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Innovation or Imitation? The effect of spillovers and competitive pressure on firms' R&D strategy choice

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September, 2011

Abstract

This article provides a theoretical and empirical analysis of a firm's optimal R&D strategy choice. In this paper a firm's R&D strategy is assumed to be endogenous and allowed to depend on both internal firms' characteristics and external factors. Firms choose between two strategies, either they engage in R&D or abstain from own R&D and imitate the outcomes of innovators. In the theoretical model this yields three types of equilibria in which either all firms innovate, some firms innovate and others imitate, or no firm innovates. Firms' equilibrium strategies crucially depend on external factors. We find that the efficiency of intellectual property rights protection positively affects firms' incentives to engage in R&D, while competitive pressure has a negative effect. In addition, smaller firms are found to be more likely to become imitators when the product is homogeneous and the level of spillovers is high. These results are supported by empirical evidence for German firms from manufacturing and services sectors.

Regarding social welfare our results indicate that strengthening intellectual property protection can have an ambiguous effect. In markets characterized by a high rate of innovation a reduction of intellectual property rights protection can discourage innovative performance substantially. However, a reduction of patent protection can also increase social welfare because it may induce imitation. This indicates that policy issues such as the optimal length and breadth of patent protection cannot be resolved without taking into account specific market and firm characteristics.

Journal of Economic Literature Classification Numbers: C35, D43, L13, L22, O31.

Keywords: Innovation; imitation; spillovers; product differentiation; market competition; intellectual property rights protection.

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1 Introduction

The economic literature on innovation has provided two confronting views concerning the relationship between innovation and imitation and its implications for policy design. According to the Schumpeterian view, imitation dampens innovation as it renders innovative efforts unprofitable. In this view, intellectual property rights (IPR) protection is a necessary mechanism that provides incentives for firms to engage in R&D and encourages technology transfer between firms. Therefore, a strong protection of intellectual property rights would be the optimal R&D policy (Arora and Gambardella, 1994; Gallini and Scotchmer, 2002; Gans and Stern, 2003; Gans et al., 2008). However, this view has recently been challenged by Aghion et al. (2001), Bessen and Maskin (2009) and Zhou (2009) who show that stronger imitation fosters innovative efforts by incumbent firms and patent protection can block the future development of technologies.

Looking at these contradictory views the question of what should be the optimal balance of innovation and imitation arises. Certainly, the evidence on innovative activity at the firm level suggests elevated heterogeneity in innovative performance within as well as across markets. The heterogeneity observed is the result of firms' decisions to engage in R&D or to abstain from own R&D and imitate the outcomes of innovators. This indicates that any policy intervention might not only affect the level of a firm's R&D performance but also the strategies adopted by firms. In this paper we are particularly interested in analyzing how external market parameters such as the intensity of IPR protection and market competition, or the degree of product differentiation affect firms' R&D strategy choices. For this purpose we extend the existing research by analyzing jointly the effect of external and internal factors on a firm's R&D strategy choice, innovation or imitation. The analysis is done both from a theoretical and an empirical perspective.

In the theoretical part of the paper we develop a two-stage Cournot model with differentiated products and strategic R&D choice. In stage 1, firms decide simultaneously what R&D strategy to apply, innovation or imitation. In stage 2, firms compete in quantities with differentiated products, conditional on their R&D strategy choice. We characterize the equilibria of this game and show how different innovation patterns that depend on the extent of spillovers, asymmetries between firms and competitive pressure arise. Three types of equilibria are obtained: equilibria in which all firms innovate, equilibria in which firms choose asymmetric R&D strategies, and equilibria in which no firm innovates. We find that the efficiency of IPR protection positively affects firms' incentives to engage in R&D, while competitive pressure has a negative effect. In addition, smaller firms are found to be more likely to become imitators when products are homogenous and the level of spillovers is high. Regarding social welfare, our results indicate that the strengthening of IPR protection can have an ambiguous effect. If a market is characterized by a high rate of innovation, a reduction of IPR protection can discourage innovative performance substantially. However, a reduction of IPR protection can also increase social welfare because it may induce imitation.

Our empirical analysis tests the predictions derived from the theoretical model. We consider a firms' R&D strategy choice between imitation and innovation. Our explanatory variables are internal factors (firm size, "absorptive capacity", and geographical market size) and external factors (IPR protection, product differentiation, competitive pressure, and demand uncertainty). We find a strong evidence for the main predictions of the theoretical model. A firms' R&D strategy choice is tightly related to external factors. First, a lower level of spillovers provides incentives to engage in R&D. Second, competitive pressure, measured by the number of competitors, and higher product substitutability have a negative effect on a firm's decision to innovate.

The main policy implication derived from our analysis is that a common IPR protection policy for all markets might be inappropriate. This is because a policy that is beneficial for a certain type of market might discourage innovation and technological progress in another with different characteristics. The analysis of spillovers on social welfare shows that a reduction of IPR protection, intended to induce imitation, can discourage innovative performance substantially in markets that are characterized by a high rate of innovation. Then, an additional reduction of IPR protection induces more imitation and increases welfare. However, after a certain point, the reduction of patent protection completely discourages innovation and therefore reduces social welfare. Moreover, IPR protection policy must be tightly coordinated with the competition policy. This is because external parameters such as IPR protection and competitive pressure jointly affect the firms' R&D strategy choice.

This paper is related to a large literature on the relationship between market structure and innovation strategy. Specifically, it is related to two strands in the literature. The first strand analyzes how firms' R&D investments are affected by market competition. Pioneer works in this field are those of Schumpeter (1934 and 1942) who argues that, on the one hand, market pressure may foster firms' innovation, but, on the other hand, it may decrease firms' R&D investments because monopoly power of larger firms acts as a major accelerator of technological progress. Actually, there is still no accordance on this Schumpeterian debate in theoretical and empirical studies. For example, some authors argue that more intensive market competition decreases a firm's incentives for innovation because when advantages from innovation are temporary, only sufficient market power guarantees that firms invest in R&D (Arrow, 1962; Futia, 1980; Gilbert and Newbery, 1982; Reinganum, 1983; or Zhou, 2009). This argument is supported by empirical studies that find that market concentration increases the pace of innovative change. For instance, Henderson and Cockburn (1996) show that large firms in the US pharmaceutical industry perform R&D more efficiently, as they can enjoy scale and scope economies. Using patent data of UK manufacturing firms, Cefis (2003) finds that, due to innovative effort, the contribution of large firms to aggregated industrial performance is above the industry mean. On the other hand, market concentration is also argued to have a dampening effect on innovation because more intensive competition acts as an important incentive for firms to innovate (Dasgupta & Stiglitz, 1980). Again, these theoretical arguments are supported by empirical evidence (Geroski, 1990; Blundell et al., 1999).

These contradictory results led to the hypothesis that the effect of market competition on firms' innovative efforts is non-monotonic. For example, Boone (2000) finds that when competition is weak, the incentives of less efficient firms to innovate increase. However, when competition becomes more intense, the incentives of efficient firms to innovate grow. Aghion et al. (2005) suggest the existence of an inverted-U relationship. Both, a low or high level of competition provide low incentives to innovate while a medium level of competition fosters innovation of firms operating on a similar technological level ("neck-and-neck firms"). On the contrary, Tishler and Milstein (2009) find that R&D investments decrease with competitive pressure. However, at a certain level of competition firms engage in "R&D wars" and spend excessively on R&D.

The above literature assumes that firms' innovation behavior is homogeneous, that is, that all firms innovate. However, empirical evidence suggests that most markets are characterized by an elevated heterogeneity of R&D activities. So, in most markets we find a core of firms that are persistent innovators while other firms either are occasional innovators or imitators (Cefis and Orsenigo, 2000; Cefis, 2003). Czarnitzki et al. (2008) find that, depending on a firm's role in the market, competitive pressure might have a different effect on innovative effort. So, while entry pressure decreases the average investment per firm, it increases innovative effort of market leaders.

The second strand of the literature to which this paper is related are studies that allow for heterogeneity in firms' R&D strategies by distinguishing between firms that innovate and those that imitate innovators. Theoretical studies have analyzed the effect of the possibility of imitation on innovative incentives in two frameworks, economic growth models (Grossman & Helpman, 1991; Aghion & Howitt, 1992) and oligopolistic competition models (Zhou, 2009). In both cases, the imitation rate is assumed to be exogenously determined. Imitation is shown to foster the innovation activity of technological leaders. This finding challenges the common view that patent protection should be strengthened. In fact, strong IPR protection may slow down the development of countries and decrease world welfare and consumer surplus (Helpman, 1993; Bessen & Maskin 2009; Che et al., 2009; Fershtman & Markovich, 2010). Additionally, Braguinsky et al. (2007) find that the relationship between innovation and imitation itself depends on other factors such as the maturity of an industry. When the industry is young and small, innovators do not have incentives to prevent imitation. But when the industry expands, innovative effort decreases because of imitation pressure.

Most of this literature assumes that innovators and imitators are exogenously given. Exceptions in the theoretical literature are Segestrom (1991) and Amir and Wooders (2000). Applying an economic growth model, Segestrom (1991) allows firms to participate in both innovative and imitative R&D races. In the steady-state, firms' equilibrium R&D strategies depend on the distribution of previous R&D outcomes and the relative price of imitation. Firms are found to benefit more from imitation in industries with a single leader, while in industries with several leaders innovation is a more profitable strategy. In a standard oligopoly framework, Amir and Wooders (2000) show that, in equilibrium, firms choose their R&D strategies asymmetrically. This gives rise to an innovator/imitator configuration in the market. Regarding the empirical literature, the determinants of firms' R&D strategy choices have been studied by a small number of authors. Using US marketing data, Robinson and Min (2002) find that innovators face higher survival risks associated with technological uncertainties. On the other hand, Zhou (2006) finds that in the presence of demand uncertainty or with more competitive pressure firms obtain higher benefits from being pioneers in innovation. Shankar et al. (1998) analyze data on sales and advertising of 13 brands of ethical drugs in the US. They show that imitators with a slightly differentiated product can grow faster than initial innovators. Therefore, in the presence of rapidly changing technologies, in the long run, imitators obtain higher benefits than innovators because the innovator's initial profits are rapidly discouraged.

The rest of the paper is arranged as follows. Section 2 presents a theoretical Cournot duopoly model of R&D strategy choice and extensions for the cases of asymmetric firms and more than two-firm competition. The empirical analysis is performed in Section 3. Section 4 discusses the policy implications of our findings. Proofs are in the Appendix.

2 A duopoly model

In this section we develop a two-stage Cournot duopoly model with differentiated products and strategic R&D choice. In stage 1, firms decide simultaneously what R&D strategy to apply, innovation or imitation. In stage 2, firms compete in quantities with differentiated products, conditional on their R&D strategy choice. We assume that each firm produces a single good and that the two goods are substitutes. The inverse demand function of good i is:

$$p_i = a - bq_i - dq_j, \;\; i, j = 1, 2, i \neq j, \tag{1}$$

where p_i is the price and q_i is the quantity of good i. We assume that $a > 0$, $b > 0$, $d \geq 0$. Furthermore, the absolute value of the own-price effect on the quantity demanded is assumed to be higher than the corresponding effect of the price of the substitute, thus $b - d \geq 0$.

