Stackelberg Game and R&D Investments: Are there First Mover Advantages?

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Abstract

In a Stackelberg game where unidirectional R&D spillovers occur, from the leader to the follower, we demonstrate that under certain conditions in an one-tier industry the standard first mover advantages disappear. Furthermore, when we introduce an upstream sector in the model we find that although the spillovers exist in most of the cases the leader gets higher profits, that is first mover advantages are valid. This holds mainly due to the effect of the R&D investments on wholesale price contracts.

JEL classification L13,L42,O32

Keywords Stackelberg game, R&D investments, Spillovers, Wholesale prices, Vertical relations

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1 Introduction

"*The early bird gets the worm*"

This describes the idea of first mover advantage but is this always correct in economics? The theoretical literature has identified the advantages for being a pioneer in a market. Usually, the leading firms have the potential to make choices with commitment value and thus to bring at disadvantage the subsequent movers. Lieberman and Montgomery (1987) discuss why early movers benefit by presenting three important factors. The first one refers to technological leadership, either through learning by doing - learning curve[1] - or success in patent races[2] while the second has to do with the acquisition of limited assets that leads to monopoly power. Third, the existence of switching costs or network effects is another important factor that awards early movers. On the other hand in some occasions (e.g. free-ride opportunities, technological uncertainty, limited incumbent adaptability) late movers benefit. This article's aim is to examine this particular issue in a simple environment illuminating the importance of considering vertical linkages.

The most commonly used approach though in theoretical papers describes situations where the participants in a market make choices (e.g. prices, quantities, R&D, advertising etc.) simultaneously and independently. This is weird since there are many occasions in business environments that firms move sequentially. The literature names these cases as Stackelberg games with some firms as leaders and the remaining firms as followers. Leaders move first and then the followers after observing their optimal choices make their decisions. Gal-Or (1985) states that in a Stackelberg game, first mover advantages always occur when the reaction functions are downwards slopping. In other words the leader exploits the fact that acts first and always obtains higher profits by making a preemptive move as in Spence (1979) and Dixit (1980). Instead, when the reaction functions are upwards slopping she proves that the second mover has advantage as in Baumol (1982), Reinganum (1983). What we do in this article is to re-examine whether first mover advantages exist in an environment where the firms not only

[1] The idea of the learning curve was supported by the Boston Consulting Group during the 1970s. Spence (1981) used this argument and showed how this can work as an entry deterrence mechanism. Some empirical evidence supporting the learning curve hypothesis is given by Ghemawat (1984), Porter (1981) Shaw and Shaw (1984).

[2] Preemptive patenting has been examined by Gilbert and Newberry (1982), Reinganum (1983) and Fudenberg et. al. (1983).

compete in quantities but in addition they invest in cost reducing R&D investments and also we focus on the role of an upstream sector.

In particular, we examine two cases, one without an upstream sector and then we add an upstream firm charging the duopolists with wholesale prices $w_i's$ to identify what the vertical structure adds in this analysis. First, we use a model with two firms and each of them chooses simultaneously its R&D investments and quantity. So, the leader chooses first the R&D investments x_i and quantity q_i and then the follower by observing them makes the same choices. The second model uses a two-trier industry where at the beginning the upstream firm makes take-it-or-leave-it offers and then the sequence of moves is as before. An important aspect of these models is the fact that there exist unidirectional R&D spillovers. It is reasonable to assume that there is a leakage of the R&D investments the leader does since these precede the follower's investments.

Clearly, this paper relates to the literature about process R&D that is conducted sequentially when one way spillovers occur and whether early movers benefit or not. The most relevant papers are by Amir and Wooders (2000), Amir et. al. (2000) and Tesoriere (2008). The first of these papers demonstrates that identical firms invest different volumes of R&D and thus the equilibrium of D'Aspremont and Jacquemin (1988) is not stable, stating also the social and firms' benefits of research joint ventures. The second paper focuses on endogenous timing of R&D investments using the model by D'Aspremont and Jacquemin with differentiated products and they show that the ratio of own spillover rate over demand cross-slope determines whether sequential or simultaneous move prevails. The third paper is close enough to ours since it allows for spillovers only when sequential move occurs and indicates that only simultaneous move is sustainable as a subgame equilibrium. We depart from this literature by assuming that both the R&D and the output choices follow a sequential move since in all these papers the firms choose quantities or prices simultaneously. Furthermore, according to our knowledge this is the first attempt that introduces an upstream sector in these kind of models.

