The expected quality will be lower for entrepreneurs with higher entry costs, since their choices are further away from the choice that maximizes the expected quality.

These predictions constitute (in part) some of the previously unexplained empirical facts that have been documented in several studies of entrepreneurship. In a recent survey of this literature, Åstebro et al. (2014) refer to these (stylized) facts as an empirical 'puzzle' which poses a challenge to fully understand and interpret entrepreneurship. To analyze the empirical predictions from our theoretical model and provide (at least partial) explanations to the 'puzzle', 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.[4] This allows us to capture

[4]See Section 6 for a detailed description of the data. Although there are other data sources of patent citations that contains the full names and addresses of inventors listed in each patent, e.g., the NBER Patent Citation Data File (See Hall, Jaffe and Trajtenberg (2001) for a detailed description), the type of information we use in this paper has, to our knowledge, not yet been collected for any other data source including the NBER data.

and control for observable differences between inventors, and as such, allow us to control for alternative explanations of the hurdle effect.

In order to briefly explain our results and relate them to the empirical 'puzzle' documented in Åstebro et al. (2014), Figure **1** plots the distributions of patent citations for the groups with low (dashed line) and high (solid line) commercialization costs.

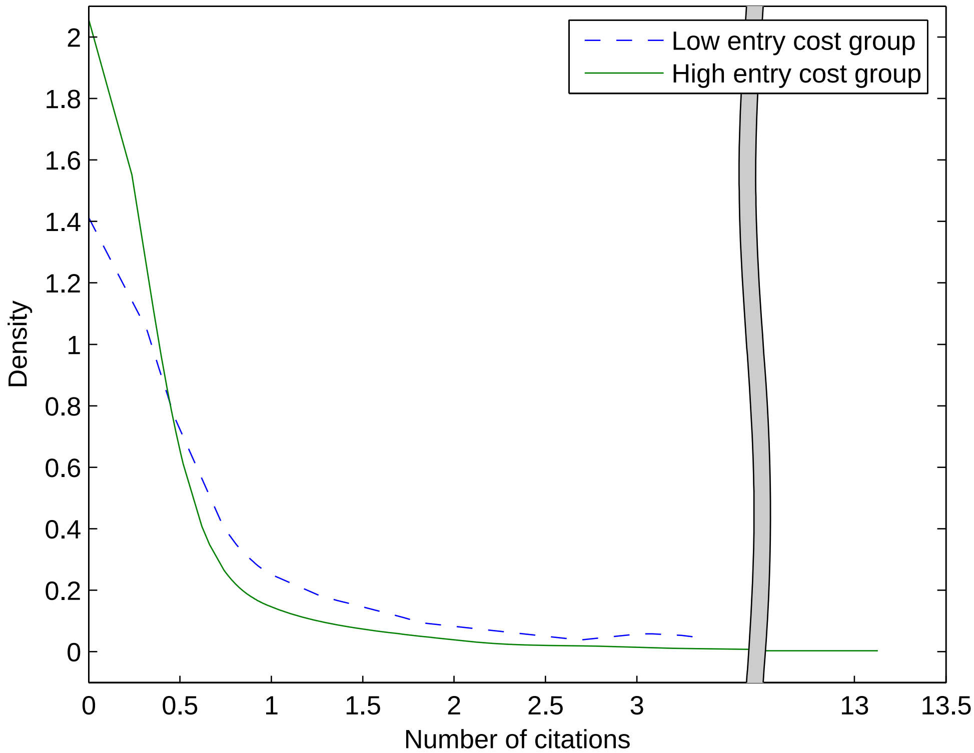

Figure 1: Kernel density of patent citations for low and high entry cost groups

In constructing these plots, we assume that self-employed inventors with patents are faced with *high* commercialization costs and inventors with patents who jointly or individually own firms with 2-10 employees comprise the group of *low* commercialization costs. We also make the identifying assumption that patents with zero number of citations identify failed (unsuccessful) R&D projects. Figure **1** shows a higher dispersion of patent citations among the self-employed inventors. This follows because inventors with firms seem to generate R&D projects that are, on average, more successful (in terms of patent citations), but self-employed inventors generates a few projects that are extremely successful (as seen from the longer tail of the density given by the solid line) and face a higher probability of failing their R&D projects (displayed by the larger point mass at zero of the density given by the solid line).[5] These results highlight

[5]Notice that the scale on the $x-$axis (measuring the number of citations) has been broken shortly after the density of the low-cost group (dashed line) vanishes, and that the density of the high-cost group (solid line) continues after the scale-break. We used a gaussian kernel and the normal reference bandwidth to calculate the kernel densities.

parts of the 'puzzle' described in Åstebro et al. (2014), namely that the expected returns from entrepreneurship tend to be low on average but exhibit large dispersion because most startups fail and only a few are very successful.

To evaluate and test our specific empirical predictions, we first conduct a preliminary analysis by using non-parametric statistical methods to compare the probability distributions of patent citations of the low- and high-cost groups. We show that the predictions are related to certain properties of these distributions, and provide a non-parametric framework to test whether these properties differ for the two groups. In the main empirical analysis we develop a regression framework to test the empirical predictions. Within this regression framework we derive and attach statistical decision hypotheses corresponding to each prediction. This allows us to separately test and evaluate each prediction. As discussed above, by including covariates in the regression analysis we can control for observable differences between inventors and therefore control for alternative mechanisms of our results.

Prediction (i) says that the group of inventors facing higher commercialization costs (i.e., the self-employed inventors) should generate more failures. Figure **1** gives graphical support to this prediction by showing that there is a larger fraction of patents without citations in the high entry cost group (i.e., the distribution of patent citations of the high-cost group has a larger point mass at zero than the low-cost group). We formulate a test of this prediction in our regression framework. In doing so, we derive the probability of success conditional on covariates and by that link prediction (i) to a simple significance test of one of the coefficients in our regression. The results from this test, as well as the results from the preliminary non-parametric analysis, are strongly supportive of prediction (i).

Building on the discussion above, Figure **1** shows that the density of the low-cost group (dashed line) vanishes much faster than the density of the high-cost group (solid line). Thus, there is a higher probability of observing more 'extreme' outcomes in the high-cost group. One interpretation of this is that self-employed inventors has a higher probability of generating breakthrough inventions (i.e., inventions receiving an 'extreme' amount of citations). In the preliminary non-parametric analysis, we apply a non-parametric estimator of the tail-mass and find that the density of the high-cost group has considerably more tail-mass than the density of the low-cost group. In our regression framework, we use that a distribution is characterized by a higher kurtosis when more of the variability is due to a few extreme differences from the mean, rather than a lot of modest differences from the mean. Thus, the density of citations of the high-cost group should have a higher kurtosis than the density of the low entry cost group, since breakthrough inventions are more common in the high-cost group. We calculate the kurtosis conditional on success, and find results which are strongly supportive of prediction (ii).

Prediction (iii) says that entrepreneurs with higher entry costs produce inventions of a lower expected quality than entrepreneurs with lower entry costs. Within our regression framework, we show that this prediction corresponds to estimating and then testing the significance of the marginal effect for one variable in the regression. The results from this significance test, as well as the results from the preliminary non-parametric analysis, show strong evidence in favor of prediction (i).

1.3. Related literature

This paper is related to the literature on R&D and market structure.[6] There are several papers studying the type of R&D project to undertake.[7] 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 stem from the fact that larger firms have a larger output over which they can apply their innovation results. This then implies that large firms have a relative advantage to pursue process innovation over product innovation since process innovations could more easily directly be used in existing business. Akcigit and Kerr (2010) use an endogenous growth framework and show that exploration R&D (creating new products) does not scale as strongly with firm size as exploitation R&D (improving existing products) due to a replacement effect.[8] In oligopolistic settings, Rosen (1991) and Cabral (2003) show that small firms may have an incentive to choose the risky strategy due to strategic output effects in the product market, i.e. small firms do not take on low risk-return projects since they cannot exploit the improvements over large output. In these papers, the difference in R&D behavior between small and large firms stems from the 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 has 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 that 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 projects A and B. This irrespective of whether it is small or large. Now consider an entrepreneur who faces an entry cost of 1 if she decides to commercialize the invention. Because $(20-1)\times 0.5 + 0\times 0.5 > 10-1$, the entrepreneur prefers the risky project A over B. 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 (i.e., the hurdle effect). Moreover, we show that incumbents have an incentive to choose safe R&D projects in order to increase the expected hurdle costs for the entrepreneur, i.e. optimize on entry deterring.[9]

Our statistical framework differ from the previously mentioned papers. Akcigit and Kerr

[6]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 some light on empirical strategies to evaluate the impact of competition on innovation.

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

[8]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.

[9]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.

(2010), for example, mainly compare (heterogeneous) groups of inventors on basis of descriptive measures that are calculated from the data. They combine this analysis with regressions to compare (and quantify) the distributions of patent citations between groups. Using the NBER patent citation data set and other data sources they find that the data supports their model. In contrast, we link our empirical predictions to statistical decision hypotheses which allow us to evaluate each prediction separately. In doing so, we use non-linear regression methods for cross-Sectional data as well as non-parametric methods for estimating probability distributions. To estimate the degree of tail-mass of a distribution we apply methods commonly used in the time series literature to model financial returns. Overall, our results from the empirical analysis strongly support the presence of a hurdle effect in (Swedish) patent data.

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) which shows 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 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.

The rest of the paper is organized as follows. Section 2 presents the theoretical model and characterize the equilibrium research projects chosen by the entrepreneur and the incumbent. Section 3 establishes why entrepreneurs choose risky R&D projects – but still not risky enough. In Section 4, we use our model to investigate the effects of pro-entrepreneurial policies on the firms' choices of research projects. Section 5 examines 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 6 we present the statistical framework and provide empirical support for the entrepreneurship hurdle effect. Section 7 concludes the paper. In an 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 well. A supplementary material contains additional estimation results together with a robustness analysis.[10] We summarize the results from the supplementary material in Section 6.4.6.

2. 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 2.1.

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 5 we generalize the model to allow for innovations that improve product quality or reduce the variable costs of production.[11]

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.[12] 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.[13] Omitting the project index, the fixed cost reduction $\Gamma(p)$ is illustrated in Figure 2.2(i). As shown in Figure 2.2(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, $\{p_i \text{ fail}, p_e \text{ fail}\}$ and $\{p_i \text{ succeed}, p_e \text{ succeed}\}$ and two asymmetric outcomes, $\{p_i \text{ fail}, p_e \text{ succeed}\}$ and $\{p_i \text{ succeed}, p_e \text{ fail}\}$.

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 incumbent). Finally, in stage 4, the product market interaction takes place where competition

[10] The supplementary material is downloadable from www.ifn.se/eng/people/research_fellows/per-hjertstrand.

[11] In addition, Section 5 adds additional entrepreneurs and incumbents and relaxes a simplifying assumption regarding the entry process.

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

[13] 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.

