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Quaderni di ricerca del
Dipartimento di Scienze Economiche
"Hyman P. Minsky"

Anno 2007 n.1

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Abstract

Recent empirical evidence about innovation shows that established firms rarely invest in radical innovation but incrementally improve the existing technology. Revolutionary breakthroughs are more likely to be introduced by new entrants. These stylized facts motivate a renewed attention of the debate on incentives to innovate. In this stream of the literature our paper emphasizes the importance of distinguishing between degrees of innovativeness when comparing an incumbent's and an entrant's incentives to invest in innovation. The model presented captures the peculiarity of a radical innovation with respect of an incremental one along three dimension: risk, impact on the existing market and capability of opening up a new market. The results reflect the empirical evidence and emphasize the role of substitutability between markets in determining the strength of this effect.

We thank L.Zirulia for helpful comments.

1 Introduction

Revolutionary breakthroughs are rare and launched mainly by small, new entrants. Established firms, on the contrary, tend to develop marginal changes to the existing technology. Data show that, although most private R&D expenditure is attributable to large corporations, only 5% of them reach remarkable degrees of innovativeness (among others see: Baumol, 2004).

Enterprises' concern with long-run growth and renewal motivates the attention toward the distinction among innovations with different characteristics of disruptiveness. Nonetheless, not enough effort has been devoted to it. Everybody is able to grasp the diversity between radical and incremental innovations, at least at an intuitive level; studies both in economics and business have recognized the importance of finding a specific characterization of innovative strategies based on the degree of innovativeness, with a plethora of meanings (Garcia & Calantone, 2002). The labels "radical" and "incremental" belong mostly to managerial literature that does not offer a unique description of the difference between the two concepts. In fact, there are many dimensions along which authors calibrate the degree of innovativeness: the level of risk implied in the strategy (e.g. Kaluzny, Veney & Gentry, 1974; Duchesneau et al., 1979; Hage, 1980; Cardinal, 2001), obviously greater in the case of radical breakthroughs; the type of knowledge being processed (e.g. Dewar & Dutton, 1986; Henderson, 1993), that might involve completely new developments or simply enlarge the existing base; performance improvement and cost reduction (e.g. Nord & Tucker, 1987), that reflect the higher investment needed to move onto a new trajectory.

Moreover, a crucial consequence of a successful radical innovation is that the start of a new technological trajectory might imply the eventual opening of a new market and consequent applications (e.g. O'Connor, 1998; Henderson & Clark, 1990): a radical innovation is a product, process, or service offering "significant improvements in performance or cost that transform existing markets or create new ones" (Leifer, Colarelli O'Connor & Rice, 2001). Personal computers, cellular telephones, computerized tomography, processors and celluloid-film cameras represent only a few examples of radical innovations.

Although diffused in managerial studies, the terms radical and incremental are not used explicitly in the economic literature. Nonetheless, similar concepts are analyzed in the context of process innovations. Industrial organization works describe as "drastic innovations" (e.g. Reinganum, 1983) those changes in technology that determine a decrease in costs such that the new equilibrium price lies below the pre-innovation cost and consequently turn the innovator into a monopolist. On the other hand, "non-drastic" or "gradual" innovations still affect costs, but only introducing an asymmetry that does not transform the market into a monopoly. Recalling previous works in managerial literature, drastic innovations can be interpreted as a particular manifestation of radical innovations that affect costs and market structure in a dramatic way.