The R&D strategy at stage 1 is realized by the choice of a binary variable x_i, where $x_i = 1$ stands for the firm's decision to engage in R&D and $x_i = 0$ means that the firm abstains from innovation. R&D investment allows a firm to reduce its unit production cost c by the amount γx_i at cost Kx_i, where $\gamma \in [0, 1]$ and $K > 0$ are known constants. However, if a firm abstains from investing in R&D at stage 1, due to spillovers, it's production cost still is reduced by imitating the rival's R&D outcomes. Concretely, if firm i innovates and firm j abstains from innovation but decides to imitate, the unit cost reduction for firm j is $\sigma\gamma x_i$. The parameter σ indicates to what extent a cost reduction of firm i allows firm j to reduce its own production costs. We assume that $\sigma \in [0, 1]$, where $\sigma = 0$ indicates that there are no spillovers and $\sigma = 1$ means that firm j obtains the same cost saving as firm i without any additional investment.[1] Resuming this, the unit production cost of firm i is given by:

$$c_i(x_1, x_2) = \begin{cases} c - \gamma x_i & \text{for } x_1 = 1 \text{ and } x_2 = 1 \\ c - \gamma(x_i + \sigma x_j) & \text{else} \end{cases}, \quad i, j = 1, 2, i \neq j \tag{2}$$

where $c > \gamma$. The innovation activity analyzed in this paper is cost-reducing (process innovation). However, the results can be straightforwardly generalized to the case of product innovation.[2]

Total production costs are $C_i(x_1, x_2) = c_i(x_1, x_2) q_i$. The objective of firm i is to choose the R&D strategy that maximizes profits:

$$\Pi_i(x_1, x_2) = \pi_i(x_1, x_2) - Kx_i \tag{3}$$

where $\pi_i(x_1, x_2)$ denotes operating profits obtained in stage 2.

The solution concept is Subgame Perfect Nash Equilibrium (SPNE) and the game is solved by backward induction. First, for given R&D strategies the optimal equilibrium outputs are solved in the second stage. Then, firms' profit-maximizing R&D strategies in stage 1 are derived.

In *stage 2*, firm i chooses the output q_i in order to maximize its operating profit:

$$\pi_i = (a - bq_i - dq_j) q_i - c_i q_i, \; i, j = 1, 2, i \neq j. \tag{4}$$

From straightforward calculations we find that the Nash-Cournot equilibrium output for firm i is given by:

$$q_i = \frac{2b(a - c_i) - d(a - c_j)}{4b^2 - d^2}, \; i, j = 1, 2. \tag{5}$$

Notice, that the output of firm i is positive as long as $(a - c_i) > \frac{d}{2b}(a - c_j)$. Firm i's optimal equilibrium operating profit is given by $\pi_i = bq_i^2, \;\; i = 1, 2$.

In *stage 1*, firms choose their profit-maximizing R&D strategy. When both firms engage in R&D (i.e. $x_1 = x_2 = 1$), quantities and profits are:

$$q_i(1,1) = \frac{a - c + \gamma}{2b + d} \quad \text{and} \quad \Pi_i(1,1) = bq_i(1,1)^2 - K. \tag{6}$$

If none of the firms engages in R&D (i.e. $x_1 = x_2 = 0$), quantities and profits are equal to those of the classical Cournot model with differentiated products:

$$q_i(0,0) = \frac{a - c}{2b + d} \quad \text{and} \quad \Pi_i(0,0) = bq_i(0,0)^2. \tag{7}$$

Finally, if one firm engages in R&D, say firm 1, and firm 2 decides to imitate, the corresponding quantities and profits are given by:[3]

$$q_1(1,0,\sigma) = \frac{(2b - d)(a - c) + (2b - d\sigma)\gamma}{4b^2 - d^2} \quad \text{and} \quad \Pi_1(1,0,\sigma) = bq_1(1,0,\sigma)^2 - K \tag{8}$$

$$q_2(1,0,\sigma) = \frac{(2b - d)(a - c) + (2b\sigma - d)\gamma}{4b^2 - d^2} \quad \text{and} \quad \Pi_2(1,0,\sigma) = bq_2(1,0,\sigma)^2. \tag{9}$$

[1] Here we focus on asymmetric spillovers (from the innovator to the imitator), which is justified when firms perform different roles in the market (see Bower and Christensen, 1995; De Bondt, 1996; Amir and Wooders, 2000).

[2] See Tishler and Milstein (2009) for this.

[3] Further on, without loss of generality, we assume that firm 1 innovates and firm 2 imitates.

The equilibrium R&D strategies are obtained as a result of each firm's best strategic response to the profit-maximizing strategy of the rival. The most interesting parameters that affect a firm's R&D strategy choice are the extent of spillovers in the industry and the degree of product differentiation, which sometimes is interpreted as a measure for the intensity of competition in the industry (for instance,Tishler and Milstein, 2009).

The value of the spillover parameter reflects the legal and technical framework of the industry, specifically, the level of IPR protection or the ease of knowledge transfer in the market. The polar cases are a blue print diffusion in the absence of IPR protection, or the absolute ease of replication ($\sigma = 1$), and an absence of any knowledge diffusion when an invention can be completely protected by a patent, or a high level of knowledge sophistication that makes it impossible to replicate ($\sigma = 0$). In practice, most markets can be characterized by some intermediate level of spillovers. The degree of product differentiation varies from completely different products ($d = 0$) to homogeneous or identical products ($d = 1$). To exclude trivial cases we make restrictions on R&D costs:

Assumption 1. Let $\underline{K} < K < \overline{K}$ where $\underline{K}$ is defined by $\Pi_i(1,1) = \Pi_i(0,0)$, $i = 1,2$ and $\overline{K}$ is defined by $\Pi_2(1,1) = \Pi_2(1,0,0)$.

This assumption guarantees that costs are not too low such that making no R&D is a possible choice and that costs are not too high such that in the absence of spillovers firms are interested in investing in R&D. Thus, the focus of the analysis is to characterize the conditions under which engaging in R&D is a Nash equilibrium. Assuming that firm 1 decides to innovate, from expressions (6) and (9) we see that firm 2 faces a trade-off when choosing between innovation and imitation. On the one hand, if firm 2 decides to innovate it must pay a cost K, which in turn allows to obtain a reduction of unit production costs. On the other hand, if firm 2 decides to imitate, it saves the payment of the R&D cost K. Then, however, the decrease in unit production costs will be lower and depend on the R&D outcome of the innovator and the value of the spillover parameter.

To characterize the equilibria of the two-stage game, let $\underline{\sigma}$ be implicitly defined by $\Pi_i(1,1) - \Pi_2(1,0,\underline{\sigma}) = 0$ and $\overline{\sigma}$ by $\Pi_1(1,0,\overline{\sigma}) - \Pi_i(0,0) = 0$. We obtain the following proposition:

Proposition 1 *(Existence of equilibria)*
For given parameter values (d, b, a, c, γ) the equilibrium R&D strategies are characterized as follows:

(i) When spillovers are low ($\sigma \leq \underline{\sigma}$) there exists a pure strategy SPNE, in which both firms engage in R&D (Region I).

(ii) When spillovers are intermediate ($\underline{\sigma} \leq \sigma \leq \overline{\sigma}$) there exist multiple pure strategy SPNE, in which one firm engages in R&D and the other firm chooses to imitate (Region II).

(iii) When spillovers are high ($\overline{\sigma} \leq \sigma$) there exists a pure strategy SPNE, in which none of the firms engages in R&D (Region III).

Furthermore, $\partial\overline{\sigma}/\partial K < 0$, $\partial\underline{\sigma}/\partial K < 0$, $\partial\overline{\sigma}/\partial\gamma < 0$, $\partial\underline{\sigma}/\partial\gamma < 0$, $\partial\overline{\sigma}/\partial(a-c) > 0$ and $\partial\underline{\sigma}/\partial(a-c) > 0$.

The three regions are displayed in Figure 1. In Region I there exists a unique SPNE in pure strategies in which both firms innovate. This equilibrium is obtained when spillovers and R&D costs are low and when markets are large. Actually, Region I corresponds to the case of a highly innovative competitive industry with either an elevated level of knowledge protection or knowledge sophistication such that innovations are difficult to copy. In Region III there exists a unique SPNE in which none of the firms innovates. This equilibrium emerges in the presence of high spillovers and elevated product homogeneity. Region III is an example of markets where competition together with free knowledge flows discourages innovation.

While firms' R&D strategies in Regions I and III are symmetric, in Region II both firms choose opposed strategies in equilibrium. Furthermore, we have multiple equilibria with one innovating and one imitating firm.[4] This is the case for intermediate spillover levels. An increase in R&D cost K and a decrease in market size $a - c$ shifts the curves to the "south-west" so that Region I becomes smaller and innovation in Region II holds for lower spillover level. Interestingly, Amir and Wooders (2000) also find that initially symmetric firms apply different R&D strategies in equilibrium and therefore perform asymmetrically. Their result holds for any submodular payoff function and Cournot and Bertrand competition. They also model one-way spillovers from an R&D innovator to an R&D imitator. However, they do not consider market factors that may affect firms' R&D strategy choices and analyze changes in social welfare only in comparison with the case where firms create a research joint venture.

We deal with the multiplicity of equilibria in Region II by assuming that either pure-strategy equilibrium is played with equal probability. The qualitative nature of the results does not depend on the selection of the equilibrium but reflects the initial symmetry between firms and their choices. So, if we allow for mixed strategy equilibria the comparison of payoffs and social welfare between regions remains the same.

Proposition 2 *(The effect of σ on aggregated output and social welfare)*

(i) Output and welfare are lower in the area of high spillovers (in Region III) than in the area of low spillovers (in Region I);

(ii) Output is increasing in σ and welfare is convex in σ for intermediate spillovers (in Region II);

(iii) Output decreases when passing from low to intermediate and from intermediate to high spillovers. Welfare can increase or decrease when passing from low to intermediate spillovers (from Region I to Region II) and welfare decreases when passing from intermediate to high spillovers (from Region II to Region III).

To illustrate the results of Proposition 2, we display the effect of changes in spillovers on aggregate industry output and welfare for some parameter values in Figure 2. We obtain two principal results. First, the relationship between the level of spillovers and aggregated industry output is non-monotonic. So, since the industry output is lower when spillovers are high than when they are low, for intermediate spillover levels an increase of σ increases industry output. Second, a similar result holds for the relationship between the level of spillovers and social welfare with the difference that the welfare might be even higher for an intermediate spillover level than for a low one.

These results imply that the answer to the question of whether spillovers favor or discourage innovation is not straightforward. In our model spillovers have two different effects on the level of R&D output. A first effect is that with higher spillovers, in equilibrium, fewer firms are innovators. This decreases R&D output. A second effect is that with higher spillovers imitators obtain greater efficiency gains from the use of innovators' less costly technology. This increases aggregated industry output and social welfare. While the first effect tends to dominate if changes in spillover levels are large, the second effect dominates for small variations of σ. However, because of discontinuities, small changes in spillovers can also lead to important reductions in R&D output, aggregated industry output and social welfare. Therefore, a crucial question is to find the right level of spillovers. This result provides a possible explanation to the long and controversial discussion concerning the

[4] See also Zhou (2009) who assumes exogenously one innovating firm and n imitators and analyzes how competitive pressure affects the innovator's incentives to engage in R&D.

duration of patents.[5]

Regarding the effect of product differentiation on aggregated industry output and social welfare we find that when the product is more homogenous firms need more IPR protection in order to maintain incentives for innovation. This finding is supported by empirical evidence for U.S. drug companies in the 1970s and 1980s. For this data Shankar et al. (1998) show that the capacity to differentiate products acts as an important factor for the imitators' survival.