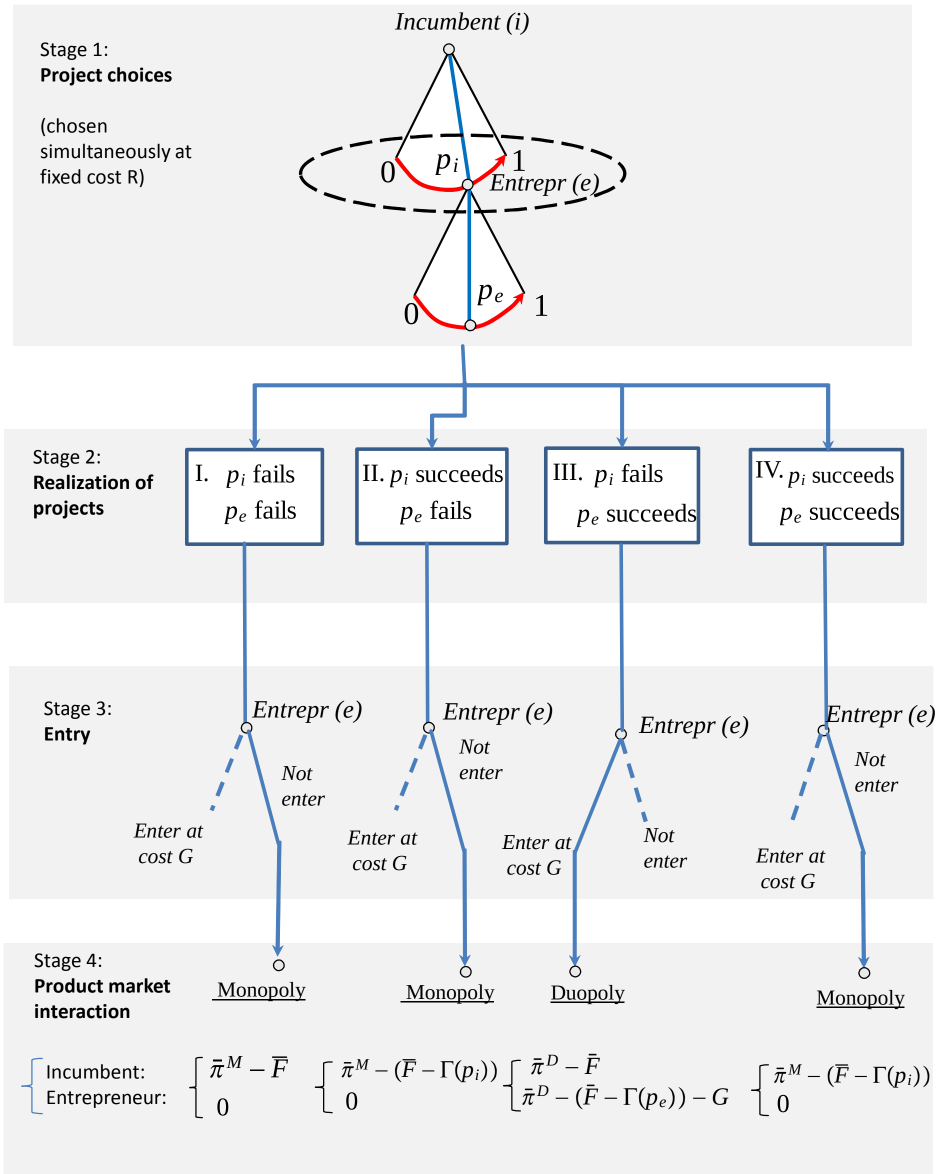

Figure 2.1: The structure of the model.

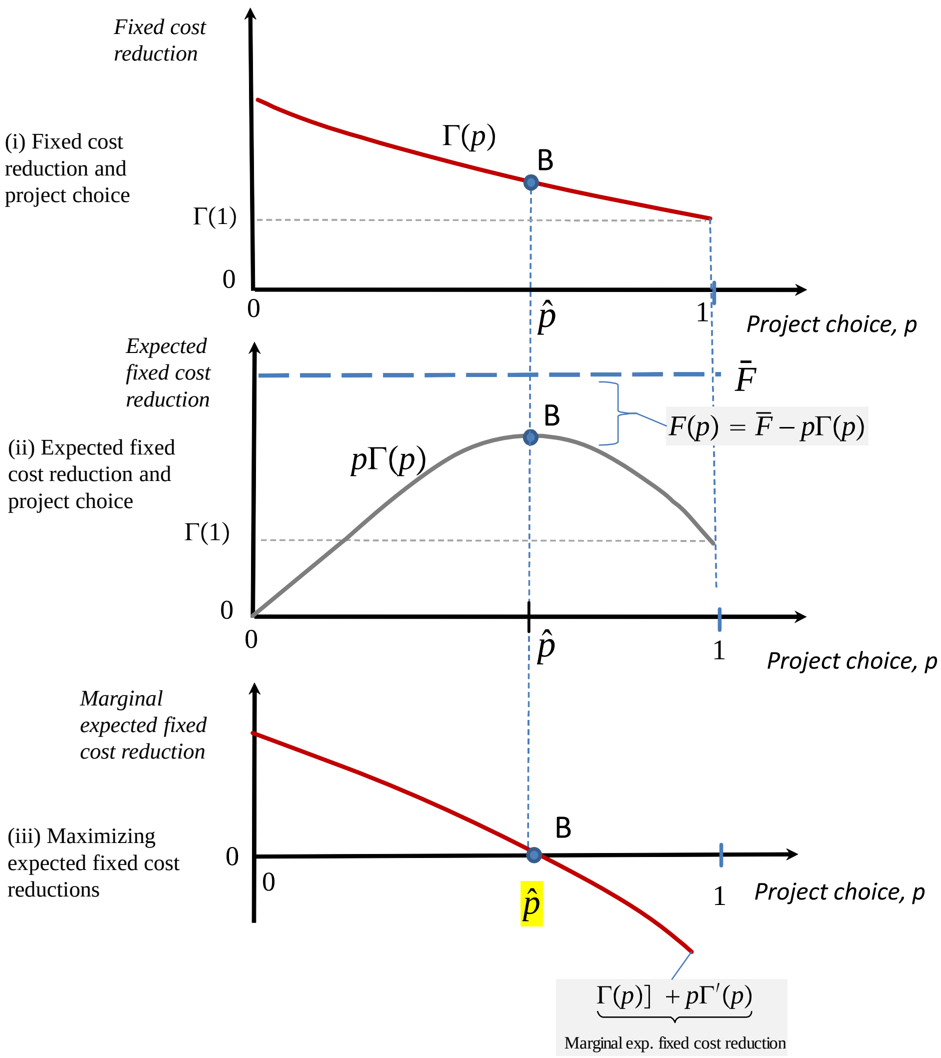

Figure 2.2: The fixed cost saving model: R&D projects and fixed cost reduction.

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.

2.1. 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:

$$\pi_j(x_j^*, x_{-j}^*) \geq \pi_j(x_j, x_{-j}^*), \tag{2.1}$$

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.

2.2. 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 2.1(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 2.1, we further assume that the entrepreneur can only enter when its R&D project is successful and the incumbent's project has failed.[14] 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 innovation, or reliably threatens to do so, and thereby reduces the likelihood of entry by the

[14] In Section 5 we extend the analysis so as to allow the entrepreneur to enter when it succeeds with the selected R&D project.

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.[15]

2.3. 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.

2.4. 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 $\bar{\pi}^D - \big(\overline{F} - \Gamma(p_e)\big) - G$ 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:

$$\mathrm{E}[\Pi_e] = p_e(1-p_i)[\bar{\pi}^D - \big(\overline{F} - \Gamma(p_e)\big) - G] - R. \tag{2.2}$$

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

$$(1-p_i)[\bar{\pi}^D - \big(\overline{F} - \Gamma(p_e^*)\big) - G] + (1-p_i)p_e^*\Gamma'(p_e^*) = 0. \tag{2.3}$$

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:

$$\Gamma(p_e^*)] + p_e^*\Gamma'(p_e^*) = \underbrace{G - \underbrace{(\bar{\pi}^D - \overline{F})}_{(+)}}_{\substack{(+)\\ \text{Hurdle effect}}} > 0. \tag{2.4}$$

As illustrated in Figure 2.3, 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 why, suppose that the entrepreneur would choose $\hat{p}$. From (2.2), this cannot be optimal since

[15] 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 $\bar{\pi}^D - \big(\overline{F} - \Gamma(p_e^*)\big) - G - L < 0$, whereas $\bar{\pi}^D - \big(\overline{F} - \Gamma(p_i^*)\big) - L > 0$, since $G > 0$. For expositional reasons, however, we do not pursue this here.

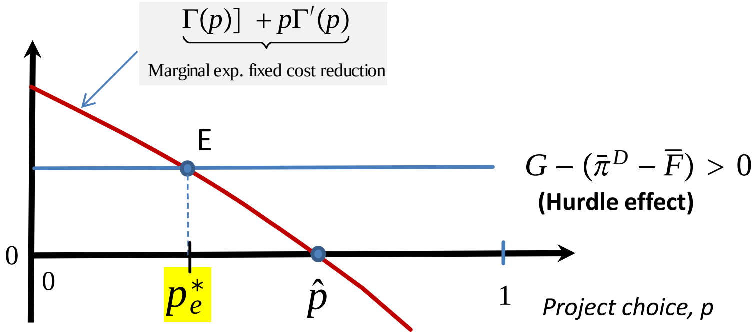

Figure 2.3: The entrepeneur's optimal project (p_e^*).

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 2.2(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 2.3), 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 (2.4) in p_e and G, we obtain

$$\frac{dp_e^*}{dG}=\frac{1}{2\Gamma'(p_e^*)+p_e^*\Gamma''(p_e^*)}<0 \tag{2.5}$$

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 2.3 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

$$\mathrm{E}[\Pi_i]=p_i[\bar{\pi}^M-\left(\overline{F}-\Gamma(p_i)\right)]+(1-p_i)\{p_e\left(\bar{\pi}^D-\overline{F}\right)+(1-p_e)\left(\bar{\pi}^M-\overline{F}\right)\}-R. \tag{2.6}$$

Consider again Figure 2.1. The incumbent's R&D project will succeed with probability

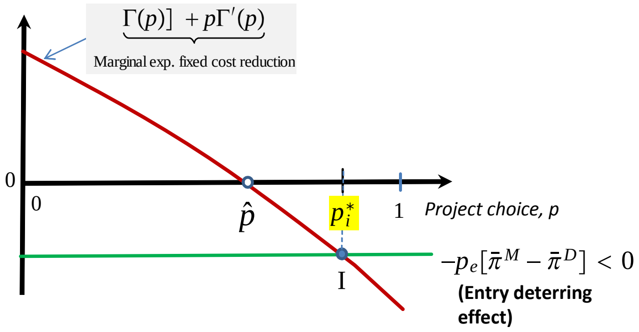

Figure 2.4: The incubent's optimal project (p_i^*).

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

$$\bar{\pi}^M - \left(\overline{F} - \Gamma(p_i)\right) + p_i\Gamma\prime(p_i) - \left\{p_e\left(\bar{\pi}^D - \overline{F}\right) + (1 - p_e)\left(\bar{\pi}^M - \overline{F}\right)\right\} = 0. \tag{2.7}$$

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 (2.7).

It is once more convenient to rewrite (2.7) as follows:

$$\Gamma(p_i^*) + p_i^*\Gamma'(p_i^*) = -p_e \underbrace{\left[\bar{\pi}^M - \bar{\pi}^D\right]}_{\substack{(+) \\ \text{Entry Deterring}}} < 0 \tag{2.8}$$

This condition is illustrated in Figure 2.4. 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 2.2(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 2.4), 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 (2.4) 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 2.5 (ii).