The concept of drastic innovation has been judged as critical to understand firms' attitude towards innovation. Arrow's seminal work (1962) claims that innovation takes place only in a competitive scenario: a monopolist has little incentive to replace himself, whereas a potential rival needs to introduce an innovation to drive established firms out of the market and find a place. According to Schumpeter (1943), however, this effect is relevant only if appropriability of innovative returns is possible and the innovator can successfully benefit from his investment's earnings preventing imitation. Subsequent works, both theoretical and empirical, have been trying to detect a specific relationship between the *ex-post* degree of competition and incentives to innovation, nonetheless without converging to a generally-accepted result. Gilbert and Newbery (1982) show that, under the assumption of deterministic innovation, a firm with monopoly power has an incentive to patent preemptively as this allows it to remain monopolist. On the contrary, Reinganum (1983) demonstrates that, in a stochastic setup, an incumbent firm invests less than its challenger when the innovation is drastic. Although the huge resonance of this debate, subsequent works (Gilbert & Newbery, 1984; Reinganum, 1984; Vickers, 1986; Riordan & Salant, 1994) provide no clue to a clear correlation between market structure and incentive to innovate. Building on the stylized fact illustrated above, in this paper we claim that the degree of competition of an industry is crucially challenged by the degree of innovativeness of the innovative strategy.

We depart from the existing literature because in depicting radical innovation as crucially differing from incremental innovation in the fact that: (1) the relationship between R&D effort and profits is stochastic; (2) the successful innovator becomes monopolist, no matter is he the incumbent or the entrant; (3) a successful investment leads to the creation of a new market. Our results show that, for a large set of parameter value, in case of a radical breakthrough, the incumbent firm invests less than the entrant despite the larger resource availability. Radical innovation satisfies the same need by means of a new product, but it displaces the existing one at a different degree. The strength of this effect depends upon the relationship between the old market - where the incumbent offers the pre-innovation product - and the new one - where the radical innovation is sold. On the other hand, with incremental innovations (captured as deterministic investments that do not open up any new market), it is the incumbent that exhibits the highest incentive to innovate. Therefore, we bring together the apparent contradiction between Gilbert and Newbery (1982)'s and Reinganum (1983)'s results by distinguishing between different types of innovation.

This paper provides a theoretical model that describes the incumbent and the entrant's patent races, where races concerns alternatively a radical or an incremental innovation. Section (2) illustrates the set-up in the radical innovation case; the corresponding model is fully developed in Section (3), while section (4) presents the set-up and the model in the incremental innovation case. Section (5) concludes.

2 Set-up: radical innovation case

Following the literature on patent race, we consider a monopolist (I) and a potential entrant (E) that simultaneously attempt to introduce an innovation, but we explicitly account for a radical innovation. As previously explained, we define a radical innovation as the introduction of a drastic innovation which allows the innovative firm to open up a new market. Therefore we consider the existence of two different markets; the former is the "old" one, where firm I is a monopolist, the latter is the "new" emerging market created by the innovation. Notice that, differently from the literature on patent race where the introduction of an innovation in the original market, displaces the old product and drives profit to zero, in the case of a radical innovation this displacement, between old and new product might be incomplete. In fact the innovative firm has been earning some of the pre-innovation returns in the old market. Therefore the total return after innovation is given by the sum of the profit in the old market and in the new-one, according to the fact that the sell of the new product in the new market could foreclose the demand in the old one. To take into account this relationship between the old and the new production, we assume different degree of substitutability between the two markets, in the sense that the new product could cannibalize the sales in the old market or not. At last, we restrict our attention on the competition in the new market so that we exclude the entrance in the existing one.

In order to introduce the innovation, both firms invest in R&D the amount x_i with $i = I, E$. The uncertainty in the innovative process takes the form of a stochastic relationship between the R&D effort and the eventual expected time of successful of the new technology. Following Reinganum (1983) and Denicolò (1999), we assume that the probability of a firm i being successful at (or before) the date t is: $\Pr\{\tau(x_i) \leq t\} = 1 - e^{h(x_i)t}$, where $h(x_i)$ is the hazard function. The idea is that the relationship between the amount spent on R&D and the likelihood of making innovation is captured by the hazard function. As in Reinganum (1983), we assume that the hazard function is twice continuously differentiable, with $h'(x_i) > 0$ and $h''(x_i < 0)$ for all $x_i \in [0, \infty)$ and $i = I, E$. Moreover, $h(0) = 0 = \lim_{x_i \to \infty} h'(x_i)$, which implies decreasing returns to scale in technology. Therefore the expected profit for firm