First, we demonstrate that indeed under certain conditions first mover advantages disappear due to the R&D leakage. That is, although the leader commits on the output choice it should also undertake its R&D investments prior to the follower. Hence, in this environment there are two opposite forces. On the one hand the output choice as we already know gives an advantage to the leader but on the other hand the direct spillovers from its R&D investments to the rival weakens its ability to increase its profits. The follower enjoys cost reductions due to the leader's R&D, one way spillovers, and we prove that this advantage dominates the aforementioned first mover advantage in classic Stackelberg occasions. Second, we show explicitly that if we include in our analysis an upstream sector with a monopolistic firm that charges wholesale prices to the duopolists the second mover advantages that appear in the previous case in most of the cases vanish and the outcome comes much closer to the standard sequential move games. Our first result reverses because by incorporating an upstream firm in our analysis it matters the effect of the downstream R&D on the wholesale prices. As it has been noted by the literature Banerjee and Lin (2003), Pavlou (2011) the higher the R&D by the downstream firms the higher are the wholesale prices. The follower's R&D investments are combined with these of the leader and hence it pays higher wholesale prices. This is the main reason why first mover advantages are reinstated.

2 One-tier model

We consider two firms - a duopoly - where they move sequential, that is one is a Stackelberg leader and the other the follower. Apart from setting their quantities both firms invest in process R&D in order to reduce their production cost. Naturally, unidirectional spillovers occur with respect to the R&D investments from the leader to the follower and the variable cost of production is as follows:

$$C^L(x^L, q^L) = (c - x^L)q^L \tag{1}$$

$$C^F(x^F, x^L, q^F) = (c - x^F - dx^L)q^F \tag{2}$$

where $c > 0$ is a constant exogenous given marginal cost, x is the level of the cost reducing R&D investments, $0 \leq d \leq 1$ captures the level of the spillovers from the leader to the follower and superscripts L, F stand for the leader and the follower respectively. The two rivals produce differentiated products and each of them faces the following inverse demand function:

$$p_i = a - q_i - \gamma q_j, \quad i \neq j, \quad i, j = 1, 2, \quad 0 < \gamma < 1,$$

where q_i and p_i are respectively the quantity and the price of D_i's final product. The parameter γ measures product substitutability. Namely, the higher is γ, the closer substitutes the products of D_i and D_j are. The above demand function system comes from the representative consumer's problem who maximizes his net utility from both products, $U(q_1, q_2) - \sum_{i=1}^{2} p_i q_i$ where U is assumed to be quadratic and strictly concave $U(q_1, q_2) = a(q_1 + q_2) - \frac{1}{2}(q_1^2 + q_2^2) - \gamma q_1 q_2$ [3].

Both firms choose at the same time the output and the level of R&D investments but in a sequential order. Thus, we work backwards and start with the maximization problem of the late mover, the follower, which maximizes its profits:

$$\max_{q^F, x^F} \pi^F(q^F, x^F, q^L, x^L) = (a - q^F - \gamma q^L)q^F - (c - x^F - dx^L)q^F - 2(x^F)^2 \tag{3}$$

where the R&D cost implies diminishing returns with a quadratic form.[4],[5]. After taking the first order conditions we obtain the optimal choices in terms of q^L, x^L.

$$q^F(q^L, x^L) = \frac{4[a - c - \gamma q^L + dx^L]}{7} \tag{4}$$

$$x^F(q^L, x^L) = \frac{a - c - \gamma q^L + dx^L}{7} \tag{5}$$

Then by using (4) and (5) that can be anticipated assuming common knowledge of rationality, the leader maximizes its profits:

$$\max_{q^L, x^L} \pi^L(q^L, x^L) = [a - q^L - \gamma q^F(q^L, x^L)]q^L - (c - x^L)q^L - 2(x^L)^2 \tag{6}$$

Taking the first order conditions and making the appropriate substitutions we obtain the following equilibrium values:

$$q^L = \frac{28(a - c)(4\gamma - 7)}{8\gamma[2(14 + d^2)\gamma - 7d]} \tag{7}$$

$$x^L = \frac{(a - c)(4\gamma - 7)(7 - 4d\gamma)}{8\gamma[2(14 + d^2)\gamma - 7d]} \tag{8}$$

[3] For more details about these demand functions see Singh and Vives (1984).

[4] The general form of the R&D cost is $\frac{mx^2}{2}$ and the parameter $m > 0$ measures the efficiency of the R&D. It is necessary to assume that $m \geq 4$, such that the second order conditions are satisfied. A similar condition is used in Milliou and Pavlou (2010) and it determines whether a pure strategy equilibrium exists.