The reaction function of the incumbent $R_i(p_e)$ is implicitly given by eq. (2.8). Differentiating it in p_e and p_i, we obtain the corresponding slope $R_i'(p_e)$:

$$\frac{dp_i^*}{dp_e} = \mathcal{R}_i'(p_e) = -\frac{(\bar{\pi}^M - \bar{\pi}^D)}{2\Gamma'(p_i^*) + p_i^*\Gamma''(p_i^*)} > 0 \tag{2.9}$$

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 (2.8): 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 2.5 starting from the cost-efficient project, $\hat{p}$, which can be obtained by substituting $p_e = 0$ into (2.8). 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 2.3 and 2.4: 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 decrease the expected net entry cost. The incumbent, on the other hand, faces no cost of

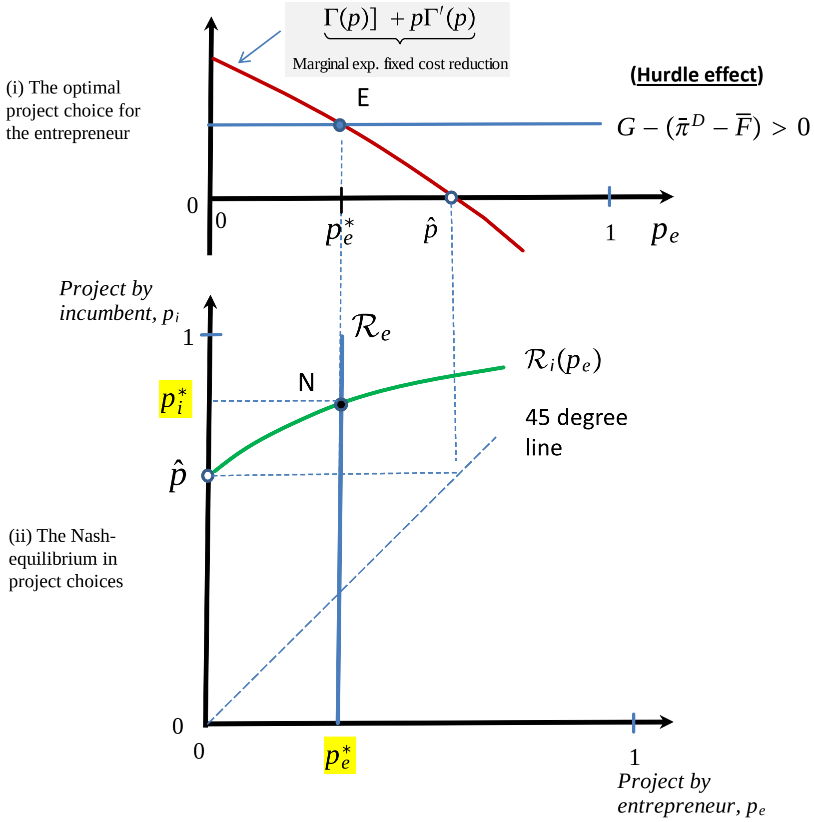

Figure 2.5: Deriving the Nash-equilibrium in project choices (N).

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, $\Gamma(p_e^*) > \Gamma(p_i^*)$.

3. 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 2.1.

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 $\bar{\pi}^D - \big(\overline{F} - \Gamma(p_e)\big) - G$, 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 2.1, 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

$$\begin{cases} \bar{W}^M = \bar{\pi}^M - \overline{F} + CS^M - 2R + 2\xi, \\ W^M(p_i) = \bar{\pi}^M - \big(\overline{F} - \Gamma(p_i)\big) + CS^M - 2R + 2\xi, \\ W^D(p_e) = \bar{\pi}^D - \big(\overline{F} - \Gamma(p_e)\big) - G + \bar{\pi}^D - \overline{F} + CS^D - 2R + 2\xi. \end{cases} \tag{3.1}$$

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, $W^D(p_e) - \bar{W}^M = \big[CS^D - CS^M\big] + \bar{\pi}^D - \overline{F} - G - \big[\bar{\pi}^M - \bar{\pi}^D\big]$: 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:

$$E[W(p_i, p_e)] = p_i W^M(p_i) + (1 - p_i)\{p_e W^D(p_e) + (1 - p_e)\bar{W}^M\} \tag{3.2}$$

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

3.1. 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 (3.2), this condition becomes

$$W^D(p_e) + p_e W^{D\prime}(p_e) = \bar{W}^M \tag{3.3}$$

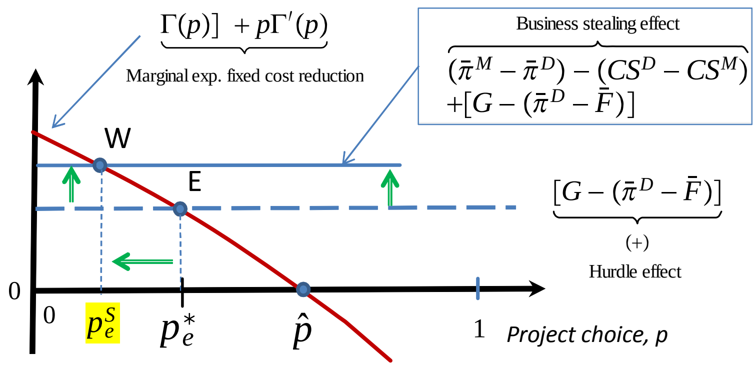

Figure 3.1: Comparing the first-best project (p_e^S) and the privately optimal project (p_e^*) for the entrepeneneur when the business stealing affect is positive, $\pi^M - \pi^D > CS^D - CS^M$.

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 (3.1), we can rewrite (3.3) as follows

$$\Gamma(p_e^S) + p_e^S\Gamma'(p_e^S) = \underbrace{[G - (\bar{\pi}^D - \overline{F})]}_{\substack{(+)\\ \text{Hurdle effect}}} + \underbrace{(\bar{\pi}^M - \bar{\pi}^D) - (CS^D - CS^M)}_{\substack{(?)\\ \text{Business stealing effect}}} \tag{3.4}$$

where p_e^S is the optimal choice of probability of success from a social point of view. Comparing (2.4) and (3.4), we see that whether or not the entrepreneur chooses a too safe or a too risky project depends on the second term in (3.4), 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 3.1.

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.

3.2. 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 (3.2), this condition becomes

$$W^M(p_i) + p_i W^{M\prime}(p_i) = p_e W^D(p_e) + (1 - p_e)\bar{W}^M \tag{3.5}$$

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 (3.1), it will be useful to write (3.5) as follows

$$\Gamma(p_i^S) + p_i^S \Gamma'(p_i^S) = -p_e \underbrace{(\bar{\pi}^M - \bar{\pi}^D)}_{\text{Entry deterring}} + \underbrace{p_e[\underbrace{\bar{\pi}^D - \left(\overline{F} - \Gamma(p_e)\right) - G}_{\text{Entrant's profit}} + \underbrace{CS^D - CS^M}_{\text{Consumer gain}}]}_{\text{Entry effect (+)}} \tag{3.6}$$

In eq. (3.6), 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 (3.6), 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 (2.8) to (3.6), 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 (3.6), $\Psi_i(0) = R_i(0)$: 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 (3.6) 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 (2.4), $\Psi_i'(p_e)$ can be re-written making use of the the first-order condition for the entrepreneur's project

$$\frac{dp_i^S}{dp_e} = \Psi_i'(p_e) = \frac{dE[W]/dp_e}{[2\Gamma'(p_i^*) + p_i^*\Gamma''(p_i^*)]\,(1-p_i^*)}. \tag{3.7}$$

Then, as shown in Figure 3.2, it follows from (2.4) and (3.7) 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 $p_e > p_e^S$.*

3.3. 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 3.2. 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 3.2. 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

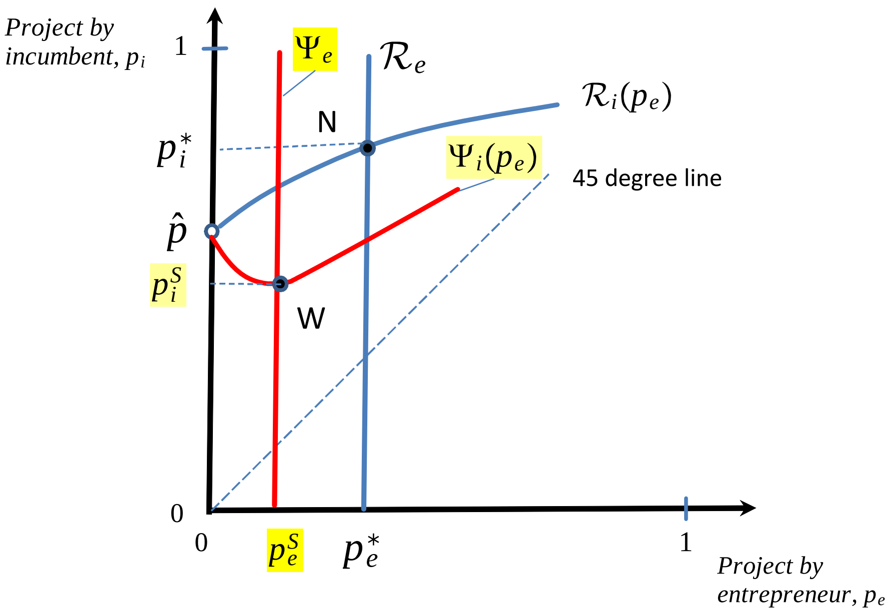

Figure 3.2: Comparing the first-best project choices (W) and Nash-equilibrium project choices (N) when the business stealing affect is positive, $\pi^M - \pi^D > CS^D - CS^M$.

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:

$$U(q_e, q_i, I) = aQ - \frac{1}{2}\left[q_i^2 + 2\gamma q_i q_e + q_e^2\right] + I \tag{3.8}$$

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.

4. Entrepreneurial policies

In the last few decades, entrepreneurship has emerged as a key issue in the policy arena.[16] 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.[17] 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.[18] 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:

$$E[\Pi_e(p_e^*, p_i^*)] = (1 - p_i^*)p_e^*[\pi^D - \left(\overline{F} - \Gamma(p_e^*)\right) - (G - s)] - (R - r) \tag{4.1}$$

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:

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

[17]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.

[18]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).

$$G \leq \bar{G}(s) = \pi^D - \left(\overline{F} - \Gamma(p_e^*)\right) + s. \tag{4.2}$$

Furthermore, it must be profitable for the entrepreneur to take on the investment cost R. From (4.1) and (4.2), the R&D cost must fulfil:

$$R \leq \bar{R}_E(r,s) = p_e^*(1-p_i^*)[\underbrace{\pi^D - \left(\overline{F} - \Gamma(p_e^*)\right) + s}_{\bar{G}(s)} - G] + r. \tag{4.3}$$

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 (2.8), 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 (2.4). 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.

4.1. 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. (2.5), (2.9) , (3.4), (3.6) and (4.1)), yields:

$$\frac{dE[W(p_e^*, p_i^*)]}{ds} = \left[\underbrace{\frac{\partial E[W(p_e^*, p_i^*)]}{\partial p_e}}_{\text{(-)}} + \underbrace{\frac{\partial E[W(p_e^*, p_i^*)]}{\partial p_i}}_{\text{(-)}} \underbrace{\mathcal{R}_i'(p_e^*)}_{(+)} \right] \underbrace{\frac{dp_e^*}{dG}}_{(-)} \underbrace{\frac{d\tilde{G}}{ds}}_{(-)} < 0 \tag{4.4}$$

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 4.1 illustrates this graphically: In Figure 4.1(i), a tax ($t = -s > 0$) on entry increases the hurdle effect, inducing the entrepreneur to choose higher risk. Then, as shown in Figure 4.1(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.