2.1 Extension: Asymmetric firms

The results of Section 2 can be extended for the case of initially asymmetric firms where the inverse demand function of good i is:

$$p_i = a_i - bq_i - dq_j, \quad i, j = 1, 2, i \neq j, b - d \geq 0, \tag{10}$$

and the unit production cost of firm i is given by:

$$c_i(x_i, x_j) = \begin{cases} c_i - \gamma x_i & \text{for } x_i = 1 \text{ and } x_j = 1 \\ c_i - \gamma(x_i + \sigma x_j) & \text{else} \end{cases}, \quad i, j = 1, 2, i \neq j. \tag{11}$$

Without loss of generality we assume that initially firm 1 is larger than firm 2, $a_1 - c_1 > a_2 - c_2$. Defining $M = (a_1 - c_1) + (a_2 - c_2)$, and $\epsilon = (a_1 - c_1)/M$, this means that $\epsilon \in \left(\frac{1}{2}, 1\right)$. The Nash-Cournot equilibrium output for firm i is given by:

$$q_i = \frac{2b(a_i - c_i) - d(a_j - c_j)}{4b^2 - d^2}, \quad i, j = 1, 2. \tag{12}$$

Now, four possible situations may occur. When none of the firms innovates, firms' outputs are given by:

$$q_1(0,0) = \frac{2b\epsilon M - d(1-\epsilon)M}{4b^2 - d^2} \quad \text{and} \quad q_2(0,0) = \frac{2b(1-\epsilon)M - d\epsilon M}{4b^2 - d^2}. \tag{13}$$

The corresponding profits are $\Pi_1(0,0) = bq_1(0,0)^2$ and $\Pi_2(0,0) = bq_2(0,0)^2$. When both firms innovate, the output of each firm is:

$$q_1(1,1) = \frac{2b\epsilon M - d(1-\epsilon)M + (2b-d)\gamma}{4b^2 - d^2} \quad \text{and} \quad q_2(1,1) = \frac{2b(1-\epsilon)M - d\epsilon M + (2b-d)\gamma}{4b^2 - d^2}. \tag{14}$$

The corresponding profits are $\Pi_1(1,1) = bq_1(1,1)^2 - K$ and $\Pi_2(1,1) = bq_2(1,1)^2 - K$. When only firm 1 engages in R&D and firm 2 decides to imitate, the firms' outputs are:

$$q_1(1,0,\sigma) = \frac{2b\epsilon M - d(1-\epsilon)M + (2b - d\sigma)\gamma}{4b^2 - d^2} \quad \text{and} \quad q_2(1,0,\sigma) = \frac{2b(1-\epsilon)M - d\epsilon M + (2b\sigma - d)\gamma}{4b^2 - d^2}. \tag{15}$$

The firms' profits are $\Pi_1(1,0,\sigma) = bq_1(1,0,\sigma)^2 - K$ and $\Pi_2(1,0,\sigma) = bq_2(1,0,\sigma)^2$. Finally, if firm 2 engages in R&D and firm 1 decides to imitate, the firms' outputs are:

$$q_1(0,1,\sigma) = \frac{2b\epsilon M - d(1-\epsilon)M + (2b\sigma - d)\gamma}{4b^2 - d^2} \quad \text{and} \quad q_2(0,1,\sigma) = \frac{2b(1-\epsilon)M - d\epsilon M + (2b - d\sigma)\gamma}{4b^2 - d^2}. \tag{16}$$

[5] Helpman (1993), Aghion et al. (2001), Bessen and Maskin (2009) and Zhou (2009), for example, argue against patents because of their redundant and excessive protection, which discourages firms' incentives for innovation. Jin et al. (2004), Halmenschlager (2006) and Fershtman and Markovich (2010) also find that the presence of patent protection on an intermediate stage would delay the pace of innovation and that lower spillovers are not the optimal public policy. Finally, Boldrin and Levine (2008) find that the greater the market scale (industry size) the more reduced should be IP protection. On the other hand, Arora and Gambardella (1994), Gans and Stern (2003), Gans et al. (2008) argue that IPR protection is essential for the existence of a market for technology.

The firms' profits are $\Pi_1(0,1,\sigma) = bq_1(0,1,\sigma)^2$ and $\Pi_2(0,1,\sigma) = bq_2(0,1,\sigma)^2 - K$.

Let $\underline{\sigma}_1$ be implicitly defined by $\Pi_1(1,1) = \Pi_1(1,0,\underline{\sigma}_1)$, $\overline{\sigma}_1$ by $\Pi_1(0,0) = \Pi_1(1,0,\overline{\sigma}_1)$, $\underline{\sigma}_2$ by $\Pi_2(1,1) = \Pi_2(1,0,\underline{\sigma}_2)$ and $\overline{\sigma}_2$ by $\Pi_2(0,0) = \Pi_2(1,0,\overline{\sigma}_2)$. Then, we obtain the following result:

Proposition 3 *(Existence of equilibria with asymmetric firms)*
Compared to the case of symmetric firms:

(i) The regions, in which both firms innovate or none of them innovates (Regions I and III) become smaller when firms are asymmetric, as for given values of d we have $\underline{\sigma}_2 < \underline{\sigma}$ and $\overline{\sigma}_1 > \overline{\sigma}$.

(ii) The region with multiple equilibria in which one of the firms innovates and the other imitates (Region II) becomes smaller, as for given d we have $\underline{\sigma}_1 > \underline{\sigma}$ and $\overline{\sigma}_2 < \overline{\sigma}$.

(iii) A new region with a unique pure strategy SPNE emerges (Region IV). In this region the large firm is an innovator and the small firm an imitator.

The four regions with the resulting equilibria are displayed in Figure 3. A specific feature of this extension is that allowing for initially asymmetric firms leads to the emergence of an area where the larger firm is an innovator and the smaller firm chooses to imitate. A similar result was found by Cabral and Polak (2004) who show that an increase in a firm's relative dominance raises incentives for that firm to innovate and decreases those of the rival. Empirical evidence widely supports this result. For instance, Henderson and Cockburn (1996) using data from individual research programs of pharmaceutical firms in the United States, suggest the advantage of large firms in the conduct of basic research.

The difference between the situations in Region II and Region IV can be explained in terms of the persistence of firms' R&D strategies. In Region II we have equilibria where the optimal strategy of a firm is opposed to that of the rival. If the rival innovates the best reply is to imitate, and vice versa. Therefore, in a repeated context of this game firms will not follow a continuous innovation strategy in Region II. On the contrary, in Region IV initially asymmetric firms always choose the same R&D strategy. The larger firm innovates and the smaller firm imitates. So, in Region IV, both firms continuously choose the same R&D strategy. The results in Proposition 3 allow us to obtain testable predictions of how market conditions such as product differentiation, firm asymmetries and spillovers affect firm's R&D strategy choice.

Proposition 4 *(The effect of ϵ, firm asymmetry, on aggregated output and social welfare)*

(i) Aggregated industry output is constant in ϵ in all regions.

(ii) In all region there exists at least one equilibrium in which social welfare is increasing in ϵ.

Endogenizing a firm's decision to innovate or to abstain from innovation we obtain that asymmetries between firms, which may lead to a persistent innovator-imitator configuration in the market, positively affects social welfare. A similar result has been obtained by Cabral and Polak (2004) who examine the relation between firm dominance and spillover levels. They find that an increase in market dominance of a firm increases it's R&D spending and the firm's profits. However, it discourages other firms to innovate. Which of the two effects dominates depends on IPR protection. They conclude that dominance is good for innovation when property rights are strong but discourages innovation when the IPR protection is weak.

2.2 Extension: n firms

In this section we analyze how the results extend to oligopoly markets with n initially symmetric firms. In this case, the corresponding inverse demand function of good i is given by:

$$p_i = a - bq_i - d\sum_{j\neq i} q_j,\ i = 1, ..., n, \tag{17}$$

We assume that spillovers occur when at least one firm decides to innovate. Thus, unit production cost are:

$$c_i\left(x_i, x_{-i}\right) = \begin{cases} c-\gamma & \text{if } x_i = 1 \\ c-\gamma\sigma & \text{if } x_i = 0 \text{ and } \exists j \text{ with } x_j = 1 \\ c & \text{else} \end{cases},\ \ i = 1, ..., n. \tag{18}$$

In *stage 2*, firm i chooses the output q_i to maximize its operating profit:

$$\pi_i = \left(a - bq_i - d\sum_{j\neq i} q_j\right) q_i - c_i q_i,\ i, j = 1, 2, i \neq j. \tag{19}$$

The Nash-Cournot equilibrium output for firm i is given by:

$$q_i = \frac{(2b-d)\left(a-c_i\right) - d\left(nc_i - \sum_{j=1}^{n} c_j\right)}{(2b-d)\left(2b+d\left(n-1\right)\right)}. \tag{20}$$

In *stage 1*, firms choose their profit-maximizing R&D strategy. When all firms engage in R&D (i.e. $x_1 = ... = x_n = 1$), outputs and profits are:

$$q_i(1, ..., 1) = \frac{a-c+\gamma}{2b+d\left(n-1\right)} \quad \text{and} \quad \Pi_i(1, ..., 1) = bq_i(1, ..., 1)^2 - K. \tag{21}$$

If none of the firms engages in R&D (i.e. $x_1 = ... = x_n = 0$), output and profits are equal to those of the classical Cournot model with differentiated products:

$$q_i(0, ..., 0) = \frac{a-c}{2b-d+dn} \quad \text{and} \quad \Pi_i(0, ..., 0) = bq_i(0, ..., 0)^2. \tag{22}$$

Furthermore, if all firms except one, say firm 1, engage in R&D the corresponding output and profit of firm 1 are given by:

$$q_1(0, 1, ..., 1, \sigma) = \frac{(2b-d)\left(a-c+\sigma\gamma\right) - \left(n-1\right)\left(1-\sigma\right)\gamma d}{(2b-d)\left(2b+d\left(n-1\right)\right)} \quad \text{and} \quad \Pi_1(0, 1, ..., 1, \sigma) = bq_1(0, 1, ..., 1, \sigma)^2. \tag{23}$$

Finally, if none of the firms innovates, except one, say firm 1, the corresponding output and profit of firm 1 are given by:

$$q_1(1, 0, ...0, \sigma) = \frac{(2b-d)\left(a-c+\gamma\right) + \left(n-1\right)\left(1-\sigma\right)\gamma d}{(2b-d)\left(2b+d\left(n-1\right)\right)} \quad \text{and} \quad \Pi_1(1, 0, ...0, \sigma) = bq_1(1, 0, ...0, \sigma)^2 - K. \tag{24}$$

To analyze how the frontiers of Region I and Region III depend on the number of firms in the market, we examine a firm's choice between innovation and imitation. First, we assume that all other firms in the industry innovate. Second, we assume that all other firms do not engage in R&D. Let $\underline{\sigma}_n$ be such that $\Pi_i(1, 1, .., 1) = \Pi_1(0, 1, ..., 1, \underline{\sigma}_n)$ and $\overline{\sigma}_n$ such that $\Pi_1(1, 0, .., 0, \overline{\sigma}_n) = \Pi_i(0, 0, .., 0)$.

Proposition 5 *(The effect of n, competitive pressure, on equilibria)*
Compared to the duopoly case with two symmetric firms we have:

(i) The region, in which all firms innovate (Region I) decreases with the number of firms in the market as for given d we have $\underline{\sigma}_n < \underline{\sigma}_{n-1}$.

(ii) The region, in which none of the firms innovates (Region III) increases with the number of firms in the market as for given d we have $\overline{\sigma}_n < \overline{\sigma}_{n-1}$.