I in the new market is defined as follows:

$$\begin{aligned} V_I(x_I, x_E) &= \int_0^\infty e^{-rt} e^{-h(x_I)t} e^{-h(x_E)t} \\ & \left[h(x_I)\Pi_I^M + (1 - \alpha h(x_I))\Pi_I^V - \alpha h(x_E)\Pi_I^V - x_I\right] dt \\ &= \frac{h(x_I)\Pi_I^M + (1 - \alpha(h(x_I) + h(x_E)))\Pi_I^V - x_I}{r + h(x_I) + h(x_E)} \end{aligned} \tag{1}$$

where Π_I^M is the monopoly profit for the incumbent in the new market, whereas $\Pi_I^V$is the incumbent profit in the old market and r is the discount rate. The parameter α denotes the degree of substitutability/complementarity of the two markets. More specifically, $\alpha = 0$ implies no strategic interaction between the two profit levels; in case of success, the expected payoff for the incumbent firm is given by the sum of the profit in the old and in the new market. Then, for $\alpha > 0$, there exist a certain degree of substitution between the two markets and consequentely the innovative profit in the new market worse off profitability level in the old one. Also notice that the market cannibalization in the old market occurs independently on identity of the innovator on the new market. Therefore profit of firm I reduces either she introduces the innovation or the rival does.

As E can enter exclusively the new market, its expected profit is defined as:

$$\begin{aligned} V_E(x_I, x_E) &= \int_0^\infty e^{-rt} e^{-h(x_E)t} e^{-h(x_I)t} \left[h(x_E)\Pi_E^M - x_E\right] dt \\ &= \frac{h(x_E)\Pi_E^M - x_E}{r + h(x_I) + h(x_E)} \end{aligned} \tag{2}$$

where Π_E^M is the monopoly profit for the entrant. Let specify that: $\Pi_I^M = \Pi_E^M$.

The difference in the incumbent and in the potential entrant payoffs arises from the fact that in the old market firm I earns positive profit Π_I^V, while the profit of the potential entrant is equal to zero, $\Pi_E^V = 0$.

3 Model and results: radical innovation case

The model developed in this section presents several analogies with Reinganum (1983). However, the main departure concerns that the implication of a radical innovation, i.e. the possibility of opening up of a new market, is now investigated. Consequently, we also consider the chance that a radical innovation might reduce the demand in the old market and the profit level.

As standard in the patent race literature, we look for the Nash equilibrium in terms of R&D investments, that is given by $(x_I^*(x_E), x_E^*(x_I))$.

Each firm chooses its investment in R&D (x_I, x_E) in order to maximize expected profits.

Proposition 1 *There exist a Nash equilibrium of the game* $\left(x_I^*\left(x_E\right), x_E^*\left(x_I\right)\right)$ *which satisfies the first and second order conditions.*

Proof. *Let us start considering the first order condition for a maximum for firm* I. *Considering the derivative of* (1) *with respect to* x_I *and rearranging, we get:*

$$\begin{aligned}\frac{\partial V_I}{\partial x_I} &= \frac{\left(r+h\left(x_I\right)+h\left(x_E\right)\right)\left(h'\left(x_I\right)\Pi_I^M-\alpha h'\left(x_I\right)\Pi_I^V-1\right)}{\left(r+h\left(x_I\right)+h\left(x_E\right)\right)^2} \\ &- \frac{-h'\left(x_I\right)\left(h\left(x_I\right)\Pi_I^M+\left(1-\alpha\left(h\left(x_I\right)+h\left(x_E\right)\right)\right)\Pi_I^V-x_I\right)}{\left(r+h\left(x_I\right)+h\left(x_E\right)\right)^2}=0\end{aligned} \tag{3}$$