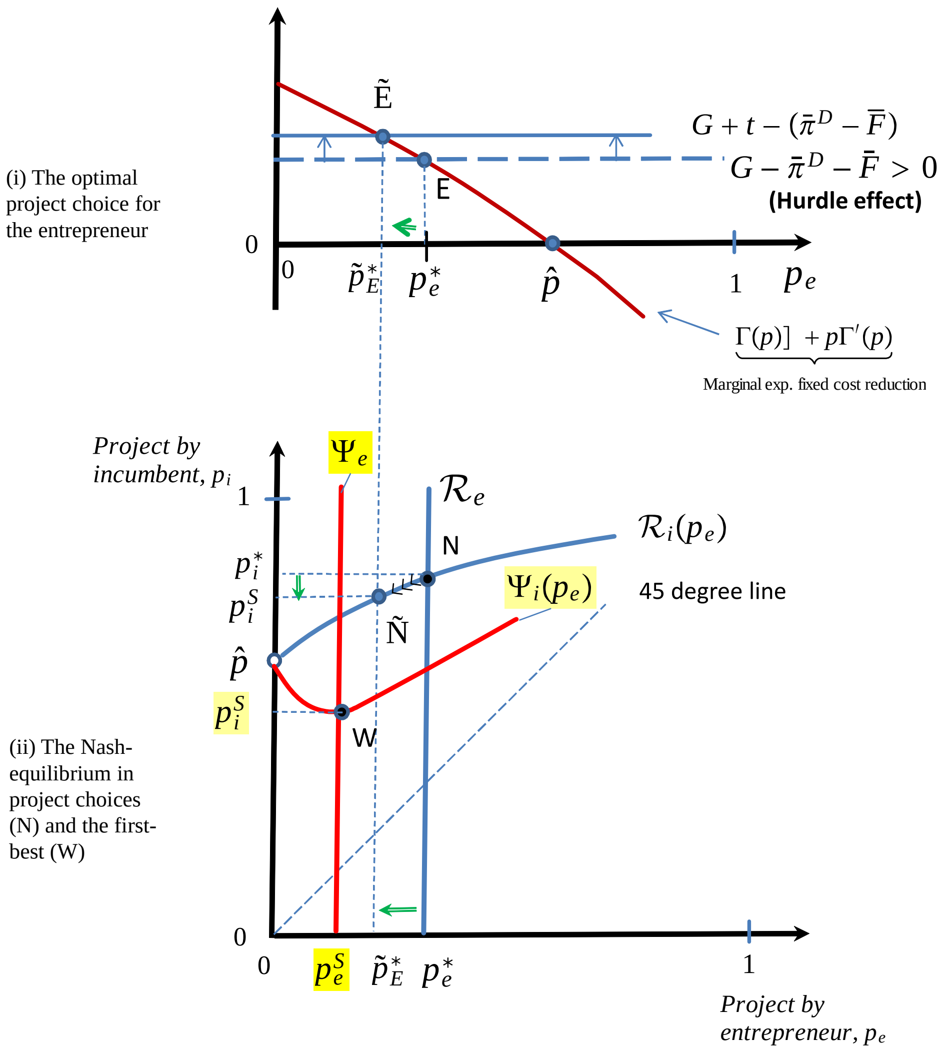

Figure 4.1: Asmall tax on entry will increase welfare when the business stealing affect is positive, $\pi^M - \pi^D > CS^D - CS^M$.

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.

5. 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).

5.1. 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.

5.2. The entrepreneur's optimal R&D project

The entrepreneur's expected payoff is given by:

$$\mathrm{E}[\Pi_e] = p_e(1 - p_i)[\pi_e^D(p_e) - G] - R \tag{5.1}$$

which is identical to (2.2), apart from the formulation of profits from a successful invention. The first-order condition, $dE[\Pi_e]/dp_e = 0$, is then:

$$\pi_e^D(p_e^*) + p_e^* \pi_e^{D\prime}(p_e^*) = G \tag{5.2}$$

which differs from (2.4) only by the constant terms $\bar{\pi}^D$ and $\overline{F}$.

Differentiating (5.2) in p_e and G, we obtain $\frac{dp_e^*}{dG} < 0$ just as in the benchmark model with fixed cost innovation.

5.3. The incumbent's optimal R&D project

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

$$\mathrm{E}[\Pi_i] = p_i \pi(p_i) + (1 - p_i)[p_e \pi_i^D(p_e)(1 - p_e)\bar{\pi}] - R \tag{5.3}$$

which is once more identical to (2.6), apart from the formulation of profits from a successful invention. The corresponding first-order condition, $dE[\Pi_i]/dp_i = 0$, is

$$\pi(p_i^*) + p_i^* \pi'(p_i^*) = \bar{\pi} - p_e[\bar{\pi} - \pi_i^D(p_e)]. \tag{5.4}$$

Compared to the expression in (2.8), 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, (5.2) and (5.3), 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 $\underset{F \to \pi_e^D(0)}{lim} p_e^*(G) = 0$. 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 (5.2), while equation (2.8) implicitly defines the incumbent's reaction function $R_i(p_e)$, whose slope is given by:

$$\mathcal{R}_i'(p_e) = -\frac{\bar{\pi} - \pi_i^D(p_e) - p_e \pi_i^{D'}(p_e)}{2\pi'(p_i^*) + p_i^* \pi''(p_i^*)} \tag{5.5}$$

and comparing it to (2.9), we see that the sign of the reaction function is now ambiguous.

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

$$E[W] = p_i W(p_i) + (1 - p_i)[p_e W^D(p_e) + (1 - p_e)\bar{W}] \tag{5.6}$$

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. (7.1) 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:

$$c_i^{Nosucc} = c, \qquad c_i^{Succ} = c - (1 - p_i), \qquad c_e^{Succ} = c - (1 - p_e) \tag{5.7}$$

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 (5.2) and (5.4), we obtain

$$p_e^*(\Lambda, G) = \frac{\Lambda+2}{3} - \frac{\sqrt{\Lambda^2+4\Lambda+27G+4}}{6}, \;\; p_i^*(\Lambda, G) = \frac{2\Lambda+2}{3} - \frac{\sqrt{\Lambda^2+2\Lambda+12\Phi(\Lambda,G)+11}}{3} \tag{5.8}$$

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 $\Lambda = a - c \geq 2$, $p_e^S < p_e^*$.*

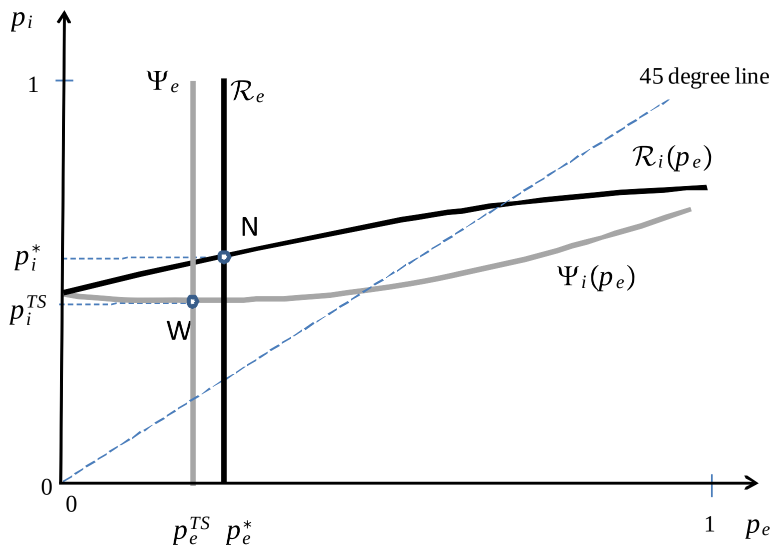

Figure 5.1: The variable cost saving model. The Nash equilibrium is given in point N and the first best solution is given in point S. Parameter values: $\Lambda = a - c = 2, G = 1$.

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 5.1. 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.

5.4. 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:

$$\mathrm{E}[\Pi_e] = p_e(1-p_i)\,(1-\theta)\,(\pi(p_e) - T - \bar{\pi}) - R_S. \tag{5.9}$$

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:

$$\frac{\partial \mathrm{E}[\Pi_e]}{\partial p_e} = \pi(p_e^*) - T - \bar{\pi} + p_e^* \pi'(p_e^*) = 0, \tag{5.10}$$

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:

$$\frac{dp_e^*}{dT} = \frac{1}{2\pi'(p_e^*) + p_e^* \pi''(p_e^*)} < 0, \tag{5.11}$$

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.

5.5. 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:

$$\mathrm{E}[\Pi_e] = p_e(1-p_i)[\pi_e^D(p_e) - F] + p_e p_i[\pi_e^D(p_e, p_i) - F] - R_E \tag{5.12}$$

where the corresponding first-order condition is given by:

$$\pi_e^D(p_e^*) - F + p_e^*\pi_e^{D\prime}(p_e^*) + p_i\{\pi_e^D(p_e, p_i) - \pi_e^D(p_e) + p_e[\pi_{e,p_e}^{D\prime}(p_e^*, p_i) - \pi_e^{D\prime}(p_e^*)]\} = 0. \tag{5.13}$$

From (5.13) 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:

$$\begin{aligned} \mathrm{E}[\Pi_i] &= p_i(1 - p_e)\pi(p_i) + p_e(1 - p_i)\pi_i^D(p_e) \\ &\quad + p_i p_e \pi_i^D(p_i, p_e) + (1 - p_i)(1 - p_e)\bar{\pi} \end{aligned} \tag{5.14}$$

with the first-order condition

$$(1 - p_e)\left[\pi(p_i^*) + p_i^*\pi'(p_i^*) - \bar{\pi}\right] + p_e\left[\pi_i^D(p_i, p_e) + p_i\pi_{i,p_i}^{D\prime}(p_i^*, p_e) - \pi_i^D(p_e)\right] = 0. \tag{5.15}$$

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 (5.15) becomes:

$$\pi(p_i^*) + p_i^*\pi'(p_i^*) - \bar{\pi} = 0 \tag{5.16}$$

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

5.6. 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:

$$\mathrm{E}[\Pi_{e_1}] = (1 - \frac{1}{2}p_{e_2})(1 - p_i)p_{e_1}[\pi_e^D(p_{e_1}) - F]. \tag{5.17}$$

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:

$$\begin{aligned} \mathrm{E}[\Pi_i] &= p_i(1-p_{e_1})(1-p_{e_2})\pi(p_i) + (1-p_i)\left[p_{e_1}(1-p_{e_2})\pi_i^D(p_{e_1}) + p_{e_2}(1-p_{e_1})\pi_i^D(p_{e_2})\right] \\ &\quad + p_i\left[p_{e_1}p_{e_2} + p_{e_1}(1-p_{e_2}) + p_{e_2}(1-p_{e_1})\right]\pi(p_i) \qquad (5.18) \\ &\quad + (1-p_i)(1-p_{e_1})(1-p_{e_2})\bar{\pi}. \end{aligned}$$

For a sufficiently high F, both entrepreneurs will choose a project with very high quality, i.e. $\underset{F\to\pi_e^D(p_{e_v})}{lim} p_{e_v}^*(F) = 0$, $v \in \{1,2\}$. 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.

5.7. 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

$$\mathrm{E}[\Pi_e] = p_e(1-p_{i_1})(1-p_{i_2})[\pi_e^T(p_e) - F] - R_F. \qquad (5.19)$$

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:

$$\frac{\partial \mathrm{E}[\Pi_e]}{\partial p_e} = \pi_e^T(p_e^*) - F + p_e^*\pi_e^{T\prime}(p_e^*) = 0. \qquad (5.20)$$

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

$$\frac{dp_e^*}{dF} = \frac{1}{2\pi_e^{T\prime}(p_e^*) + p_e^*\pi_e^{T\prime\prime}(p_e^*)} \qquad (5.21)$$

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, $\underset{F\to\pi_e^T(p_e)}{lim} p_e^*(F) = 0$.

6. 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 6.1 for the benchmark fixed cost

savings model.

Figure 6.1(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 reduces the net expected commercialization cost (the hurdle effect).

Figure 6.1(ii) shows that the expected fixed cost reduction will decrease when the entrepreneur is induced to choose a more uncertain project. This is 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 6.1(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 a 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 entails 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.

6.1. Data and variables

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.[19] In that year, 1082 patents were given to small (less than 500 employees) Swedish firms and individuals.[20] Information about inventors, applying firms, their addresses and the application date for each patent was obtained from the Swedish Patent and Registration Office (PRV, www.prv.se). Thereafter, a questionnaire was sent out to the inventors of the patents in 2004.[21] The inventors were asked where the invention was created, if

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

[20] In 1998, a total of 2760 patents were 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 smaller firms.