Figure 4 displays how Regions I and III change when the number of firms in the market increases. Regarding Region I, we observe that the probability of a particular firm to engage in R&D decreases as the number of competitors increases. With more competitors initially symmetric firms will be innovators only when products are sufficiently differentiated and IPR protection is high. This finding is supported by empirical evidence from Shankar (1998). Though Region I shirks with entry, notice that the overall innovative performance in the market increases within Region I as entrants also engage in R&D. With more competitors what was formerly Region II becomes more complex as further possible equilibria emerge. For example, with three firms we can have multiple equilibria with one innovator and two imitators or with two innovators and one imitator. Concerning Region III, we find that the entry of new firms means that equilibria with no innovating firm will occur for lower spillover values and for more differentiated products. Together, these results imply that the effect of entry on total R&D performance and welfare depends on spillovers and product differentiation. Concretely, we get the following result.

Proposition 6 *(The effect of n, competitive pressure, on industry R&D output and welfare)*

(i) Entry increases total R&D output and welfare when spillovers are low and products are highly differentiated.

(ii) Entry decreases total R&D output and welfare when spillovers are high and products are rather homogenous.

This result is similar to that of De Bondt et al (1992) who find that more rivals typically lead to reduced investments, output and profitability, while consumer surplus and welfare increase, or at least do not decrease. On the contrary, Tishler and Milstein (2009) show that social welfare decreases with the number of competitors. However, their model doesn't account for spillovers of R&D between firms, and the increase in competition leads to excessive R&D spending.

3 Empirical analysis

The empirical analysis is intended to examine the consistency of the predictions that can be derived from the theoretical model. Specifically, it contributes to the literature by including firm internal characteristics as well as external market parameters (competitive pressure, spillover level, product substitutability) in the analysis of a firms' R&D decision. This is important, because the innovation strategy of a firm must be considered in the context of its global market strategy as it serves to maintain and improve the firm's market position. Therefore, when managers decide to launch an R&D project, they consider both internal firm characteristics and external factors such as rivals' strategies, competitive pressure, knowledge specificity, intellectual property protection, availability of funding, public support etc. A variation in one of these external factors might critically affect the firm's resources and capabilities and thereby the firm's innovation strategy.

Empirical studies during the last decades discussed the determinants of R&D activity mainly based on internal firm characteristics such as firm size, appropriability of the outcomes of innovation, access to international markets, cooperation with customers, suppliers and others (Patel and Pavitt, 1992; Crépon et al., 1998; Loof and Heshmati, 2002; Veugelers and Cassiman, 2005). Less attention has been paid to external factors. This certainly is due to the problems that its measurement rises. For example, the intensity of market competition has been proxied with concentration measures, such as concentration ratios or the Hirshman-Herfinadahl index, based on industry data (Geroski, 1990; Blundel et al., 1999; Aghion et al., 2005). The problem with this approach is that the market in which firms compete can hardly be identified by the industrial sector. So, firms within one sector might not compete at all if their products meet different consumer needs. Another example is the measurement of spillovers. The average spillover level has been measured with industry data as an average of firm R&D expenditures in the industry (Bloom et al., 2007; Czarnitzki and Kraft, 2007). However, firms can protect the outcomes of their R&D activity by using legal protection mechanisms as well as by secrecy. So, this indicator might wrongly reflect the spillover level in the industry or in the market.

The common problem with the measurement of these variables is that market characteristics such as the firm's market position, the level of knowledge protection or demand uncertainty are not directly observable. The Mannheim Innovation Panel (MIP), a survey used in this study, allows to improve the measures of external factors. This is because firms provide information about these factors according to their own perceptions of market characteristics, which definitely determine their R&D strategies.

3.1 Data and variables

To investigate the determinants of firms' R&D strategy choices, we use data from MIP conducted by the Centre for European Economic Research (ZEW). The database has a cross-sectional structure. It covers a representative sample of German manufacturing and service sectors during the period 1995-2007. It includes important information on the introduction of new products, services and processes within firms, as well as details on innovation activity and the degree of success achieved by firms through the introduction of new products and the improvement of processes. Remarkably, the MIP questionnaire of 2005 asks firms about internal *and* external factors that affect their decisions regarding commercialization and innovation during the period 2002-2004. Thereby, it provides valuable information for the purposes of our study.

Our dependent variable (STR) represents a firm's R&D strategy choice. STR is a categorical variable that indicates if, between 2002 and 2004, a firm did not introduce any innovation, introduced a product that is new for the firm but known in the market or introduced a product that is new for the market. As it is common in the economic literature, we interpret the introduction of a product that is new for the market as innovation while the introduction of a product that is new for the firm (but not for the market) is interpreted as imitation (Vinding, 2006).

That the rate of innovating and imitating firms varies across industries, can be observed for the representative sample of German firms. In Table 1 we display the rate of innovating firms for manufacturing and services sectors in the year 2005. The highest rate of non-innovating firms can be observed in sectors such as mining, textiles and food and tobacco, and many of the services sectors. On the other hand, in sectors such as chemicals, medical instruments and electrical equipment we find that most firms are innovators. Thus, we observe that firms' R&D strategies vary across industries and markets which also agrees with the results of our theoretical model that suggest that the level of a firm's innovative performance can be affected by market characteristics. Consequently, to study firms' R&D strategy choices, we include two categories of independent variables into our empirical model: variables that measure internal and external factors. As commonly used in firm-level studies, our internal factors are: firm size (SIZE02), absorptive capacity (AC03), firm's group membership (GROUP), turnover from exports (EX02), geographical market size to which a firm accesses (GEO), and, specific to our data, firm location in the territory of former Eastern Germany (OST).[6]

Most studies on firm innovation control for firm size, measured by the number of employees or turnover, as larger firms are supposed to be more efficient in the conduct of innovation (Henderson and Cockburn, 1996; Shefer and Frenkel, 2005). In our study SIZE02 is measured by the number of employees. Regarding GROUP and EX02, former studies suggest that firms, which belong to the group, and firms, which export abroad, have more incentives and resources for innovation. GEO is used as a proxy for the firm´s market size. We distinguish between firms that have access to different markets: local or regional markets, the German (i.e. nation-wide) market, the market of EU member, EU candidate and EFTA member countries and the world market. The variable GEO in the empirical analysis corresponds to $(a - c)$ in the theoretical model. Alternatively, SIZE02 is also related to $(a - c)$. According to the theoretical model, we expect a positive effect of GEO and SIZE02 on a firm's propensity to engage in R&D (see Proposition 1).

Apart from the traditional internal factors mentioned above, the literature adopted the term absorptive capacity, which is a measure of a firm's ability to identify, assimilate and apply new knowledge given the firm's experience, human capital skills, and organizational procedures' flexibility and relevance (Cohen and Levintal, 1989). Firms that have higher absorptive capacity are expected to dispose of more capability for R&D. There is a number of ways to measure a firm's absorptive capacity (see Schmidt, 2005). Given the cross-sectional structure of our data, AC03 is measured as the proportion of all employees with a university degree or other higher education qualification in 2003. As a firm's absorptive capacity depends on that of its employees, the general level of education, experience and training of employees, this seems to be a good proxy for a firm's absorptive capacity. Finally, we use the dummy variable OST to control whether a firm is located in former Eastern Germany. Historically, firms belonging to the western and eastern part of Germany were affected by different institutional settings. Therefore, the innovative performance might differ among firms in these regions.

Regarding the external factors, our variables are: intellectual property rights protection (IPR and av_IPR), the pace of technological change (TEC), competitive pressure (COM), product differentiation (DIF), and demand uncertainty (DEM). The MIP survey is based on firms' perceptions regarding their external environment. Because manager's decisions are based on their subjective perceptions of external factors this allows to assess better the determinants of firms' R&D strategy choices. The external factors IPR, TEC, DIF, DEM are represented by categorical variables. In order to get information on them, each firm was asked to what extent it was affected by these factors. Firms' answers take values in Likert scale from 0 ("not applicable") to 3 ("applies strongly").

The level of intellectual property protection is measured by IPR. IPR is an index constructed as the sum of the scores of the success of legal protection mechanisms for innovations and inventions (patents, registered and industry design, trademarks and copyright), rescaled from 0 (minimum level) to 1 (maximum level). To deal with possible endogeneity of IPR, as in Schmidt (2006), we calculate for each firm the average IPR across the NACE 3-digit industry code excluding this firm (av_IPR). A higher value of this variable means better protection of intellectual property (or more difficulty for copying). In the theoretical model this corresponds to a lower value of σ. We suggest a positive effect of successful IPR protection in the industry on firms' incentives to innovate. Another measure of spillovers is TEC, which is an evaluation of the pace of technological change in the industry provided by firms. A higher value of TEC corresponds to a lower level of spillovers, as it reflects higher knowledge complexity. Therefore, according to predictions from the theoretical model we expect a positive effect of TEC on firms' "innovativeness".

The variable COM is measured by the number of main competitors reported by a firm. Since a firm has better vision of its market, this indicator closer measures the intensity of market competition. This is a proxy for n, the number of firms, in the theoretical model. According to Proposition 5, we expect a negative impact of

[6] Numbers in the variable definitions indicate the year of measurement.

competitive pressure on the propensity of a firm to engage in R&D. Another indicator for competitive pressure is the degree of product substitutability (DIF) which corresponds to d/b, in the theoretical setup. From the theoretical results we do not get a clear prediction for the sign of the parameter estimate of this variable, i.e. for its influence on firms' decisions to become innovators. The variable DEM measures demand uncertainty related to changes in consumers tastes. Following some previous studies, we expect that unforeseeable demand negatively affects the incentives of firms to innovate. Especially, it might discourage persistent innovation (see Caballero and Pindyck, 1996; Czarnitzki and Toole, 2008). The asymmetries between firms are captured by the parameter ϵ in the theoretical model. The effect of ϵ is captured by the variables SIZE02 and GEO. We expect that a firm that is larger than its rivals is more likely to engage in R&D, while a firm that is smaller than its rivals would be more likely to become an imitator when product substitutability is high. We also control for unobserved heterogeneity in the innovative performance across sectors by, following OECD taxonomy for NACE Rev.1 codes, including 25 aggregated industry sectors and 5 industry classes (high-tech manufacturing, high-tech services, medium-high- and medium-low-tech manufacturing, and low-tech manufacturing and services) according to R&D intensity.[7]

A detailed description of the variables, their theoretical counterparts and expected signs are provided in Table 2. Table 3 presents descriptive statistics on the variables used. 28% of the firms in our sample belong to high-tech services sectors, 8% to high-tech manufacturing and 27% to medium-tech manufacturing. Over 27% of firms introduced product innovations that were new to their market by 2005, while 33% of firms introduced products that were known to their market but new for the firm. 40% of firms abstained from innovation. The average firm in the sample has 575 employees, among them, 20% have higher education. 34% of firms are group members, and 34% of the firms are from Eastern Germany. Over 70% of the firms indicate that intellectual property is not well-protected, and only 1.5% recognize a high success of legal protection mechanisms. From the correlation analysis, we find that there are no systematic correlations between variables that could affect the results of our econometric analysis.

3.2 Econometric analysis and results

We test our model using a multinomial logit and an ordinal logit specification. A firm chooses whether to engage in R&D considering:

$$y_i^* = \mathbf{x}_i'\beta_1 + \mathbf{z}_i'\beta_2 + \varepsilon_i$$

where y_i^* is the unobserved latent variable which is the utility obtained from continuous innovation activities. The vectors $\mathbf{x}_i$ and $\mathbf{z}_i$ contain the proxies for internal and external parameters that affect the firms' R&D strategy choice. The observed dependent variable y_i is a choice between 3 alternatives: to abstain from innovation, to imitate and to engage in R&D. The probability that the ith response falls into the jth category is given by $\pi_{ij} = \Pr\{y_i = j\}$. The appropriate model to treat these probabilities would be one that considers them as unordered strategic choices, or, as naturally ordered strategy choices representing the degree of innovativeness in the firm's activity.