Analogously for firm E, differentiating (2) *with respect to* x_E *and rearranging, we get:*

$$\begin{aligned}\frac{\partial V_E}{\partial x_E} &= \frac{\left(r+h\left(x_I\right)+h\left(x_E\right)\right)\left(h'\left(x_E\right)\Pi_E^M-1\right)}{\left(r+h\left(x_I\right)+h\left(x_E\right)\right)^2} \\ &- \frac{h'\left(x_E\right)\left(h\left(x_E\right)\Pi_E^M-x_E\right)}{\left(r+h\left(x_I\right)+h\left(x_E\right)\right)^2}=0\end{aligned} \tag{4}$$

equations (3) *and* (4) *implicitly define the best response functions of the two firms. Considering only the numerator, we can write*

$$\begin{aligned}f_I\left(x_I,x_E\right) &= \left(r+h\left(x_I\right)+h\left(x_E\right)\right)\left(h'\left(x_I\right)\Pi_I^M-\alpha h'\left(x_I\right)\Pi_I^V-1\right) \\ &-h'\left(x_I\right)\left(h\left(x_I\right)\Pi_I^M+\left(1-\alpha\left(h\left(x_I\right)+h\left(x_E\right)\right)\right)\Pi_I^V-x_I\right)\end{aligned} \tag{5}$$

$$\begin{aligned}f_E\left(x_I,x_E\right) &= \left(r+h\left(x_I\right)+h\left(x_E\right)\right)\left(h'\left(x_E\right)\Pi_E^M-1\right) \\ &-h'\left(x_E\right)\left(h\left(x_E\right)\Pi_E^M-x_E\right)\end{aligned} \tag{6}$$

respectively for firm I *and firm* E. *Notice that* $sgn\frac{\partial V_I}{\partial x_I}=sgn f_I$ *and* $sgn\frac{\partial V_E}{\partial x_E}=sgn f_E$.

The model does not allow for an explicit solution of the first order conditions system. Therefore we should prove that the payoff function is single peaked in a compact interval . It is easy to check that: $f_I(0,0)=0$ *when* $h'(0)=\frac{r}{r\Pi_I^M-(\alpha r+1)\Pi_I^V}$ *and* $f_E(0,0)=0$ *when* $h'(0)=\frac{1}{\Pi_E^M}$. *Therefore we can write:*

$$h'(0) \geq \max\left(\frac{1}{\Pi_E^M}, \frac{r}{r\Pi_I^M-(\alpha r+1)\Pi_I^V}\right) \tag{7}$$

Now, we look at the slope of (5) *and* (6) *according to the increase of* x_I *and* x_E. *Assuming that* $x_I \to \infty$, *we obtain* $f_E\left(x_I, 0\right)=0$ *if*

$\frac{r+1}{(r+1)\Pi_I^M-[\alpha(r+1)+1]\Pi_I^V}$ *; analogously, assuming that* $x_E \to \infty$ *, we obtain* $f_I(0, x_E) = 0$ *if* $h'(0) = \frac{r+1}{(r+1)\Pi_I^M-(1+r\alpha)\Pi_I^V}$. *Therefore:*

$$h'(x) \leq \min\left\{\frac{r}{r\Pi_I^M-(\alpha r\ +\ 1)\Pi_I^V}, \frac{r+1}{(r+1)\Pi_I^M-(1+r\alpha)\Pi_I^V}\right\} \tag{8}$$

Under conditions (7) *and* (8)*, the profit function of firm* I *is initially increasing and subsequently decreasing. Therefore there exist two best response functions which satisfy the first order conditions:* $\phi_I(x_E)$ *and* $\phi_E(x_I)$.