[21] 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.

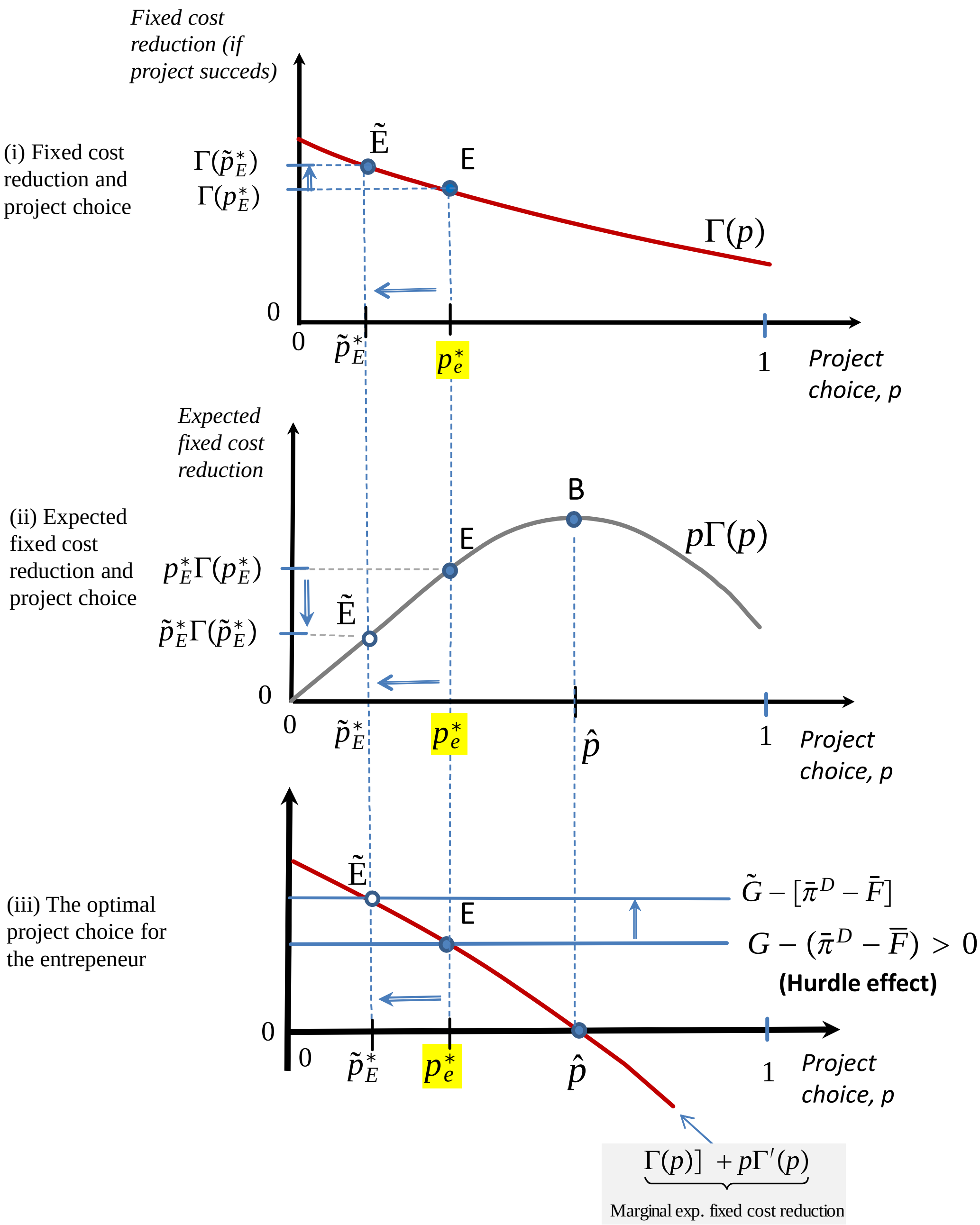

Figure 6.1: Illustrating empirical predictions in the benchmark fixed cost savings model

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.[22] From these 867, we focus on the 624 patents where the inventor has some ownership of the invention.[23]

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 initially exclude the 97 patents belonging to firms with more than 10 employees from our sample of 624 patents. Thus, our (baseline) empirical analysis is based on data from a set of 527 patents.

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 (baseline) empirical analysis is aimed at comparing the characteristics of these two groups.

In the supplementary material accompying the paper, we complement this analysis with other comparisons.[24] Specifically, we: (i) compare the group of self-employed inventors with the group of 97 patents that belong to firms with 11-500 employees (i.e., the group excluded in our baseline analysis), and (ii) compare the joint group of self-employed and micro companies (2-10 employees) with the group of 97 patents from firms with 11-500 employees. All these results strongly supports our empirical predictions and gives strong evidence in favor of the hurdle effect. Section 6.4.6 summarizes the main results from this robustness analysis.

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] The mean number of citations is calculated both within and across technology classes.[26]

Let L denote the group facing *low* entry costs, that is, in our baseline analysis, L denotes the group of inventors who jointly or individually own firms with 2-10 employees. Let $\{m_i^L\}_{i=1}^{122}$

[22]The 20% non-respondents did so in an unsystematic manner: 10% were due to the inventors having old addresses, 5% had correct addresses but were not possible to reach, and 5% 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.

[23]Of all 624 patents, 364 (∼58%) were commercialized, i.e., the holder received income from the patent.

[24]The supplementary material is downloadable from www.ifn.se/eng/people/research_fellows/per-hjertstrand.

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

[26]The 624 patents in the original sample 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 technology class at the four-digit ISIC-level.

denote the mean number of citations for the 122 patents held by inventors in group L. Similarly, let H denote the group facing *high* entry costs; thus, H denotes the group of inventors who are self-employed. Let $\{m_i^H\}_{i=1}^{405}$ denote the mean number of citations for the 405 patents held by inventors in group H. Finally, let $\{B_i^L\}_{i=1}^{122}$ and $\{B_i^H\}_{i=1}^{405}$ be binary variables taking on the value of one if the patent receives any forward citations within the five-year period, and zero if it does not:

$$B_i^L = \begin{cases} 1 & \text{if} \quad m_i^L > 0 \\ 0 & \text{if} \quad m_i^L \leq 0 \end{cases} \tag{6.1}$$

$$B_i^H = \begin{cases} 1 & \text{if} \quad m_i^H > 0 \\ 0 & \text{if} \quad m_i^H \leq 0. \end{cases} \tag{6.2}$$

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

Table 1: Descriptive statistics.

Series	#obs.	Mean	Std.	Median	Min	Max
m^L	122	0.5428	0.8143	0	0	3.3245
m^H	405	0.3526	0.9852	0	0	13.7678
B^L	122	0.4836	0.5018	0	0	1
B^H	405	0.2963	0.4572	0	0	1

Most evident from this table (and from the kernel density plot in Figure **??**) is that the distribution of m^H has a larger point mass at zero and a longer tail than the distribution of m^L.

6.2. Identification strategy

Our theoretical model predicts that the probability that an R&D project succeeds will decrease as entry costs decrease. When we test this prediction on our data, the identification strategy hinges on the possibility to observe failed R&D projects. Given that we can do so, the key to identifying the relationship between the probability of success and entry costs comes from the observed variation between successful and unsuccessful projects from our sample of firms with different entry costs. There are different ways to define a failed R&D project. In general terms, it is a project that does not generate any value. A failed project may be one where a patent application is denied. However, a failed project may also be one where a patent is granted, but the invention fails to reach the market, i.e., it is never implemented. We want to identify both these types as failures. Put the other way, a success is one where the invention is both patented and then put to work: it creates commercial value in a firm by reducing costs or by increasing sales. In our data set, we do not observe whether inventions are implemented. However, we do observe forward patent citations. As we have described, forward citations are regarded as the most important quality indicator in the literature (see Harhoff et al, 1999; Lanjouw and Schankerman, 1999, Hall et al., 2005, **ADDITIONAL REFERENCE**). If a

patent has forward citations, it is much more likely to have generated commercial value than if it has no forward citation at all (recall that self-citations are excluded). Therefore, we make the assumption that patents with zero forward citations are associated with failed R&D projects.

Our data set does not allow us to identify the first kind of failed R&D project; it does not include information on unsuccessful patent applications. However, given that there are economies of scale in writing patent applications it is likely that failed patent applications are more common for self-employed entrepreneurs than for established firms. This should imply that our results are likely to understate the effect of entry costs on the probability of successful R&D projects.

One important aspect of our identification strategy concerns identification of the causal relationship. We need to be able to rule out reverse causality. In other words, we want to exclude any possibility that the outcome of the R&D project has determined the entrepreneur's choice of organization mode (firm or self-employed). In our data set, the information about firm size is collected at the application date of the patent. At this stage, the commercial value is still highly uncertain. This allows us to identify the causal relationship (i.e., the hurdle effect).

Another important aspect of our identification strategy concerns identification of the correct mechanism. That is, we need to rule out that there are other (unobserved) underlying factors why some inventors do not want to start larger firms and for that reason behave in a more risky way in R&D. We address this important issue in detail in Section 6.4.1.

Finally, our empirical (identification) strategy consists of two parts. In a preliminary analysis, we show how the empirical predictions from the theoretical model can be non-parametrically identified. We do so by linking certain properties of the distribution of patent citations to each prediction. This allows us to test each prediction separately by comparing the distributions of patent citations for the two groups. Section 6.3 gives the details and the results from this preliminary (non-parametric) analysis. In the main empirical analysis, we introduce covariates (exogenous variables) to control for other possible explanations (mechanisms) of the hurdle effect and to capture and account for (observable) differences between firms. This allows us to test each empirical prediction conditional upon these variables within a regression framework. Section 6.4 gives a detailed account of the empirical (identification) strategy and the results from this regression analysis.

6.3. Preliminary analysis

We begin by checking whether the two groups L and H differ in general. For this purpose, we need the following assumption.

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

This assumption states that $\left\{m_i^L\right\}_{i=1}^{122}$ and $\left\{m_i^H\right\}_{i=1}^{405}$ 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 probability density functions (pdfs) of the distributions of L and H. We test if $f_L\left(m^L\right)$ and $f_H\left(m^H\right)$ are

(statistically) equivalent by evaluating the following hypothesis:

$$\begin{aligned} H_0 &: f_L\left(m^L\right) = f_H\left(m^H\right), \\ H_1 &: f_L\left(m^L\right) \neq f_H\left(m^H\right). \end{aligned} \tag{HYP1}$$

On the one hand, failing to reject H_0 means that $\left\{m_i^L\right\}_{i=1}^{122}$ and $\left\{m_i^H\right\}_{i=1}^{405}$ are drawn from the same underlying distribution, so that L and H cannot differ in the way suggested by our empirical predictions. On the other hand, rejecting H_0 implies that $\left\{m_i^L\right\}_{i=1}^{122}$ and $\left\{m_i^H\right\}_{i=1}^{405}$ are drawn from different underlying distributions, but provides no answer to the question *how* they differ.

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

$$f_l\left(m^l\right) = \begin{cases} \frac{1}{n^l h^l} \sum_{r=1}^{n^l} \left[K\left(\frac{m^l - m_r^l}{h^l}\right) + K\left(\frac{m^l + m_r^l}{h^l}\right)\right] & \textit{if } m^l \geq 0, \quad \textit{and,} \\ 0 & \textit{if } m^l < 0, \quad \textit{for } l = L, H, \end{cases} \tag{6.3}$$

where $n^L = 122$ and $n^L = 405$, and K refers to the kernel function (K is chosen to be the standard second-order Gaussian kernel). The bandwidths h^l for $l = L, H$ are calculated from the reflected data samples $\left[m_1^l, ..., m_{n^l}^l, -m_1^l, ..., -m_{n^l}^l\right]$ using the Sheater and Jones (1991) plug-in method. In the Li-test, we set the bandwidth equal to $\min\left\{h^L, h^H\right\}$. As recommended by Li and Racine (2007), we calculate the p-value for the test statistic using the consistent bootstrap procedure described in Li (1999).[28] We find that the Li-test strongly rejects H_0 that $f_L\left(m^L\right)$ and $f_H\left(m^H\right)$ are equal (p-value = 0.0002). Thus, we find that the two distributions differ and therefore continue to test each prediction separately.