First, consider the multinomial response model.[8] We are interested in analyzing how ceteris paribus changes in the elements of the vectors $\mathbf{x}_i$ and $\mathbf{z}_i$ of covariates associated with the ith individual affect the response

[7] Aggregations of manufacturing and services based on NACE Rev 1.1, Eurocomission.

[8] The regressors of the model are alternative-invariant, as the the choice depends on attributes of individuals and not on the characteristics of the alternatives. Therefore, the choices are not conditioned on the alternatives.

probability for category j:

$$\pi_{ij} = \Pr(y_i = j|\mathbf{x}_i) = \frac{\exp\left(\mathbf{x}_i'\beta_1 + \mathbf{z}_i'\beta_2\right)}{1 + \sum_{j=1}^{J} \exp\left(\mathbf{x}_i'\beta_1 + \mathbf{z}_i'\beta_2\right)},$$

where $j = 1, ..., J$. The assumption of independence of irrelevant alternatives is tested by the standard Hausman test (Hausman and McFadden, 1984), which compares coefficients obtained in a multinomial model with those obtained by pairwise estimation of alternatives chosen with the same reference in a binary choice model.

Second, consider the ordinal logit model, which is obtained directly from a binary model by splitting y^* into J ordinal categories:

$$y_i = j \;\text{ if }\; \tau_{j-1} < y_i^* < \tau_j,$$

where τ_j are the estimated cutpoints (thresholds). The probability of observing $y = j$ for given values of x is:

$$\Pr(y = j|x) = \Pr\left(\tau_{j-1} < y_i^* < \tau_j|x\right).$$

For model evaluation we report pseudo-R^2. The regression parameters usually are not interpreted directly. Instead, we consider marginal effects of changes in regressors on the outcome probabilities. The marginal effects of R&D strategies are reported with respect to the reference category, which is a firm's decision to abstain from innovation.

Table 4 provides the estimates for multinomial logit specifications. Table 5 provides the estimates for ordered logit specifications. Both estimated models show effects of similar direction and magnitude. Hence, the effects of market parameters on firm R&D strategies are robust to the model specification. The results suggest that a firm's R&D strategy is affected to great extent by both internal and external factors (see Tables 4 and 5). The pseudo-R^2 takes values from 0.1607 to 0.1987. As expected, firm size, absorptive capacity and group membership have a significant positive impact on a firm's innovativeness, measured as its propensity to engage in innovation. Geographical market size also has a strong positive effect. This fact provides empirical support for Propositions 1 and 3 of our theoretical setup. Notably, the location of a firm in former Eastern Germany is related to a lower propensity of the firm to engage in R&D, although this effect is lowly significant.

The estimation results suggest crucial importance of external (market) factors for a firm's R&D strategy choice. The success of legal IPR protection in the industry crucially affects a firms' choice to engage in imitative or innovative activity. This might be due to several reasons. First, the reduction of uncertainty about the R&D outcomes and future profits due to patent protection plays a very important role in the decision of firms to engage in R&D. This result provides support for the arguments of Arora and Gambardella (1994), Gans and Stern (2003), and Gans et al. (2008) that the perception of protection for new ideas provides more incentives for firms to innovate. Second, better IPR protection might enhance open innovation. Acording to the "open innovation paradigm", firms use patents as a channel of knowledge disclosure and dissemination. This benefits other firms in the industry and allows them to be more innovative (Chesbrough, 2003).

Competitive pressure measured by the number of main competitors negatively affects firms' incentives to innovate, which supports the results in Proposition 5. A similar result has been obtained in a previous study by Czarnitzki et al. (2008) who use a framework with Stackelberg competition and endogenous market entry. They conclude that entry pressure results in a decrease of firm's innovation incentives. Although, when entry pressure is high, market leaders tend to spend more on R&D. Regarding the degree of product substitutability, we find a positive effect. This indicates that in markets with highly substitutable products firms have more incentive to do R&D. As expected, demand uncertainty negatively affects firms' decision to innovate. Most industry dummies result significant. Concerning industry classes, medium- and high-tech manufacturing and high-tech services show significant positive effects with respect to the base category, other manufacturing and services sectors.

4 Concluding remarks

This paper analyzes how the equilibrium R&D strategies of firms are affected by external factors such as spillovers and competitive pressure. The theoretical and empirical analysis contributes to the understanding of a firm's R&D strategy choice. In this paper, especially, we focus on a firms' choice to innovate or to imitate.

From the theoretical model we obtain that when firms choose endogenously their optimal R&D strategies three types of equilibria arise: equilibria in which all firms innovate, equilibria in which firms choose asymmetric R&D strategies with one innovating and one imitating firm, and, finally, equilibria in which no firm innovates. We find that stronger intellectual property rights protection provides higher incentives for firms to engage in R&D. Nevertheless, smaller firms are less likely to be innovators in markets with homogenous product and high levels of spillovers. An increase in the number of competitors or more demand uncertainty decrease firms' incentives to innovate. Regarding social welfare, depending on external factors, stronger intellectual property rights protection can provide both higher and lower incentives for firms to engage in R&D. If a market is characterized by a high rate of innovation a reduction of IPR protection can discourage innovative performance substantially. However, a reduction of IPR protection can also increase social welfare because it may induce imitation and resulting in higher aggregate industry output.

Following the prediction from the theoretical model, in the empirical part of the paper we explicitly consider that firms may have different innovation strategies (imitate or innovate) and analyze which factors affect firms' R&D strategy choice. Our explanatory variables are internal factors (firm size category, absorptive capacity, and geographical market size) and external factors (product differentiation, competitive pressure, IPR protection perception by firms and on average in the industry, and demand uncertainty). We find strong empirical evidence for our main predictions from the theoretical model. A firms' R&D strategy choice is tightly related to external factors. First, the efficiency of legal IPR protection provides incentives to engage in R&D as it guarantees better appropriation of the benefits of innovation. Second, competitive pressure, measured by the number of competitors, has a negative effect.

Some important policy implications are obtained from our results. We find that a common IPR protection policy irrespective specific market and firms characteristics is inappropriate. The analysis of spillover effects on social welfare shows that a reduction of IPR protection can discourage innovative performance but also allow for imitation with a positive total welfare effect. Another implication of our findings is that the IPR protection policy must be tightly coordinated with the competition policy because external parameters such as IPR protection and competitive pressure jointly affect the firms' R&D strategy choice.

5 Appendix.

5.1 Proof of Proposition 1

Define $\overline{\sigma}$ such that firm i is indifferent between engaging and abstaining from R&D when firm j imitates:

$$\Pi_1(1,0,\overline{\sigma}) - \Pi_i(0,0) = b\left(\frac{2b\,(a-c+\gamma) - d\,(a-c+\overline{\sigma}\gamma)}{4b^2-d^2}\right)^2 - K - b\left(\frac{2b\,(a-c) - d\,(a-c)}{4b^2-d^2}\right)^2 = 0, \qquad (25)$$

that is:

$$\overline{\sigma} = \frac{2b\,(a-c+\gamma) - d\,(a-c)}{d\gamma} - \frac{\left(4b^2-d^2\right)}{d\gamma}\sqrt{\frac{K}{b} + \left(\frac{a-c}{2b+d}\right)^2}. \qquad (26)$$

Define $\underline{\sigma}$ such that firm i is indifferent between engaging and abstaining from R&D when firm j engages in R&D:

$$\Pi_i(1,1)-\Pi_2(1,0,\underline{\sigma}) = b\left(\frac{2b\,(a-c+\gamma)-d\,(a-c+\gamma)}{4b^2-d^2}\right)^2 - K - b\left(\frac{2b\,(a-c+\underline{\sigma}\gamma)-d\,(a-c+\gamma)}{4b^2-d^2}\right)^2 = 0 \quad (27)$$

that is:

$$\underline{\sigma} = \frac{-2b\,(a-c)+d\,(a-c+\gamma)}{2b\gamma} + \frac{\left(4b^2-d^2\right)}{2b\gamma}\sqrt{\left(\frac{a-c+\gamma}{2b+d}\right)^2 - \frac{K}{b}} \quad (28)$$

First, consider the partial derivatives. From equations (26) and (28) we have: $\partial\overline{\sigma}/\partial K < 0$, $\partial\underline{\sigma}/\partial K < 0$, $\partial\overline{\sigma}/\partial\gamma = -\overline{\sigma}/\gamma < 0$, $\partial\underline{\sigma}/\partial\gamma = -\ \underline{\sigma}/\gamma < 0$,

$$\partial\overline{\sigma}/\partial\,(a-c) \;=\; \frac{2b-d}{d\gamma}\left[1-\left(\frac{a-c}{2b+d}\right)\left(\frac{K}{b}+\left(\frac{a-c}{2b+d}\right)^2\right)^{-1/2}\right] > 0,\text{ and} \quad (29)$$

$$\partial\underline{\sigma}/\partial\,(a-c) \;=\; -\frac{2b-d}{2b\gamma}\left[1-\left(\frac{a-c+\gamma}{2b+d}\right)\left(\left(\frac{a-c+\gamma}{2b+d}\right)^2-\frac{K}{b}\right)^{-1/2}\right] > 0. \quad (30)$$

To prove existence of the equilibria we make the following claims:

Claim 1: $\overline{\sigma} > \underline{\sigma}$.

We have:

$$\overline{\sigma}-\underline{\sigma} = \frac{\left(4b^2-d^2\right)}{\gamma d}\left(\frac{(a-c+\gamma)}{2b} - \sqrt{\frac{K}{b}+\left(\frac{a-c}{2b+d}\right)^2} - \frac{d}{2b}\sqrt{\left(\frac{a-c+\gamma}{2b+d}\right)^2-\frac{K}{b}}\right) \quad (31)$$

This is an increasing function in K under assumption 1, i.e.

$$\partial\frac{\overline{\sigma}-\underline{\sigma}}{\partial K} = \frac{\left(4b^2-d^2\right)}{2b\gamma d}\left(-\left(\frac{K}{b}+\left(\frac{a-c}{2b+d}\right)^2\right)^{-\frac{1}{2}} + \frac{d}{2b}\left(\left(\frac{a-c+\gamma}{2b+d}\right)^2-\frac{K}{b}\right)^{-\frac{1}{2}}\right) > 0 \quad (32)$$

for $K > \underline{K}$. Therefore, a sufficient condition for $\overline{\sigma} > \underline{\sigma}$ is that the condition holds for $K = \underline{K}$:

$$\begin{aligned}\overline{\sigma}-\underline{\sigma} \;&=\; \frac{\left(4b^2-d^2\right)}{\gamma d}\left(\frac{(a-c+\gamma)}{2b} - \sqrt{\frac{\underline{K}}{b}+\left(\frac{a-c}{2b+d}\right)^2} - \frac{d}{2b}\sqrt{\left(\frac{a-c+\gamma}{2b+d}\right)^2-\frac{\underline{K}}{b}}\right)\\ &=\; \frac{1}{2b}\,(2b-d) > 0.\end{aligned} \quad (33)$$

Claim 2: $\overline{\sigma} < 1$.

From assumption 1 we have that $K > \underline{K} = b\left(\frac{a-c+\gamma}{2b+d}\right)^2 - b\left(\frac{a-c}{2b+d}\right)^2$. Thus

$$\overline{\sigma} < \frac{2b\,(a-c+\gamma)-d\,(a-c)}{d\gamma} - \frac{\left(4b^2-d^2\right)}{d\gamma}\sqrt{\frac{\underline{K}}{b}+\left(\frac{a-c}{2b+d}\right)^2} = 1 \quad (34)$$

Claim 3: $\underline{\sigma} > 0$.