In order to verify that the equilibrium is a maximum, we now check second order conditions. Let us start with firm I*:*

$$\frac{\partial f_I(x_I, x_E)}{\partial x_I} = h''(x_I)\left[\Pi_I^M(r + h(x_E)) - (\alpha r + 1)\Pi_I^V + x_I\right] \tag{9}$$

We know, by assumption $h''(\cdot) < 0$*, also* (7) *and* (8) *grant that:*

$\left[\Pi_I^M(r + h(x_E)) - (\alpha r + 1)\Pi_I^V + x_I\right] > 0$*. Therefore the derivative* (9) *is negative. For firm* E*:*

$$\frac{\partial f_E(x_I, x_E)}{\partial x_E} = h''(x_E)\left[(r + h(x_I))\Pi_E^M + x_E\right] \tag{10}$$

Again, by assumption $h''(\cdot) < 0$*, therefore the derivative* (10) *is negative.*
■

So far, we have shown that the equilibrium exists and it implies a positive investment in R&D for both firms. The following proposition clarifies which firm invests more .

Proposition 2 *With radical innovation, for* $\alpha \in \left(-\frac{1}{r}, 1\right]$*, in equilibrium, the entrant* (E) *invests more in R&D than the incumbent* (I)*:* $x_E^*(x_I) > x_I^*(x_E)$

Proof. *First, we prove that the existence of a competitor increases the investment in R&D. Second, we show that the entrant invests more than the incumbent. By the implicit function theorem:*

$$\frac{\partial \phi_E}{\partial x_I} = -\frac{\dfrac{\partial^2 V_E(x_I, \phi_E)}{\partial x_I \partial x_E}}{\dfrac{\partial^2 V_E(x_I, \phi_E)}{\partial x_E^2}} \tag{11}$$

$$\frac{\partial \phi_I}{\partial x_E} = -\frac{\dfrac{\partial^2 V_I(\phi_I, x_E)}{\partial x_I \partial x_E}}{\dfrac{\partial^2 V_I(\phi_I, x_E)}{\partial x_I^2}} \tag{12}$$

Notice that both the denominators are negative by second order conditions. Furthermore, rearranging first order conditions and recalling the definitions of (1) *and* (2) *, we can write:*

$$V_I(\phi_I, x_E) = \frac{h'(x_I)\Pi_I^M - \alpha h'(x_I)\Pi_I^V - 1}{h'(x_I)} \tag{13}$$

$$V_E(x_I, \phi_E) = \frac{h'(x_E)\Pi_E^M - 1}{h'(x_E)} \tag{14}$$

Considering (12), $h'(x_E) > 0$ *by definition, therefore* $sgn\frac{\partial^2 V_I(\phi_I, x_E)}{\partial x_I \partial x_E} = sgn\left(h'(x_I)\Pi_I^M - \alpha h'(x_I)\Pi_I^V - 1\right)$*. The inequality* $V_I(\phi_I, x_E) > 0$ *implies that* $\left(h'(x_I)\Pi_I^M - \alpha h'(x_I)\Pi_I^V - 1\right) > 0$*, therefore (12) is positive. The same holds for firm* E*.*

In the aim of investigating who invests more, we compare the two reaction functions: ϕ_I *and* ϕ_E*. They differ for the following term:* $\left[-h'(x_I)\Pi_I^V(\alpha r + 1)\right]$ *. Again using the implicit function theorem, we get:*

$$\frac{\partial \phi_I}{\partial \Pi_I^V} = -\frac{\dfrac{\partial^2 V_I(\phi_I, x_E)}{\partial x_I \partial \Pi_I^V}}{\dfrac{\partial^2 V_I(\phi_I, x_E)}{\partial x_I^2}} \tag{15}$$

The numerator becomes: $-\left(-h'(x_I)\left[\alpha\left(r + h(x_E)\right) + 1\right]\right) > 0$*; the denominator is negative, consequently* I*'s best response function is lower of* E*'s one. It proves that:* $x_E^* > x_I^*$*.* ■