6.3.1. Prediction (i): The probability of success decreases as entry costs increase

Our first empirical prediction states that the probability of having a successful patent should decrease when entry costs increases. Thus, given that zero forward citations indicates failure there should be a higher probability of drawing the value zero in the high-cost group (H) than in the low-cost group (L). Consequently, $f_H\left(m^H\right)$ should have a larger point mass at zero than $f_L\left(m^L\right)$. To test this prediction, we consider the binary variables B^L and B^H defined by (6.1) and (6.2). Our identifying assumption implies that $B^L = B^H = 0$ represents unsuccessful patents. We need the additional assumption.

Assumption B2: The binary variables B^L and B^H are Bernoulli distributed variables with

[27] 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 $f_H\left(m^H\right)$.

[28] 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.

survivor probabilities ω^L and ω^H, respectively.

This assumption states that B^L and B^H are Bernoulli random variables such that $\omega^L = P\left[B^L = 1\right] = P\left[m^L > 0\right]$ and $\omega^H = P\left[B^H = 1\right] = P\left[m^H > 0\right]$. Thus, ω^L and ω^H denote the probabilities of patents being cited at least once during the five-year period in the two groups or in other words, denotes the probabilities that the R&D projects are successful. Prediction (i) states that $\omega^H < \omega^L$, which can be evaluated using the following hypothesis:

$$\begin{aligned} &H_0 : \omega^H = \omega^L \Leftrightarrow \text{Equal probability of success in L and H} \Leftrightarrow \text{Prediction (i) does not hold,} \\ &H_1 : \omega^H < \omega^L \Leftrightarrow \text{Lower probability of success in H} \Leftrightarrow \text{Prediction (i) holds.} \end{aligned} \quad \text{(HYP2)}$$

We test (HYP2) using a two-sample $Z-$test of equal proportions, which gives a test statistic of -3.8296 with p-value < 0.000. Thus, H_0 in (HYP2) is strongly rejected implying that the data supports prediction (i), i.e., we find evidence that the probability of success decreases with increasing entry costs.

6.3.2. Prediction (ii): The quality of a successful innovation increases as entry costs increase

When entrepreneurs choose more risky projects, the hurdle effect implies that successful projects have a higher probability of attaining higher quality. This property is captured by our second empirical prediction which states that we should see more extreme outcomes in terms of quality (i.e., the number of citations) when entry is more costly.

In the statistical and econometrical literature, the probability of extreme events is most often measured by the kurtosis and the degree of tail-fatness. Prediction (ii) then stipulates that the high-cost group should have a larger tail mass (i.e., a fatter and longer tail) than the low-cost group. Thus, a test of this prediction can be constructed by comparing the degree of tail-mass of the low- and high-cost groups. Recall that $f_H\left(m^H\right)$ and $f_L\left(m^L\right)$ denotes the pdfs of the high-cost (H) and low-cost (L) groups, respectively. The degree of tail-mass of $f_H\left(m^H\right)$ and $f_L\left(m^L\right)$ can be estimated using the modified Hill estimator proposed by Huisman, Koedijk, Kool and Palm (2001). The original Hill estimator (Hill, 1975) produces an index measure of the tail-mass for the power-law family of distributions. Since this family covers a wide range of heavy-tailed distributions, the Hill estimator is quite general in that it can measure the degree of tail-mass for a large family of underlying distributions. The modified Hill estimator is a weighted average of Hill estimators for different threshold values that corrects for the small-sample bias of the original Hill estimator. Applying the modified Hill estimator to our data, we obtain a test statistic of 4.9966 for $f_L\left(m^L\right)$ and 1.9455 for $f_L\left(m^L\right)$.[29] According to these results, the distribution $f_H\left(m^H\right)$ has considerably more tail-mass than $f_L\left(m^L\right)$ (because a lower estimated tail index value indicates a fatter and longer tail.). Thus, our results show evidence in support of prediction (ii), that is, successful projects by inventors with high entry costs obtain a higher quality.

[29]Since prediction (ii) states that the quality should increase conditional on that the project is a success, we use only positive-valued number of citations when calculating the modified Hill estimator. Moreover, we follow Huisman et al. (2001) and choose the midpoint of the samples as the threshold value.

To get some intuition of these results, we can relate them in a parametric example: Suppose that $f_L(m^L)$ and $f_H(m^H)$ are the pdfs of two $t-$distributions with different degrees of freedom. As such, the tail index estimates obtained from the modified Hill estimator are equal to the number of degrees of freedom. Thus, the difference in tail-mass would in our case correspond to the difference between $t-$distributions with approximately 2 and 5 degrees of freedom - a quite substantial difference.

6.3.3. Prediction (iii): The quality of an innovation decreases as entry costs increase

Our third prediction says that the expected quality of the invention should decrease when entry costs increases. Let $\mu^L = \int_\Omega m^L f_L(m^L)\, dm^L$ and $\mu^H = \int_\Omega m^H f_H(m^H)\, dm^H$ be the expected number of citations for the groups L and H, respectively, where Ω denotes the support of L and H. Prediction (iii) stipulates that $\mu^H < \mu^L$, which can be evaluated with the following hypothesis.

$$\begin{aligned} &H_0 : \mu^H = \mu^L \Leftrightarrow \text{The expected number of citations is equal in } L \text{ and } H \Leftrightarrow \text{Prediction (iii) does not hold} \\ &H_1 : \mu^H < \mu^L \Leftrightarrow \text{The expected number of citations is lower in } H \Leftrightarrow \text{Prediction (iii) holds.} \end{aligned} \tag{HYP3}$$

We tested this hypothesis using a simple $t-$test and obtained the test statistic -2.1488 with p-value 0.0163. Thus, H_0 is rejected at the 5% significance level. This provides support for prediction (iii) implying that the expected quality decrease as entry costs increases.

6.4. Regression analysis

We now turn to the main analysis and develop a regression framework to test each empirical prediction. In doing so, we introduce covariates and controls in order to account for possible alternative explanations (mechanisms) of the hurdle effect and to capture and account for (observable) differences between firms. Our regression framework allow us to test the empirical predictions conditional upon these variables.[30] Specifically, since our dependent variable (m) given by the average number of forward citations is a left-censored continuous variable (at zero), we run Tobit regressions of the following form:

$$m_j = \max\left\{0, \gamma \mathbb{D}_j + \delta' \mathbf{x}_j + u_j\right\}, \tag{6.4}$$

for $j = 1, ..., 527$, where u_j is a mean zero normally distributed residual, and $(\gamma, \delta')'$ is the vector of parameters to be estimated. The observables in the Tobit model are:

- m : the (average) number of forward citations for our total sample of 527 patents, i.e.,

$$\{m_j\}_{j=1}^{527} \equiv \left\{m_j^L\right\}_{j=1}^{122} \cup \left\{m_j^H\right\}_{j=1}^{405},$$

- $\mathbb{D}$: a dummy variable taking on the values

$$\mathbb{D}_j = \begin{cases} 1 & \textit{if patent } j \textit{ belongs to the low entry cost group } L \\ 0 & \textit{if patent } j \textit{ belongs to the high entry cost group } H, \end{cases} \tag{6.5}$$

[30] The variables were collected through the questionaire sent out to all inventors.

for all $j = 1, ..., 527$. Thus, $\mathbb{D}_j$ equals 1 if the inventor of patent j jointly or individually owns a firm with 2-10 employees, and $\mathbb{D}_j$ equals 0 if the inventor of patent j is self-employed.

- $\mathbf{x}$: the matrix of covariates and controls. Table 2 describes these variables and gives some descriptive statistics for all observables.

Table 2: Description of variables and descriptive statistics

Notation	Description	Mean	Std.	Med.	Max	Min
	Dependent variable					
m	Average number of forward citations	0.44	1.02	0	13.8	0
	Explanatory variables					
$\mathbb{D}$	Dummy defined by Eq. (6.5)	0.23	0.42	0	1	0
GOVFIN	Percent of R&D financed by government	10.8	22.0	0	80	0
PRIVFIN	Percent of R&D financed by private venture capital	3.2	14.3	0	100	0
OTHFIN	Percent of R&D financed by universities/research foundations	2.6	13.9	0	100	0
UNIV	Dummy that equals 1 if the patent was created at a university and 0 otherwise	0.05	0.2	0	1	0
MOREPAT	Dummy that equals 1 if the inventors have more similar (competitive patents) and 0 otherwise	0.3	0.5	0	1	0
KOMPL	Dummy that equals 1 if complementary patents are needed to create a product and 0 otherwise	0.2	0.4	0	1	0
OWNER	Percent of the patent that is directly or indirectly owned by the inventor	93.6	19.3	100	100	3
INVNMBR	Number of inventors of the patent	1.3	0.6	1	4	1
SEX	Share of inventors who are female	0.03	0.17	0	1	0
ETH	Share of inventors with an ethnic background other than Western European or North American	0.03	0.15	0	1	0
Reg	Region dummys (in total 5 dummys)					
Ind	Industry dummys (in total 15 dummys)					

Notes: "Std." refers to the standard deviation and "Med." refers to the median

6.4.1. Control variables to account for possible alternative mechanisms

As we briefly discussed when addressing the identification strategy, an important issue concerns whether we have identified the correct underlying mechanism of the hurdle effect. The most natural starting point in dealing with this issue is to rephrase it as an omitted variables problem: Are there other (unobserved) underlying factors why some inventors do not want to start larger firms and for that reason behave in a more risky way in R&D? The natural answer is academic scientists.

DISCUSSION TO BE ADDED – EXCLUDE UNIVERSITY DUMMY FROM REGRESSION SPECIFICATION

Of all other possible alternative explanations (mechanisms), the most likely ones seem to be related to ability. It is important to note that ability cannot explain all three results that our empirical analysis gives. That is, if ability would explain the hurdle effect, then not only should the more capable inventors with firms on average produce inventions of higher quality, but there should also be a higher probability that they produce more 'breakthrough' inventions. But our empirical results show the opposite: higher entry costs are associated with inventions of higher quality. However, it is possible that ability could be a factor explaining two out of three of our empirical findings. Is it the case that inventors with firms are more able and therefore produces R&D projects that fail less often? And are their innovations of higher expected quality? Since we lack any direct measure of ability in our set of explanatory variables we use a variety of instruments to control for ability. These instruments include the variables (See Table 2 for a more detailed definition of the variables):

- MOREPAT (indicates whether the inventor has additional similar patents): Appealing to a learning-by-doing argument, it seems likely that inventors with similar patents are more experienced and have learned from previous mistakes which would then enhance the ability to avoid failure. Thus, we expect that MOREPAT is positively correlated with ability.

- PRIVFIN (gives the share of R&D financed by private venture capital): Obtaining private venture capital financing implies that the inventor has passed the screening performed by the venture capitalist, and can benefit from the venture capitalists' expertise. Both factors are expected to be positively correlated with ability.