From assumption 1 we have $K < \overline{K} = b\left(\frac{a-c+\gamma}{2b+d}\right)^2 - b\left(\frac{(2b-d)(a-c)-d\gamma}{4b^2-d^2}\right)^2$. Thus, $\underline{\sigma} > \frac{-2b(a-c)+d(a-c+\gamma)}{2b\gamma} + \frac{\left(4b^2-d^2\right)}{2b\gamma}\sqrt{\left(\frac{a-c+\gamma}{2b+d}\right)^2 - \frac{\overline{K}}{b}} = 0$.

Together, claims 1-3 prove the existence of the different equilibria.

5.2 Proof of Proposition 2

First, consider aggregated output. We have:

$$q(1,1) = \frac{2(a-c+\gamma)}{2b+d} > q(1,0,\sigma) = \frac{2(a-c)+(1+\sigma)\gamma}{2b+d} > q(0,0) = \frac{2(a-c)}{2b+d} \tag{35}$$

and $\partial q(1,0,\sigma)/\partial\sigma > 0$ which proves the statements regarding aggregated output.

Next, consider social welfare. When both firms engage in R&D, (i.e. $x_i = 1,\ \ i = 1,2$) social welfare is:

$$W(1,1) = (3b+d)\left(\frac{a-c+\gamma}{2b+d}\right)^2 - 2K \tag{36}$$

If none of the firms engages in R&D, (i.e. $x_i = 0,\ \ i = 1,2$) social welfare is:

$$W(0,0) = (3b+d)\left(\frac{a-c}{2b+d}\right)^2 \tag{37}$$

Finally, if firm 1 engages in R&D and firm 2 decides to imitate, social welfare is:

$$\begin{aligned} W(1,0,\sigma) &= \Pi_1(1,0,\sigma) + \Pi_2(0,1,\sigma) + dq_1(1,0,\sigma)q_2(0,1,\sigma) + \frac{1}{2}b\left(q_1^2(1,0,\sigma) + q_2^2(0,1,\sigma)\right) \\ &= \frac{3}{2}b\left(\frac{a-c}{2b+d} + \frac{(2b-d\sigma)\gamma}{4b^2-d^2}\right)^2 + \frac{3}{2}b\left(\frac{a-c}{2b+d} + \frac{(2b\sigma-d)\gamma}{4b^2-d^2}\right)^2 \\ &\quad + d\left(\frac{a-c}{2b+d} + \frac{(2b-d\sigma)\gamma}{4b^2-d^2}\right)\left(\frac{a-c}{2b+d} + \frac{(2b\sigma-d)\gamma}{4b^2-d^2}\right) - K \end{aligned} \tag{38}$$

To prove statement (i), from (36) and (37) we have:

$$\begin{aligned} W(1,1) - W(0,0) &= (2b+d)^{-2}(2a-2c+\gamma)(3b+d)\gamma - 2K \\ &> (2b+d)^{-2}(2a-2c+\gamma)(3b+d)\gamma - 2\overline{K} \\ &= \frac{2(b-d)\left(4b^2-d^2\right)(a-c) + \left(4b^3-bd^2+d^3\right)\gamma}{\left(4b^2-d^2\right)^2}\gamma > 0 \end{aligned} \tag{39}$$

To prove statement (ii), consider the second derivative of (38):

$$\frac{\partial^2 W(1,0,\sigma)}{\partial \sigma^2} = \frac{\left(12b^2-d^2\right)b\gamma^2}{\left(4b^2-d^2\right)^2} > 0. \tag{40}$$

Finally, to prove statement (iii), we analyze when

$$W(1,0,\underline{\sigma}) < W(1,1). \tag{41}$$

By definition of $\underline{\sigma}$ we have $\Pi_2(0,1,\underline{\sigma}) = \Pi_2(1,1)$. So, (41) is equivalent to

$$\Pi_1(1,0,\underline{\sigma}) + dq_1(1,0,\underline{\sigma})q_2(0,1,\underline{\sigma}) + \frac{1}{2}b\left(q_1^2(1,0,\underline{\sigma}) + q_2^2(0,1,\underline{\sigma})\right) < \Pi_1(1,1) + (d+b)\,q_1(1,1)q_2(1,1) \tag{42}$$

or

$$\frac{1}{2}\gamma\left(\underline{\sigma}-1\right)\left(2\left(b-d\right)\left(a-c\right)+\gamma\left(b-2d+b\underline{\sigma}\right)\right) < 0 \tag{43}$$

or

$$\frac{1}{4}\gamma\left(\underline{\sigma}-1\right)\left(\left(2b-3d\right)\left(a-c+\gamma\right)+\left(4b^2-d^2\right)\sqrt{\left(\frac{a-c+\gamma}{2b+d}\right)^2-\frac{K}{b}}\right) < 0. \tag{44}$$

This is true if $2b > 3d$ or $K < \frac{8(b-d)(a-c+\gamma)^2 bd}{(4b^2-d^2)^2}$. Notice, that in case of homogeneous products the conditions are not fulfilled such that $W(1,0,\underline{\sigma}) > W(1,1)$.

Next, we analyze when

$$W(1,0,\overline{\sigma}) > W(0,0). \tag{45}$$

By definition of $\overline{\sigma}$ we have $\Pi_1(1,0,\overline{\sigma}) = \Pi_1(0,0)$. So (45) is equivalent to

$$\Pi_2(0,1,\overline{\sigma}) + dq_1(1,0,\overline{\sigma})q_2(0,1,\overline{\sigma}) + \frac{1}{2}b\left(q_1^2(1,0,\overline{\sigma}) + q_2^2(0,1,\overline{\sigma})\right) > \Pi_2(0,0) + (d+b)\,q_1^2(0,0) \tag{46}$$

orϵ

$$2\left(a-c\right)\left(b-d+\left(3b-d\right)\underline{\sigma}\right)+\gamma\left(b+3b\sigma^2-2d\underline{\sigma}\right) > 0 \tag{47}$$

which always holds.

5.3 Proof of Proposition 3

From the definition of $\underline{\sigma}_1$, $\overline{\sigma}_1$, $\underline{\sigma}_2$ and $\overline{\sigma}_2$ we obtain:

$$\underline{\sigma}_1 = -\frac{2b\epsilon M - d\left(1-\epsilon\right)M - d\gamma}{2b\gamma} + \frac{4b^2-d^2}{2b\gamma}\sqrt{\frac{\left(2b\epsilon M - d\left(1-\epsilon\right)M + \gamma(2b-d)\right)^2}{\left(4b^2-d^2\right)^2} - \frac{K}{b}} \tag{48}$$

$$\overline{\sigma}_1 = \frac{2b\left(M\epsilon+\gamma\right) - Md\left(1-\epsilon\right)}{d\gamma} - \frac{\left(4b^2-d^2\right)}{d\gamma}\sqrt{\frac{K}{b} + \frac{\left(2b\epsilon M - d\left(1-\epsilon\right)M\right)^2}{\left(4b^2-d^2\right)^2}} \tag{49}$$

$$\underline{\sigma}_2 = -\frac{2b\left(1-\epsilon\right)M - d\left(\epsilon M+\gamma\right)}{2b\gamma} + \frac{\left(4b^2-d^2\right)}{2b\gamma}\sqrt{\frac{\left(2b\left(1-\epsilon\right)M - d\epsilon M + \gamma(2b-d)\right)^2}{\left(4b^2-d^2\right)^2} - \frac{K}{b}} \tag{50}$$

$$\overline{\sigma}_2 = \frac{2b\left(1-\epsilon\right)M - d\epsilon M + 2b\gamma}{d\gamma} - \frac{4b^2-d^2}{d\gamma}\sqrt{\left(\frac{2b\left(1-\epsilon\right)M - d\epsilon M}{4b^2-d^2}\right)^2 + \frac{K}{b}} \tag{51}$$

Because $\epsilon \in \left(\frac{1}{2}, 1\right)$, statement (i) is true if

$$\frac{\partial \underline{\sigma}_2}{\partial \epsilon} = \frac{(2b+d)\,M}{2b\gamma}\left(1 - \frac{\frac{(2b(1-\epsilon)M - d\epsilon M + \gamma(2b-d))}{(4b^2-d^2)}}{\sqrt{\frac{(2b(1-\epsilon)M - d\epsilon M + \gamma(2b-d))^2}{(4b^2-d^2)^2} - \frac{K}{b}}}\right) < 0 \text{ and} \tag{52}$$

$$\frac{\partial \overline{\sigma}_1}{\partial \epsilon} = \frac{(2b+d)\,M}{d\gamma}\left(1 - \frac{\frac{(2b\epsilon M - d(1-\epsilon)M)}{(4b^2-d^2)}}{\sqrt{\frac{K}{b} + \frac{(2b\epsilon M - d(1-\epsilon)M)^2}{(4b^2-d^2)^2}}}\right) > 0 \tag{53}$$

which holds if $K > 0$.

Similarly, statement (ii) is true if

$$\frac{\partial \underline{\sigma}_1}{\partial \epsilon} = \frac{(2b+d)\,M}{2b\gamma}\left(-1 + \frac{\frac{2(2b\epsilon M - d(1-\epsilon)M + \gamma(2b-d))}{(4b^2-d^2)}}{\sqrt{\frac{(2b\epsilon M - d(1-\epsilon)M + \gamma(2b-d))^2}{(4b^2-d^2)^2} - \frac{K}{b}}}\right) > 0 \text{ and} \tag{54}$$

$$\frac{\partial \overline{\sigma}_2}{\partial \epsilon} = \frac{(2b+d)\,M}{d\gamma}\left(-1 + \frac{\frac{2(2b(1-\epsilon)M - d\epsilon M)}{(4b^2-d^2)}}{\sqrt{\left(\frac{2b(1-\epsilon)M - d\epsilon M}{4b^2-d^2}\right)^2 + \frac{K}{b}}}\right) < 0 \tag{55}$$

which also holds if $K > 0$.

Finally, statement (iii) follows directly from the former two. When all regions shrink, a new region must emerge. The characteristics of the equilibrium in this region follow from the definition of the regions' frontiers.

5.4 Proof of Proposition 4

Statement (i) follows immediately from:

$$q(0,0) = \frac{M}{2b+d}, \quad q(1,1) = \frac{M+2\gamma}{2b+d} \quad \text{and} \quad q(1,0,\sigma) = q(0,1,\sigma) = \frac{M+(1+\sigma)\gamma}{2b+d} \tag{56}$$

which are all independent from ϵ.