Corollary 3 *With radical innovation and* $\alpha \leq -\dfrac{1}{r}$ *in equilibrium, the incumbent* (I) *invests more in R&D than the entrant* (E)*:* $x_I^*(x_E) > x_E^*(x_I)$*.*

Proof. *Analogously to the proof of Proposition 2, but consider the numerator of (15). For* $\alpha = -\frac{1}{r}$ *the two reaction functions,* $\phi_I(x_E)$ *and* $\phi_E(x_I)$*, are equal; therefore the two firms invest the same amount in R&D:* $x_I^* = x_E^*$*. For* $\alpha < -\frac{1}{r}$*, the numerator of (15) becomes positive. Therefore the reaction function of firm* E *is lower than* I'*s one:* $x_I^* > x_E^*$*.*

So far, we have proved that, for a large set of α*'s values, the entrant invests more in R&D than the incumbent. On this respect we can claim that our definition of radical innovation restores the result of drastic innovation in a stochastic model; this result is sharply driven by the profit displacement in the old market. However, differently from the case of drastic innovation, we have a range of* α*'s values such that the opposite result holds: the incumbent invests more than the entrant. If we interpret* α *as the degree of market substitutability, in the case of* $\alpha = 0$ *(i.e. when* *markets are unrelated), the incumbent's payoff is given by the sum of the expected profit in the new market and in the old one. For* $\alpha \in (0,1]$, *we assume there exist a certain degree of substitution between the two markets and consequently a certain level of cannibalization (increasing in the value of* α*) of the profit in the old market. Conversely, for* $\alpha < 0$ *we deal with the case of complementarity between the two markets, the profit in the old markets increase whether the innovation occurs. If we restrict the range of parameter value to* $\alpha < -\frac{1}{r}$ *our result implies that the incumbent has the highest incentive to innovate.* ■

4 Set-up, model and results: incremental innovation case

Analogously to the previous analysis, we consider two firms, I and E, investing in R&D the amount x_i with $i = I, E$. Differently from the radical case, we assume here that the firms are looking for an incremental innovation. Therefore, we assume, as in the Gilbert and Newbery (1982) model, the patent date is a deterministic function of R&D investment; in other words, the date of success is deterministically correlated to the amount invested in R&D. The innovation is granted to the firm investing more in R&D. Therefore we do not need to introduce the hazard function, but we assume that the relationship between the amount spent on R&D and the innovative outcome goes troughs the profit functions. An incremental innovation does not open up a new market (differently from the previous part) and completely displaces the pre-innovation product in the existing market. More precisely, given the nature of innovation, the entrant firm could enter the market only as a duopolist, sharing the oligopolistic profit with the incumbent. While the incumbent firm remains monopolist as long as he prevents the rival from innovating. Thus, the expected profit, respectively for firm I and E are defined as follows:

$$\begin{aligned} V_I(x_I, x_E) &= \int_0^T e^{-rt}\Pi_I^M(x_I)\,dt + \int_T^\infty \Pi_I^D(x_I, x_E)\,e^{-rt}dt \\ &= \frac{\Pi_I^M(x_I)}{r}\left(1 - e^{-rT}\right) + e^{-rT}\frac{\Pi_I^D(x_I, x_E)}{r} - x_I \end{aligned} \tag{16}$$

$$\begin{aligned} V_E(x_I, x_E) &= \int_T^\infty \Pi_E^D(x_I, x_E)\,e^{-rt}dt \\ &= e^{-rT}\frac{\Pi_E^D(x_I, x_E)}{r} - x_E \end{aligned} \tag{17}$$

where Π_I^M is the incumbent's monopoly profit, Π_j^D, with $j = I, E$ are the duopoly profits and T is the date of innovation. As previously, we look for a Nash equilibrium in terms of a couple of investment in R&D, (x_I^*, x_E^*), as shown in the following proposition.