6.4.2. Regression estimation results

We begin our analysis by discussing the (baseline) regression estimation results from the Tobit model (6.4) which are reported in Table 3. This table gives the estimates and standard errors of the regression coefficients $\left(\gamma, \delta'\right)'$, the estimates of the left-censored marginal effects (i.e., $\partial E\left[m \mid \mathbf{x}\right] / \partial x_j$) and the left-truncated marginal effects (i.e., $\partial E\left[m \mid \mathbf{x}, m > 0\right] / \partial x_j$), and finally the corresponding p-values of the coefficients and marginal effects for a one-sided (right-tailed) hypothesis test.[31]

First, we see from columns 2 and 3 that the coefficient γ corresponding to the dummy $\mathbb{D}$ which indicates whether the patent belongs to the high or low entry cost group is strongly significant. The interpretation of this is that patents in the low-cost group receives on average more citations (i.e., their projects are of higher quality) than those in the high-cost group. Second, looking at our control variables, we see that MOREPAT is (positively) significant. This means that inventions with additional patents are on average of higher quality than inventions

[31] Standard errors for the marginal effects were calculated using the delta method. For a binary variable x_j the left-censored marginal effect is calculated as $E\left[m \mid \mathbf{x}, x_j = 1\right] - E\left[m \mid \mathbf{x}, x_j = 0\right]$ and the left-truncated marginal effect is calculated as $E\left[m \mid \mathbf{x}, m > 0, x_j = 1\right] - E\left[m \mid \mathbf{x}, m > 0, x_j = 0\right]$. Table 3 reports the mean marginal effects taken over all observations. See Cameron and Trivedi (2005, ch.16) for more discussion on marginal effects in the Tobit model.

without any previous patents. Relating this to the discussion in the previous Section, it is perhaps not surprising as inventors with similar patents may be more experienced and have better perception of the probability of success (i.e., learning-by-doing).

Third, other significant variables are KOMPL and SEX. The positive significance of KOMPL means that patents that requires complementary patents are on average of a higher quality. A likely explanation for this result is that such inventions may be more technologically advanced and is therefore expected to be of higher quality than other less technological inventions. The interpretation of the (negatively) significant variable SEX is that inventions produced by a larger fraction of women recieves on average fewer citations.

Next, we will show how each empirical prediction relates to the dummy variable $\mathbb{D}$. In particular, we will derive statistical decision hypotheses based on this variable corresponding to each prediction. This allows us to test each prediction separately within our regression framework.

Table 3: Estimates of coefficients and marginal effects in Tobit model

Variable	Estimate (Std. err.)	p-value[a]	Left-censored marginal effect (Std. err.)	p-value[a]	Left-truncated marginal effect (Std. err.)	p-value[a]
$\mathbb{D}$	0.924 (0.242)	$< 0.000^{***}$	0.346 (0.098)	$< 0.000^{***}$	0.282 (0.078)	$< 0.000^{***}$
GOVFIN	0.006 (0.005)	0.106	0.002 (0.0015)	0.101	0.002 (0.001)	0.103
PRIVFIN	0.005 (0.005)	0.147	0.002 (0.0016)	0.143	0.001 (0.001)	0.145
OTHFIN	−0.001 (0.012)	0.454	−0.0004 (0.004)	0.454	−0.0004 (0.003)	0.454
UNIV	0.536 (0.823)	0.258	0.178 (0.273)	0.257	0.152 (0.234	0.258
MOREPAT	0.422 (0.217)	0.026^{**}	0.140 (0.072)	0.026^{**}	0.120 (0.062)	0.026^{**}
KOMPL	0.410 (0.241)	0.045^{**}	0.136 (0.080)	0.045^{**}	0.117 (0.069)	0.045^{**}
OWNER	0.006 (0.006)	0.125	0.002 (0.002)	0.124	0.002 (0.0016)	0.124
INVNMBR	0.164 (0.155)	0.146	0.054 (0.052)	0.146	0.047 (0.044)	0.146
SEX	−1.006 (0.683)	0.071^{*}	−0.334 (0.224)	0.069^{*}	−0.286 (0.193)	0.070^{*}
ETH	0.185 (0.792)	0.408	−0.061 (0.263)	0.408	0.053 (0.225)	0.408
Constant	−1.774 (0.754)	0.001^{***}				
Region dummys	YES					
Industry dummys	YES					
# obs.	527					
Log-likelihood	−548.068					

Note: The dependent variable (m) is the mean number of forward citations. The standard errors are robust standard errors. [a]

[a]The p-value is for a one-sided (right-tailed) hypothesis test. ***, **, * show significance at the 1%, 5%, and 10% level, respectively.

6.4.3. Prediction (i): The probability of success decreases as entry costs increase

Our theoretical model postulates that entrepreneurs facing high entry costs choose more risky projects to overcome the hurdle effect. Based on this, prediction (i) says that the probability of having a successful patent should decrease when entry costs increases. Consider the Tobit model (6.4) and recall our identifying assumption that a patent is successful if it recieves at least one forward citation (i.e., if $m > 0$). The probability of having a successful patent is given by:

$$P\left[m_j > 0\right] = P\left[\gamma \mathbb{D}_j + \delta' \mathbf{x}_j + u_j > 0\right] = P\left[u_j \leq \gamma \mathbb{D}_j + \delta' \mathbf{x}_j\right] = \Phi\left(\frac{\gamma \mathbb{D}_j + \delta' \mathbf{x}_j}{\sigma}\right),$$

where σ is the standard error of the residual u and Φ denotes the cdf of the standard normal distribution. If we recall from Eq. (6.5) that $\mathbb{D} = 0$ represents the low entry-cost group and $\mathbb{D} = 1$ the high entry-cost group, then the probability of having a successful patent conditional on entry costs is:

$$\begin{array}{ll} \text{Probability of success given high entry costs:} & P\left[m_j > 0 \mid \mathbb{D}_j = 0\right] = \Phi\left(\frac{\delta' \mathbf{x}_j}{\sigma}\right) \\ \text{Probability of success given low entry costs:} & P\left[m_j > 0 \mid \mathbb{D}_j = 1\right] = \Phi\left(\frac{\gamma + \delta' \mathbf{x}_j}{\sigma}\right). \end{array} \tag{6.6}$$

Prediction (i) states that the probability of success should decrease when entry costs increases, in which case we must have:

$$P\left[m_j > 0 \mid \mathbb{D}_j = 1\right] > P\left[m_j > 0 \mid \mathbb{D}_j = 0\right] \;\Leftrightarrow\; \Phi\left(\frac{\gamma + \delta' \mathbf{x}_j}{\sigma}\right) > \Phi\left(\frac{\delta' \mathbf{x}_j}{\sigma}\right), \tag{6.7}$$

where the equivalence follows directly from (6.6). Using that Φ is a continuous and strictly increasing function, it is then easy to show that the following proposition must hold.

Proposition 9. *Prediction (i) holds, that is, (6.7) is true, if and only if* $\gamma > 0$.

Proposition 9 suggests that prediction (i) can be tested by evaluating the following one-sided hypothesis:

$$\begin{array}{l} H_0 : \gamma = 0 \Leftrightarrow \text{Prediction (i) does not hold,} \\ H_1 : \gamma > 0 \Leftrightarrow \text{Prediction (i) holds.} \end{array} \tag{HYP4}$$

Columns 2 and 3 in Table 3 shows that the estimate of γ is highly significant (it is equal to 0.924 with p-value < 0.000). Thus, our regression analysis shows strong evidence that prediction (i) holds, i.e., the probability of success decreases with increasing entry costs.

6.4.4. Prediction (ii): The quality of a successful innovation increases as entry costs increase

When entrepreneurs choose more risky projects, the hurdle effect implies that successful projects has a higher probability of attaining higher quality. Thus, our second empirical prediction says that we should see more extreme outcomes in terms of quality when entry is more costly. As discussed above, the probability of extreme events is most often measured by the kurtosis and the degree of tail-fatness of a probability distribution. A distribution is characterized by a

higher kurtosis when more of the variability is due to a few extreme differences from the mean, rather than a lot of modest differences from the mean.[32]

Let the kurtosis of the distribution of patent citations conditional on success (i.e., $m > 0$) and *low* entry costs (i.e., $\mathbb{D} = 0$) be denoted $kurt\,[m \mid m > 0, \mathbb{D} = 0]$. Correspondingly, let the kurtosis of the distribution of patent citations conditional on success and *high* entry costs (i.e., $\mathbb{D} = 1$) be denoted $kurt\,[m \mid m > 0, \mathbb{D} = 1]$. Further define the difference between these two measures of kurtosis as

$$K = kurt\,[m \mid m > 0, \mathbb{D} = 0] - kurt\,[m \mid m > 0, \mathbb{D} = 1]\,. \tag{6.8}$$

According to prediction (ii), successful projects should be characterized by a higher probability of "breakthrough" inventions (i.e., extreme events) when entry costs increase, in which case the kurtosis for the high-cost group is larger than for the low-cost group, i.e.,

$$kurt\,[m \mid m > 0, \mathbb{D} = 0] > kurt\,[m \mid m > 0, \mathbb{D} = 1]\,, \tag{6.9}$$

or equivalently $K > 0$. The following proposition formalizes this link.

Proposition 10. *Prediction (ii) holds if (6.9) is true, i.e., if $K > 0$.*

The kurtosis in the Tobit model conditional on success and covariates $\mathbf{x}$ is calculated as (Pender, 2015):

$$kurt\,[m_j \mid \mathbf{x}, m_j > 0] = \frac{12\Psi r^3 - 4h_1 r^2 - 3\Psi^2 r^2 - 6r^4 + h_2 r}{\left(1 + \Psi r - r^2\right)^2}, \tag{6.10}$$

for all $j = 1, ..., 527$, where

$$r = \frac{\phi\,(\Psi)}{1 - \Phi\,(\Psi)}; \quad h_1 = \Psi^2 - 1\,; \quad h_2 = \Psi^3 - 3\Psi; \tag{6.11}$$

$$\Psi = -\left(\frac{\gamma \mathbb{D}_j + \delta' \mathbf{x}_j}{\sigma}\right). \tag{6.12}$$

The kurtosis conditional on success and entry costs in the Tobit model is then calculated by (6.10) and (6.11) and setting either $\mathbb{D} = 0$ for high entry costs or $\mathbb{D} = 1$ for low entry costs in (6.12), i.e.,

Kurtosis given high entry costs:	$kurt[m_j \mid x, m_j > 0, \mathbb{D}_j = 0]$	with $\Psi = -\left(\frac{\delta' x_j}{\sigma}\right)$
Kurtosis given low entry costs:	$kurt[m_j \mid x, m_j > 0, \mathbb{D}_j = 1]$	with $\Psi = -\left(\frac{\gamma + \delta' x_j}{\sigma}\right)$

Define K_j as in Eq. (6.8), i.e., $K_j = kurt\,[m_j \mid \mathbf{x}, m_j > 0, \mathbb{D}_j = 0] - kurt\,[m_j \mid \mathbf{x}, m_j > 0, \mathbb{D}_j = 1]$,

[32] More generally, the kurtosis can be seen as a joint measure of the degree of tail-mass and peakedness of a distribution. This becomes clear after considering the following simple illustration: take two overlapping left-censored distributions. 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. Since the amount of tail-mass measures the probability of extreme events, a larger mass implies a higher probability of extreme outcomes.