To prove statement (ii), consider the social welfare in the different regions:

$$W(0,0) = \frac{\left(12b^2-d^2\right)b-2\epsilon\left(1-\epsilon\right)\left(3b-d\right)\left(2b+d\right)^2}{2\left(4b^2-d^2\right)^2}M^2 \tag{57}$$

$$W(1,1) = \frac{2\gamma\left(3b+d\right)\left(2b-d\right)^2\left(M+\gamma\right)+\left(\left(12b^2-d^2\right)b-2\epsilon\left(1-\epsilon\right)\left(3b-d\right)\left(2b+d\right)^2\right)M^2}{2\left(4b^2-d^2\right)^2}-2K \tag{58}$$

$$\begin{aligned}W(1,0,\sigma) &= \frac{3}{2}b\left(\frac{2b\epsilon M-d\left(1-\epsilon\right)M+\left(2b-d\sigma\right)\gamma}{4b^2-d^2}\right)^2+\frac{3}{2}b\left(\frac{2b\left(1-\epsilon\right)M-d\epsilon M+\left(2b\sigma-d\right)\gamma}{4b^2-d^2}\right)^2\\ &\quad +d\frac{2b\epsilon M-d\left(1-\epsilon\right)M+\left(2b-d\sigma\right)\gamma}{4b^2-d^2}\frac{2b\left(1-\epsilon\right)M-d\epsilon M+\left(2b\sigma-d\right)\gamma}{4b^2-d^2}-K\end{aligned} \tag{59}$$

$$\begin{aligned}W(0,1,\sigma) &= \frac{3}{2}b\left(\frac{2b\epsilon M-d\left(1-\epsilon\right)M+\left(2b\sigma-d\right)\gamma}{4b^2-d^2}\right)^2+\frac{3}{2}b\left(\frac{2b\left(1-\epsilon\right)M-d\epsilon M+\left(2b-d\sigma\right)\gamma}{4b^2-d^2}\right)^2\\ &\quad +d\frac{2b\epsilon M-d\left(1-\epsilon\right)M+\left(2b\sigma-d\right)\gamma}{4b^2-d^2}\frac{2b\left(1-\epsilon\right)M-d\epsilon M+\left(2b-d\sigma\right)\gamma}{4b^2-d^2}-K\end{aligned} \tag{60}$$

Differentiation with respect to ϵ yields:

$$\frac{\partial W(0,0)}{\partial\epsilon} = \frac{\partial W(1,1)}{\partial\epsilon}=\frac{\left(2\epsilon-1\right)\left(3b-d\right)\left(2b+d\right)^2}{\left(4b^2-d^2\right)^2}M^2\geq 0 \tag{61}$$

$$\frac{\partial W(1,0,\sigma)}{\partial\epsilon} = \frac{\left(\left(2\epsilon-1\right)M+\gamma\left(1-\sigma\right)\right)\left(3b-d\right)M}{\left(2b-d\right)^2}\geq 0 \tag{62}$$

for $\epsilon\in\left(\frac{1}{2},1\right)$. This guarantees that social welfare increases with ϵ in Regions I, III and IV in which we have a unique equilibrium. Furthermore, the last expression is sufficient to guarantee that there is at least one equilibrium in Region II in which social welfare increases with ϵ. This happens when the large firm is the innovator and the small firm the imitator. In the opposite case, in which the small firm is the innovator and the large firm the imitator we get

$$\frac{\partial W(0,1,\sigma)}{\partial\epsilon}=\frac{\left(\left(2\epsilon-1\right)M-\gamma\left(1-\sigma\right)\right)}{\left(2b-d\right)^2}\left(3b-d\right)M. \tag{63}$$

Then, social welfare does not necessarily increase with ϵ.

5.5 Proof of Proposition 5

To prove statement (i), from the definition of $\underline{\sigma}_n$ by $\Pi_i(1,...,1)-\Pi_1(0,1,...,1,\underline{\sigma}_n)=0$ we get:

$$\begin{aligned}\underline{\sigma}_n &= \frac{-\left(2b-d\right)\left(a-c\right)+\left(n-1\right)\gamma d}{\gamma\left(2b-2d+dn\right)}+\frac{\left(2b-d\right)\left(2b+d\left(n-1\right)\right)}{\gamma\left(2b-2d+dn\right)}\sqrt{\left(\frac{a-c+\gamma}{2b-d+dn}\right)^2-\frac{K}{b}}\\ &= \frac{-\left(2b-d\right)\left(a-c+\gamma\right)}{\gamma\left(2b-2d+dn\right)}+1+\left(\frac{\left(2b-d\right)}{\gamma}+\frac{\left(2b-d\right)d}{\gamma\left(2b-2d+dn\right)}\right)\sqrt{\left(\frac{a-c+\gamma}{2b-d+dn}\right)^2-\frac{K}{b}}\end{aligned} \tag{64}$$

From differentiation we get:

$$\begin{aligned}\frac{\partial \underline{\sigma}_n}{\partial n} &= \frac{d\left(2b-d\right)\left(a-c+\gamma\right)}{\gamma\left(2b-2d+dn\right)^2} - d\left(\frac{\left(2b-d\right)d}{\gamma\left(2b-2d+dn\right)^2}\right)\sqrt{\left(\frac{a-c+\gamma}{2b-d+dn}\right)^2-\frac{K}{b}} \\ &\quad -d\left(\frac{\left(2b-d\right)}{\gamma}+\frac{\left(2b-d\right)d}{\gamma\left(2b-2d+dn\right)}\right)\left(\left(\frac{a-c+\gamma}{2b-d+dn}\right)^2-\frac{K}{b}\right)^{-\frac{1}{2}}\left(\frac{a-c+\gamma}{2b-d+dn}\right)^2\left(2b-d+dn\right)^{-1} \\ &< 0 \qquad (65)\end{aligned}$$

iff

$$\frac{K}{b}+\frac{\left(2b-3d+dn\right)\left(a-c+\gamma\right)^2}{\left(2b-d+dn\right)d^2}>0 \qquad (66)$$

which always holds.

To prove statement (ii), from the definition of $\overline{\sigma}_n$ by $\Pi_1(1,0,..,0,\overline{\sigma}_n)-\Pi_i(0,0,..,0)=0$ we get:

$$\overline{\sigma}_n = 1+\frac{\left(2b-d\right)\left(a-c+\gamma\right)}{\left(n-1\right)\gamma d}-\frac{\left(2b-d\right)\left(2b+d\left(n-1\right)\right)}{\left(n-1\right)\gamma d}\sqrt{\left(\frac{a-c}{2b-d+dn}\right)^2+\frac{K}{b}} \qquad (67)$$

From differentiation we get:

$$\begin{aligned}\frac{\partial \overline{\sigma}_n}{\partial n} &= -\frac{\left(2b-d\right)\left(a-c+\gamma\right)}{\left(n-1\right)^2\gamma d}+\frac{2\left(2b-d\right)b}{\left(n-1\right)^2 d\gamma}\sqrt{\left(\frac{a-c}{2b-d+dn}\right)^2+\frac{K}{b}} \\ &\quad +d\frac{\left(2b-d\right)\left(2b+d\left(n-1\right)\right)}{\left(n-1\right)\gamma d}\left(\left(\frac{a-c}{2b-d+dn}\right)^2+\frac{K}{b}\right)^{-\frac{1}{2}}\left(\frac{a-c}{2b-d+dn}\right)^2\left(2b-d+dn\right)^{-1} \\ &< 0 \qquad (68)\end{aligned}$$

iff

$$-\left(a-c+\gamma\right)+2b\sqrt{\left(\frac{a-c}{2b-d+dn}\right)^2+\frac{K}{b}}+\left(n-1\right)d\left(\left(\frac{a-c}{2b-d+dn}\right)^2+\frac{K}{b}\right)^{-\frac{1}{2}}\left(\frac{a-c}{2b-d+dn}\right)^2<0 \qquad (69)$$

which is an increasing function in K. Therefore, a sufficient condition is that this holds for $\overline{K}$:

$$\overline{K}=b\left(\frac{a-c+\gamma}{2b-d+dn}\right)^2-b\left(\frac{\left(2b-d\right)\left(a-c\right)-d\gamma}{\left(2b-d\right)\left(2b+d\left(n-1\right)\right)}\right)^2 \qquad (70)$$

defined by $\Pi_j(1,1,...,1)=\Pi_j(1,0,...,0,\sigma=0)$, $j\neq 1$. This yields:

$$\begin{aligned}&-\left(a-c+\gamma\right)+2b\sqrt{\left(\frac{a-c}{2b-d+dn}\right)^2+\left(\frac{a-c+\gamma}{2b-d+dn}\right)^2-\left(\frac{\left(2b-d\right)\left(a-c\right)-d\gamma}{\left(2b-d\right)\left(2b+d\left(n-1\right)\right)}\right)^2} \\ &+\left(n-1\right)d\left(\left(\frac{a-c}{2b-d+dn}\right)^2+\left(\frac{a-c+\gamma}{2b-d+dn}\right)^2-\left(\frac{\left(2b-d\right)\left(a-c\right)-d\gamma}{\left(2b-d\right)\left(2b+d\left(n-1\right)\right)}\right)^2\right)^{-\frac{1}{2}}\left(\frac{a-c}{2b-d+dn}\right)^2 \\ <\;& -\frac{\left(2\left(a-c\right)+\gamma\right)\left(n-1\right)d\gamma}{\left(a-c+\gamma\right)\left(2b-d+dn\right)}<0 \qquad (71)\end{aligned}$$

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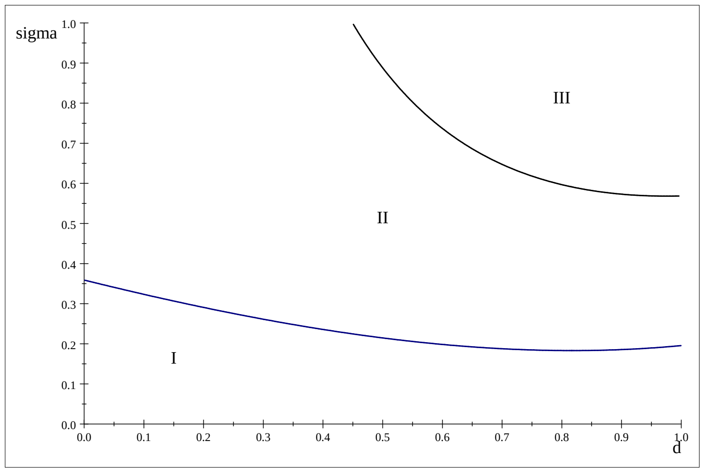

Figure 1: The three regions of model equilibria for $b = 1$, $\gamma = 1$, $a - c = 4$ and $K = 1, 5$.

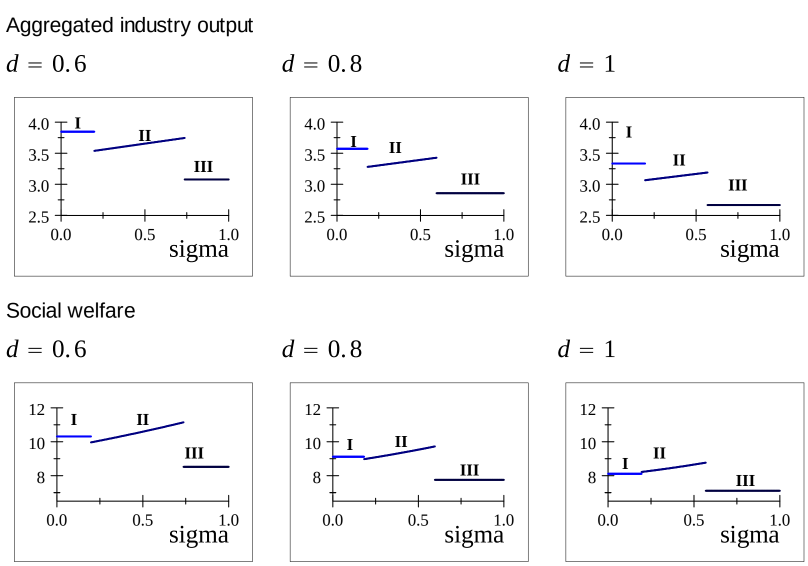

Figure 2: Aggregated industry output and social welfare as functions of σ for $b = 1$, $d = 0.6$, $a - c = 4$, $\gamma = 1$, and $K = 1.5$.