[5] For expositional simplicity we impose $m = 4$ and we discuss for the role of m at the final section.

Plugging (7) and (8) into (4),(5) we obtain the respective equilibrium values for the follower:

$$q^F = \frac{4(a-c)[16\gamma^2 - 7(7+d) + 4(7+(d-1)d)\gamma]}{8\gamma[2(14+d^2)\gamma - 7d] - 343} \quad (9)$$

$$x^F = \frac{(a-c)[16\gamma^2 - 7(7+d) + 4(7+(d-1)d)\gamma]}{8\gamma[2(14+d^2)\gamma - 7d] - 343} \quad (10)$$

2.1 Profit comparison

In comparing the equilibrium profits we observe that although the two firms are initially equally efficient, that is c is common to both participants, finally in contrast to the standard Stackelberg (quantity game) case the follower, under certain conditions, is better off.

Proposition 1 *In this one-tier model late mover benefits, that is second mover advantages occur,* $\pi^F > \pi^L$ *if and only if* $\gamma < \gamma_\pi(d)$*, with* $\frac{\partial \gamma_\pi(d)}{\partial d} > 0$ *and* $\gamma_\pi(1) = 0.884, \gamma_\pi(0) = 0$*.*

As we prove in this analysis, indeed the second mover is better off when the products are not very close substitutes (see Figure 1 below) while the spillover parameter although it plays a role it seems to be more passive. The follower exploits the unidirectional R&D spillovers and enjoys higher efficiency that leads to higher profits than its competitor even though it precommits to its output. The crucial thing for the spillovers is that a leakage from the leader to the follower takes place, that is $d \neq 0$ and not that much the extend of it. On the other hand our results indicate that the second mover advantages occur only when there is some differentiation between the products of the two rivals because otherwise no such effect occurs. Note that in this sequential game there are two opposing forces for the leader. It commits to an output level that gives it an advantage but at the same time it invests in R&D that leaks to its rival and in this way it hurts itself. With homogeneous products the former effect dominates the latter since the leader is more reluctant to invest in R&D and thus no second mover advantages observed. When instead the products are differentiated then the second effect, that is the advantage the follower acquires (due to higher efficiency), is the one that prevails. Hence, naturally the follower outperforms the leader. Next, we investigate how an upstream sector affects the aforementioned result.

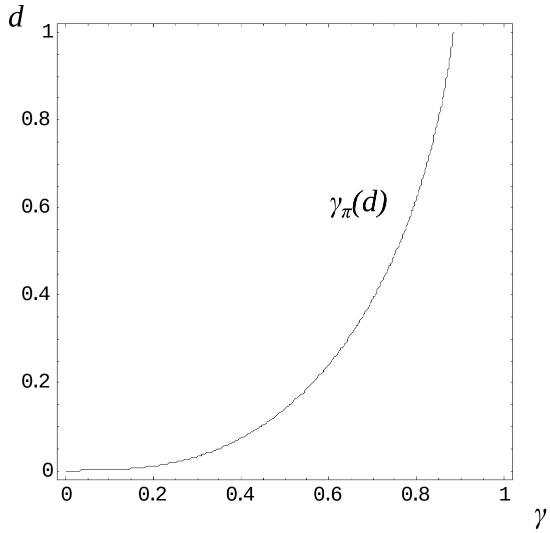

Figure 1: The critical value $\gamma_\pi(d)$

3 Two-tier model

Introducing an upstream sector with a manufacturer or an input producer that supplies the downstream duopolists with an essential facility things do not work alike. This case is much closer to the standard case where moving first pays off. The sequence of moves is as follows, first the upstream firm makes a take-it-or-leave-it offer to the downstream firms, proposing a wholesale (per-unit/marginal) price, and the rest of it remains the same. The leader commits to output and to R&D investments and after that the follower makes similar decisions. The variable production cost becomes:

$$C^{LV}(x^{LV}, q^{LV}, w^{LV}) = (c - x^{LV} - w^{LV})q^{LV} \quad (11)$$

$$C^{FV}(x^{FV}, x^{LV}, q^{FV}, w^{FV}) = (c - x^{FV} - dx^{LV} - w^{FV})q^{FV} \quad (12)$$

Where w denotes the wholesale price the upstream party charges to the downstreams and the superscript V, that stands for vertical, is used to differentiate with the previous case. The follower maximizes the expression below:

$$\max_{q^{FV},x^{FV}} \pi^{FV}(q^{FV},x^{FV},q^{LV},x^{LV}) = (a-q^{FV}-\gamma q^{LV})q^{FV}-w^{FV}q^{FV}-(c-x^{FV}-dx^{LV})q^{FV}-2(x^{FV})^2 \quad (13)$$