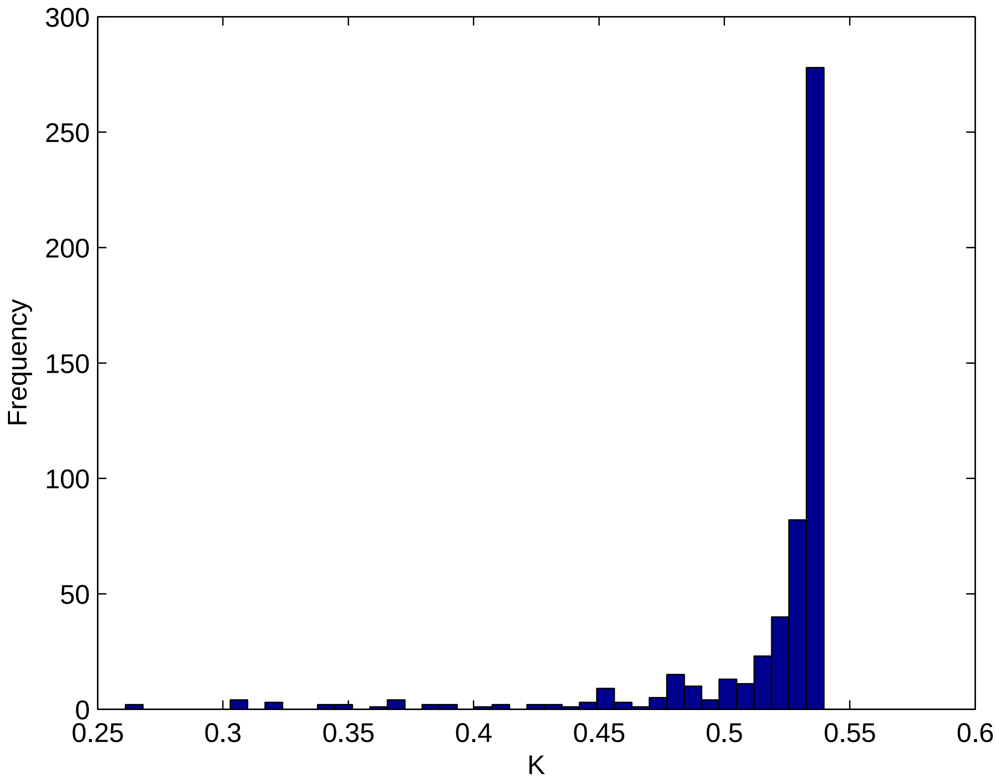

Figure 6.2: Histogram of estimated differences in kurtosis (K)

for all $j = 1, ..., 527$. Table 4 presents summary statistics of $\{K_j\}_{j=1}^{527}$ and Figure 6.2 plots the estimates of $\{K_j\}_{j=1}^{527}$ in a histogram.

Table 4: Summary statistics of the difference in kurtosis (K)

Series	Mean	Std.	Median	Min	Max
K	0.5168	0.0446	0.5341	0.2611	0.5397

As seen from Table 4, all values $\{K_j\}_{j=1}^{527}$ are positive. In fact, as Figure 6.2 shows, a very large fraction of these values are clustered around 0.5-0.53, with only a few values lower than 0.4. Thus, the kurtosis conditional on success and *high* entry costs is larger than the kurtosis conditional on success and *low* entry costs. Following the discussion above, this result should be read as that the distribution of patent citation given *high* entry costs have larger tails and is therefore characterized by a higher probability of extreme outcomes than the distribution given *low* entry costs. This is in line with prediction (ii), and provides strong evidence in favor of this prediction.

6.4.5. Prediction (iii): The quality of an innovation decreases as entry costs increase

Our theoretical model postulates that those entrepreneurs facing high entry costs choose more risky projects to overcome the hurdle effect. As such, prediction (iii) states that conditional on increasing entry costs, expected quality should decrease, in which case we have:

$$E\left[m_j \mid \mathbf{x}, \mathbb{D}_j = 1\right] > E\left[m_j \mid \mathbf{x}, \mathbb{D}_j = 0\right]. \tag{6.13}$$

Since $\mathbb{D}$ is a binary variable taking on the value 1 if the patent belongs to the low entry cost group and zero otherwise, we can use (6.13) to define the left-censored marginal effect $ME^{LC}(\mathbb{D})$ as

$$ME^{LC}(\mathbb{D}_j) = E\left[m_j \mid \mathbf{x}, \mathbb{D}_j = 1\right] - E\left[m_j \mid \mathbf{x}, \mathbb{D}_j = 0\right].$$

Thus, it is clear that the following proposition holds.

Proposition 11. *Prediction (iii) holds, that is, (6.13) is true, if and only if* $ME^{LC}(\mathbb{D}) > 0$.

Proposition 11 suggests that prediction (iii) can be evaluated with the following one-sided (right-tailed) decision hypothesis:

$$\begin{aligned} &H_0 : ME^{LC}(\mathbb{D}) = 0 \Leftrightarrow \text{Prediction (iii) does not hold} \\ &H_1 : ME^{LC}(\mathbb{D}) > 0 \Leftrightarrow \text{Prediction (iii) holds.} \end{aligned} \tag{HYP5}$$

Columns 4 and 5 in Table 3 report the estimates of the left-censored marginal effects from where we see that $ME^{LC}(\mathbb{D}) = 0.346$ with p-value < 0.000. Thus, the estimate of $ME^{LC}(\mathbb{D})$ is highly (positively) significant. This provides support for prediction (iii) implying that the expected quality decreases as entry costs increases.

We also calculated the left-truncated marginal effect of $\mathbb{D}$, which gives the marginal effect *conditional* on that the patent is successful. Let the left-truncated marginal effect be denoted $ME^{LT}(\mathbb{D}_j) = E\left[m_j \mid \mathbf{x}, \mathbb{D}_j = 1, m_j > 0\right] - E\left[m_j \mid \mathbf{x}, \mathbb{D}_j = 0, m_j > 0\right]$. We evaluated the following hypothesis.

$$\begin{aligned} &H_0 : ME^{LT}(\mathbb{D}) = 0 \\ &H_1 : ME^{LT}(\mathbb{D}) > 0. \end{aligned} \tag{HYP6}$$

Columns 6 and 7 in Table 3 reports the left-truncated marginal effects. From those columns we see that $ME^{LT}(\mathbb{D}) = 0.282$ with p-value < 0.000. Thus, $ME^{LT}(\mathbb{D})$ is highly (positively) significant thereby providing additional strong support for prediction (iii).

6.4.6. Summary of results from the robustness analysis

In addition to the baseline regression analysis presented here, we performed various robustness checks. These checks, which are found in the supplementary material accompying the paper, consists of two parts.[33] Initially, we consider in addition to the two groups in our baseline analysis also a third group of patents held by inventors who own (larger) firms of 11-500 employees. This group of inventors - originally excluded in our baseline analysis - consists of data on 97

[33] The supplementary material is downloadable from www.ifn.se/eng/people/research_fellows/per-hjertstrand.

patents (See Section 6.1). At first, we compare the characteristics of patent citations for this group of firms with the group of self-employed inventors. We apply our regression framework to this data and obtain results that are very similar to our baseline analysis; in particular, we find that each empirical prediction is strongly supported by the data. Detailed results from this comparison are given in Section 1.1 in the supplementary material.

We then merge the group of self-employed inventors with the group of inventors who owns micro-companies (2-10 employees) and compare the characteristics of this joint group with the one consisting of patents from firms of 11-500 employees. The results from this comparison are very much in line with the previous two, that is, we find clear evidence in favor of each empirical prediction. More detailed results are given in Section 1.2 in the supplementary material.

As a final set of robustness checks, we reran our regressions excluding either the region dummys, industry dummys, or both region and industry dummys. Section 2 in the supplementary material reports these results for the baseline analysis. Overall we find results similar to those with included region and industry dummys, i.e., they all support our empirical predictions. This suggests that our estimation results are robust.

6.4.7. What do we learn from all this?

We believe that several conclusions can be drawn from our empirical study of the entrepreneurship hurdle effect. First, the preliminary analysis show that it is rather safe to draw the conclusion that there is a difference between how self-employed inventors and inventors with a firm succeed on the market. It is true that the preliminary analysis does not control for observable covariates across the groups and that it does not account for sorting based on comparative advantages or ability. For this reason, we introduced covariates by developing a regression framework to evaluate and test the empirical predictions. Our second conclusion is that we still find strong evidence in favor of the entrepreneurship hurdle effect even after controlling for these observable differences. Third, our results also sheds some light on the empirical 'puzzle' documented in Åstebro et al. (2014) and discussed in the introduction: the expected returns from entrepreneurship tend to be low on average but exhibit large dispersion because most startups fail and only a few are very successful.

7. 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 provide a regression framework to test the empirical predictions of the model. We show how each empirical prediction can be tested within this framework.

Using unique data over Swedish patents, we find strong empirical evidence supporting these predictions.

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 to *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:

$$U(\mathbf{q}, I) = aQ - \frac{1}{2}\left[q_i^2 + 2\gamma q_i q_e + q_e^2\right] + I \tag{7.1}$$

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

$$P_j = a - q_j - \gamma q_h, \quad j \neq h\ . \tag{7.2}$$

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 (2.1) becomes

$$\frac{\partial \pi_j}{\partial q_j} = P_j - c_j - q_j^* = 0 \tag{7.3}$$

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

$$q_i^M = \frac{\Lambda}{2} \text{ and } q_i^D = q_e^D = \frac{\Lambda}{2+\gamma}. \tag{7.4}$$

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 (7.2), prices are $P_i^m = a - q_i^M$ and $P_i^D = P_e^D = a - (1+\gamma)\, q^D$. We then have that the consumer surplus in each market structure is given by

$$\begin{cases} CS^D = CS(\mathbf{q}^D) = aQ^D - \frac{1}{2}\left[\left(q_i^D\right)^2 + 2\gamma q_i^D q_e^D + \left(q_e^D\right)^2\right] - P_i^D q_i^D - P_e^D q_e^D \\ CS^M = CS(q_i^M) = a q_i^M - \frac{1}{2} q_i^M - P_i^M q_i^M. \end{cases} \tag{7.5}$$

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:

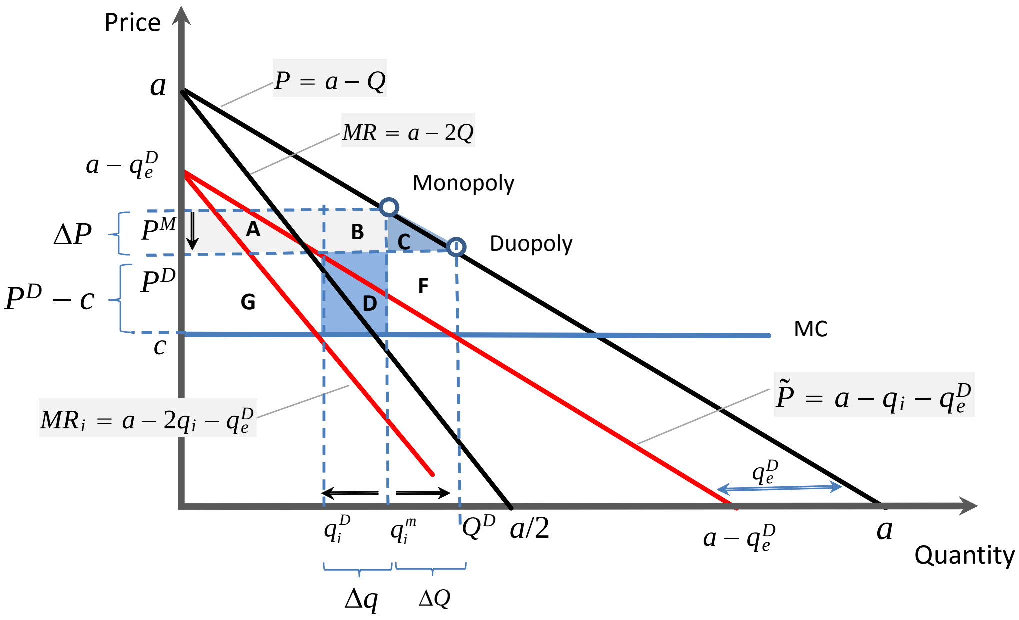

Figure 7.1: The business stealing effect in **a** Cournot model with homogenous goods is the area D-C.

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 7.1. 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

$$\pi^M - \pi^D - (CS^D - CS^M) = \frac{1}{8}\Lambda^2 \frac{3\gamma - 2}{\gamma + 2}. \tag{7.6}$$

From (7.6), 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.