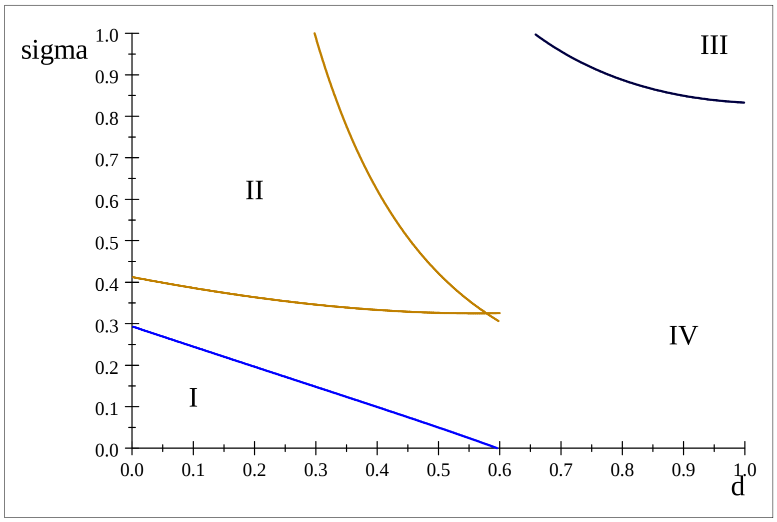

Figure 3: The four regions of model equilibria for $b = 1$, $\gamma = 1$, $M = 8$, $\epsilon = \frac{11}{20}$ and $K = 1.5$.

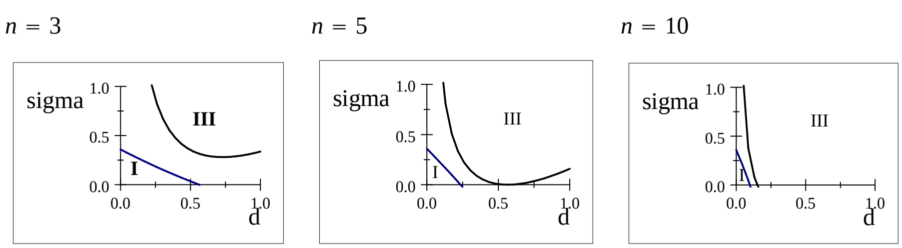

Figure 4: The regions of model equilibria for $b = 1$, $\gamma = 1$, $a - c = 4$ and $K = 1.5$.

N	Industry	No-Innovation, %	Imitation, %	Innovation, %	TOTAL firms
	Manufactring	*29.52*	*33.50*	*36.98*	*1,985*
0	Agriculture / Farming	32.00	36.00	32.00	25
1	Mining	69.49	16.95	13.56	59
2	Food / Tobacco	42.62	36.89	20.49	122
3	Textiles	44.64	28.57	26.79	112
4	Wood / Paper	37.61	36.24	26.15	218
5	Chemicals	13.84	29.56	56.60	159
6	Plastics	28.46	34.96	36.59	123
7	Glass / ceramics	35.44	27.85	36.71	79
8	Metals	41.30	31.16	27.54	276
9	Machinery	19.49	36.02	44.49	236
10	Electrical equipment	13.44	39.25	47.31	186
11	Medical and other instruments	13.86	33.66	52.48	202
12	Transport equipment	20.21	37.23	42.55	94
13	Furniture	38.30	32.98	28.72	94
	Services	*50.78*	*32.09*	*17.13*	*1,926*
14	Wholesale	60.81	26.35	12.84	148
15	Retail / Automobile	71.43	23.38	5.19	77
16	Transport / Communications	62.79	27.57	9.63	301
17	Banking / Insurance	26.63	50.00	23.37	184
18	IT / Telecommunications	15.88	50.00	34.12	170
19	Technical services	35.29	32.68	32.03	306
20	Firm-related services	42.22	34.81	22.96	135
21	Real estate / Renting	68.54	22.47	8.99	89
22	Construction	85.23	12.50	2.27	88
23	Energy / Water supply	67.16	25.37	7.46	134
24	Film / Broadcasting	52.17	32.61	15.22	46
25	Other services	61.69	29.84	8.47	248
	TOTAL	*39.99*	*32.80*	*27.21*	*3,911*

Table 1: The patterns of innovativeness in German manufacturing and services sectors (3911 observations, year 2005).

			Expected Sign*
Variable	Label	Parameter	Innovativeness
	Dependent variables		
STR	Firms' R&D strategy: 0=non-innovation, 1=imitation or 2=innovation.		
	Independent variables		
Internal factors:			
SIZE02	Size of the firm in 2002, measured as a number of employees	$(a-c), \epsilon$	+
AC03	A firm's absorptive capacity measured by the proportion of all employees who have a university degree or other higher education qualification in 2003		+
GROUP	Firms that belong to the group of firms: 0=no; 1=yes		+
EX02	The firm's turnover from export in 2002		?
GEO	Geographical size of the market availabe for the firm: 0=local or regional market, 1=nation-wide market in Germany, 2=EU and EFTA countries and EU candidates, 3=world market	$(a-c)$	+
ost	Firms from the former Eastern Germany: 0=no, 1=yes		?
External factors:			
av_IPR	The success of legal protective mechanisms for innovations and inventions (patent, registered / industry design, trademark, copyright): the sum of listed factors evaluated as 0=not applicable, 1=hardly applies, 2=rather applies, 3=strongly applies, rescaled such that it varies between 0 (minimum level) and 1 (maximum level). For each firm this value is calculated in its 3-digit NACE Rev.1 industrial code excluding the firm itself.	σ	+
TEC	Technologies change rapidly in the sector: 0=not applicable, 1=hardly applies, 2=rather applies, 3=strongly applies	σ	+
COM	High threat to the own market position due to entrance: 0=not applicable, 1=hardly applies, 2=rather applies, 3=strongly applies	n	-
DIF	Products of competitors can easily be substituted by products of the firm: 0=not applicable, 1=hardly applies, 2=rather applies, 3=strongly applies	d/b	?
DEM	The development of demand is unforeseenable: 0=not applicable, 1=hardly applies, 2=rather applies, 3=strongly applies		-

Table 2: Description of Variables. *Base category is "Non-innovation".

Variable	Mean	Std. dev.	Min	Max
STR	0.872	0.810	0	2
SIZE02	574.855	7423.857	0	426000
AC03	19.924	24.439	0	100
GROUP	0.338	0.473	0	1
EX02	63.863	1028.382	0	46353.17
GEO	1.352	1.136	0	3
ost	0.343	0.475	0	1
av_IPR	0.276	0.243	0	2.4
TEC	1.257	0.878	0	3
COM	1.564	0.854	0	3
DIF	1.802	0.922	0	3
DEM	1.861	0.808	0	3

Table 3: Descriptive statistics.

Dependent Variable: STR										
	Model I				Model II				Mfx for Model II	
Independent Variable	Coef. (1)	Std. Err.(1)	Coef. (2)	Std. Err.(2)	Coef. (1)	Std. Err.(1)	Coef. (2)	Std. Err.(2)	mfx (1)	mfx (2)
Internal factors										
SIZE02	0.000*	0.000	0.001*	0.000	0.000*	0.000	0.001*	0.000	0.000	0.000
AC03	0.016*	0.003	0.026*	0.004	0.014*	0.003	0.024*	0.003	0.001	0.003
GROUP	0.431*	0.131	0.820*	0.146	0.415*	0.128	0.772*	0.143	0.009	0.103
EX02	−0.000	0.000	−0.001**	0.000	−0.000	0.000	−0.001***	0.000	−0.000	−0.000
GEO	0.352*	0.061	0.659*	0.071	0.354*	0.058	0.696*	0.067	0.008	0.093
ost	0.172	0.122	−0.269	0.147	0.154	0.119	−0.283**	0.144	0.070	−0.070
External factors										
av_IPR	0.757**	0.409	1.238*	0.435	0.892*	0.360	1.597*	0.390	0.037	0.205
TEC	0.681*	0.073	0.710*	0.085	0.709*	0.069	0.713*	0.081	0.093	0.056
COM	−0.044	0.066	−0.290*	0.082	−0.045	0.064	−0.278*	0.080	0.021	−0.048
DIF	0.290*	0.064	0.086	0.076	0.326*	0.063	0.128***	0.074	0.066	−0.013
DEM	−0.242*	0.076	−0.283*	0.088	−0.272*	0.073	−0.270*	0.085	−0.036	−0.021
Ind. dummies	*yes**				–					
Ind. classes:	–									
MLTM					0.153	0.176	0.515**	0.202	−0.027	0.087
MHTM					0.292	0.233	0.597**	0.247	−0.004	0.085
HTM					0.990*	0.317	1.505*	0.328	0.018	0.181
HTS					0.164	0.146	0.140	0.191	0.024	0.008
N obs.:	2289				2289					
Pseudo R_2:	0.1987				0.1804					
Log likelihood	−2003.6339				−2049.4607					
LR test	993.99				902.34					
% corr.pred.	66.7%				69.8%					

Table 4: Mlogit estimation of innovativeness of firms as a function of internal and external factors. * Significant at 1%, ** Significant at 5%, *** Significant at 10%.

Dependent Variable: STR						
	Model I				Model II	
Independent Variable	Coef.	Std. Err.	mfx (1)	mfx (2)	Coef.	Std. Err.
Internal factors						
SIZE02	0.000*	0.000	$8.05e-06$	0.000	0.000*	0.000
AC03	0.016*	0.002	0.001	0.003	0.015*	0.002
GROUP	0.554*	0.093	0.017	0.099	0.486*	0.044
EX02	−0.000*	0.000	−0.000	−0.000	−0.000***	0.000
GEO	0.461*	0.047	0.021	0.079	0.496*	0.044
ost	−0.187**	0.094	−0.009	−0.031	−0.195**	0.092
External factors						
av_IPR	0.900*	0.279	0.041	0.154	0.995*	0.252
TEC	0.481*	0.053	0.022	0.082	0.491*	0.051
COM	−0.163*	0.052	−0.007	−0.028	−0.152*	0.051
DIF	0.103**	0.050	0.005	0.018	0.139*	0.049
DEM	−0.201*	0.058	−0.009	−0.034	−0.206*	0.055
Ind. dummies:	*yes**				–	
Ind. classes:	–					
MLTM					0.367*	0.137
MHTM					0.447*	0.163
HTM					0.866*	0.183
HTS					0.150	0.119
N obs.:	2289				2289	
Pseudo R_2:	0.1736				0.1607	
Log likelihood	−2066.5515				−2098.7808	
LR test	868.15				803.70	
% corr.pred.	68.3%				68.3%	

Table 5: Ordered logit estimation of innovativeness of firms as a function of internal and external factors. * Significant at 1%, ** Significant at 5%, *** Significant at 10%.

Variables	STR	SIZE02	AC03	GROUP	EX02	GEO	ost	av_IPR	TEC	COM	DIF	DEM
STR	1.00											
SIZE03	0.07	1.00										
AC03	0.21	−0.02	1.00									
GROUP	0.21	0.09	0.00	1.00								
EX03	0.06	0.23	0.03	0.10	1.00							
GEO	0.41	0.06	0.10	0.21	0.10	1.00						
ost	−0.09	−0.05	0.16	−0.16	−0.05	−0.10	1.00					
av_IPR	0.34	0.02	0.06	0.08	0.07	0.49	−0.03	1.00				
TEC	0.25	−0.02	0.14	−0.02	0.02	0.11	−0.08	0.13	1.00			
COM	−0.08	−0.00	−0.01	−0.04	−0.00	−0.02	−0.04	−0.06	0.03	1.00		
DIF	0.04	0.05	−0.09	0.11	0.03	−0.00	−0.08	0.00	0.04	0.17	1.00	
DEM	−0.04	−0.04	0.05	−0.12	−0.01	0.05	0.07	0.02	0.17	0.11	0.15	1.00

Table 6: Correlation analysis