Proposition 4 *There exist a pair of Nash equilibrium strategies,* $(x_I^*(x_E), x_E^*(x_I))$, *which satisfy first and second order conditions.*

Proof. *The first order conditions which implicitly define a best response function are, respectively for* I *and* E*:*

$$\frac{\partial V_I(x_E,\phi_I)}{\partial x_I} = \frac{\partial}{\partial x}\left(\frac{\Pi_I^M(x_I)}{r}\left(1-e^{-rT}\right)+e^{-rT}\frac{\Pi_I^D(x_I,x_E)}{r}-x_I\right) = \frac{\left(1-e^{-rT}\right)}{r}\frac{\partial\Pi_I^M(x_I)}{\partial x_I}+\frac{e^{-Tr}}{r}\frac{\partial\Pi_I^D(x_I,x_E)}{\partial x_I}-1=0 \tag{18}$$

$$\frac{\partial V_E(\phi_E,x_I)}{\partial x_E} = \frac{\partial}{\partial x_E}\left(e^{-rT}\frac{\Pi_E^D(x_I,x_E)}{r}-x_E\right) = \frac{e^{-Tr}}{r}\frac{\partial\Pi_E^D(x_I,x_E)}{\partial x_E}-1=0 \tag{19}$$

where we assume that each firm profit function is increasing in its own investment in R&D at a declining rate.

We can now introduce the second order conditions in order to prove the existence of a maximum.

$$\frac{\partial}{\partial x_I}\left(\frac{\left(1-e^{-rT}\right)}{r}\frac{\partial\Pi_I^M(x_I)}{\partial x_I}+\frac{e^{-Tr}}{r}\frac{\partial\Pi_I^D(x_I,x_E)}{\partial x_I}-1\right) = \frac{\left(1-e^{-rT}\right)}{r}\frac{\partial^2\Pi_I^M(x_I)}{\partial x_I^2}+\frac{e^{-Tr}}{r}\frac{\partial^2\Pi_I^D(x_I,x_E)}{\partial x_I^2}<0 \tag{20}$$

$$\frac{\partial}{\partial x_E}\left(\frac{e^{-Tr}}{r}\frac{\partial\Pi_E^D(x_I,x_E)}{\partial x_E}-1\right)=\frac{e^{-Tr}}{r}\frac{\partial^2\Pi_E^D(x_I,x_E)}{\partial x_E^2}<0 \tag{21}$$

■

We turn now to comparative statics by looking at which one of the two firms has an higher incentive to invest in R&D. The result is summarized in the next Proposition.

Proposition 5 *With incremental innovation, in equilibrium, the incumbent* (I) *invests more in R&D than the entrant* (E)*:* $x_I^*(x_E) > x_E^*(x_I)$

Proof. *First, let us define* $x_I^* = \phi_I(x_I^*, x_E)$ *and* $x_E^* = \phi_E(x_I, x_E^*)$*. Second, we prove that* $x_I^* = \phi_I(x_I^*, x_E) > x_E^* = \phi_E(x_I, x_E^*)$*. In fact, the only* *difference between* $\phi_I(x_I^*, x_E)$ *and* $\phi_E(x_I, x_E^*)$ *is the term* $\frac{\left(1-e^{-rT}\right)}{r}\frac{\partial\Pi_I^M(x_I)}{\partial x_I}$. *Thus, we derive the best response function with respect to* $\Pi_I^M(x_I)$. *We have to consider the following derivative of an implicit function:*

$$\frac{\partial\phi_I(x_I^*, x_E)}{\partial\Pi_I^M(x_I)} = -\frac{\partial V_I^2(\phi_I, x_E)/\partial x_I \partial\Pi_I^M}{\partial V_I^2(\phi_I, x_E)/\partial x_I^2}$$

Since, due to second order conditions, the denominator is negative, we focus on the numerator.

$$\partial V_I^2(\phi_I, x_E)/\partial x_I \partial\Pi_I^M =$$

$$\frac{\partial}{\partial\Pi_I^M}\left(\frac{\left(1-e^{-rT}\right)}{r}\frac{\partial\Pi_I^M(x_I)}{\partial x_I} + \frac{e^{-Tr}}{r}\frac{\partial\Pi_I^D(x_I, x_E)}{\partial x_I} - 1\right) \tag{22}$$

The only element to look at is $\frac{\left(1-e^{-rT}\right)}{r}\frac{\partial\Pi_I^M(x_I)}{\partial x_I}$, *where* $\frac{\partial\Pi_I^M(x_I)}{\partial x_I} > 0$ *and* $\frac{\left(1-e^{-rT}\right)}{r} > 0$. Therefore $x_I^* > x_E^*$. ■

Proposition (5) shows that the incumbent's best response lies above the entrant's one. Thus in the case of incremental innovation the incumbent has a higher incentive to invest in R&D: $x_I^* > x_E^*$.

5 Discussion and conclusions

Recent empirical evidence about innovation shows that established firms rarely invest in radical innovation and incrementally improve the existing technology. Revolutionary breakthroughs, when pursued, are more likely to be introduced by new entrants. These stylized facts motivate a renewed attention of the debate on incentives to innovate. We believe the distinction between innovations in terms of degrees of innovativeness deserves particular attention despite the fact that an exhaustive browse of the literature reveals that the definition of radical and incremental innovations are still puzzling, both at the theoretical and at the empirical level. Our paper tries to fill this gap and emphasizes the importance of distinguishing between degrees of innovativeness when comparing an incumbent's and an entrant's incentives to invest in innovation. We characterize a radical innovation as risky, drastic and able to open up a new market.

In this context, we prove that incumbent large corporations are more likely to introduce incremental innovations, whereas radical breakthroughs are rare and mainly developed by new small entrants. More precisely, with a radical innovation case, for a large set of the substitutsbility parameter's values, we prove that the entrant firm invests more in R&D than the incumbent one whereas, in the incremental case, the incumbent firm provides a larger amount of investment in R&D than the entrant. In such respect, our results replicate the empirical evidence. Besides shading a new light on the interpretation of radical and incremental innovations, we introduce a unique framework to deal with both types of innovation, keeping together the deterministic setup by Gilbert & Newbery (1982) and the stochastic one by Reinganum (1983).

Our results concerning radical innovation are mainly driven by the degree of substitutability (complementarity) between the existing and the new market. In fact, as long as substitutability between the old and the new market occurs, the standard result holds: the entrant invests more in R&D than the incumbent. Conversely, when complementarity between old and new markets arises, the incumbent firm takes advantage of larger profit and invests more in R&D. Notice that in this case we have the result of dominance maintenance even with a stochastic environment.

The conventional reference in the literature when speaking of market substitutability or complementarity relates to market cannibalization with a multiproduct monopolist, either in case of durable-goods (e.g. Bulow,1982) or with quality differentiation (e.g. Moorthy & Png, 1984). Although these concepts present some similarities, it is important to emphasize that we focus on an oligopoly with two asymmetric firms, instead of a monopoly. Furthermore, similarly to Denicolò (2000) who deals with the concept of business stealing, we do not consider a model of vertical differentiation, but a situation of market competition between two different products: the old pre-innovation product and the new radically-innovative one (of a highest quality). Competition is shifted in the new market, in such a way that the price of the new product, in principle, could be lower than the price of the existing one. Notice that the issue of substitutability (complementarity) arises only in the case of radical innovation; conversely, with incremental innovation we only have two substitute products in the same market.

The previous findings determine significant the consequences in terms of policy implications. In fact, our analysis crucially claims that, in the aim of implementing the right incentives mechanism to foster innovation at firm and market level, the authority needs first to clarify which kind of innovation has to be pursued.

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