In this case the relevant values in terms of q^{LV}, x^{LV}, w^{FV} are the following:

$$q^{FV}(q^{LV},x^{LV}) = \frac{4[a-c-\gamma q^{LV}-w^{FV}+dx^{LV}]}{7} \quad (14)$$

$$x^{FV}(q^{LV},x^{LV}) = \frac{a-c-\gamma q^{LV}+dx^{LV}-w^{FV}}{7} \quad (15)$$

Using the above optimal choices the leader maximizes its profits:

$$\max_{q^{LV},x^{LV}} \pi^{LV}(q^{LV},x^{LV}) = [a-q^{LV}-\gamma q^{FV}(q^{LV},x^{LV})]q^{LV}-w^{LV}q^{LV}-(c-x^{LV})q^{LV}-2(x^{LV})^2 \quad (16)$$

Taking the first order conditions we obtain the optimal values in terms of the wholesale prices:

$$q^{LV}(w^{LV},w^{FV}) = \frac{28[a(4\gamma-7)-4\gamma(c+w^{FV})+7(c+w^{LV})]}{8\gamma[2(14+d^2)\gamma-7d]-343}$$

$$x^{LV}(w^{LV},w^{FV}) = \frac{(7-4d\gamma)[a(4\gamma-7)-4\gamma(c+w^{FV})+7(c+w^{LV})]}{8\gamma[2(14+d^2)\gamma-7d]-343}$$

$$q^{FV}(w^{LV},w^{FV}) = \frac{4[A+B+49w^{FV}+4(d-4\gamma)\gamma w^{FV}+(7d-4(7+d^2)\gamma)w^{LV}]}{Q}$$

$$x^{FV}(w^{LV},w^{FV}) = 4q^{FV}(w^{LV},w^{FV})$$

where

$A = c(7(4+d)-4(7+(d-1)d)\gamma-16\gamma^2)$

$B = a(4(7+(d-1)d)\gamma-7(7+d)+16\gamma^2)$

$Q = 8\gamma[2(14+d^2)\gamma-7d]-343$

The behavior of the downstream firms is awaited by the upstream monopolist since this is a game of perfect information and chooses the appropriate wholesale prices to obtain the highest possible profits:

$$\max_{w^{LV},w^{FV}} w^{LV}q^{LV}(w^{LV},w^{FV})+w^{FV}q^{FV}(w^{LV},w^{FV}) \quad (17)$$

The maximization with respect to the wholesale prices gives the optimal values of them:

$$w^{LV} = \frac{(a-c)[G+V+64d^2\gamma^3]}{49(d^2-196)-56d(28+d^2)\gamma+16(392+28d^2+d^4)\gamma^2} \quad (18)$$

$$w^{FV} = \frac{7(a-c)[28(d-3)d\gamma-49(14+d)+16(28+d^2)\gamma^2]}{49(d^2-196)-56d(28+d^2)\gamma+16(392+28d^2+d^4)\gamma^2} \quad (19)$$

where

$G = 49(d-7)(14+d) - 28d(35+2d(3+d))\gamma$

$V = 16(196 + d(d(21+(d-1)d)-7))$

Plugging (18) and (19) into the above expressions we obtain the equilibrium values with an upstream monopolist and the equilibrium profits are the ones below:

$$\pi^{LV} = \frac{686(a-c)^2[4(14-(2-d)d)\gamma-7(14+d)+32\gamma^2]^2}{[49(d^2-196)-56d(28+d^2)\gamma+16(392+28d^2+d^4)\gamma^2]^2} \quad (20)$$

$$\pi^{FV} = \frac{2(a-c)^2[7(14+d^2)-4(14+d^2)\gamma]^2[8\gamma(2(14+d^2)\gamma-7d)-343]}{[49(d^2-196)-56d(28+d^2)\gamma+16(392+28d^2+d^4)\gamma^2]^2} \quad (21)$$

3.1 Profit comparison

Using the above equilibrium profits and comparing them we get a result that is described in the following proposition.

Proposition 2 *The presence of an upstream supplier reinstates first mover advantages,* $\pi^{LV} > \pi^{FV}$ *if and only if* $\gamma < \gamma_{\pi v1}(d)$ *and* $\gamma > \gamma_{\pi v2}(d)$ *, with* $\frac{\partial \gamma_{\pi v1}(d)}{\partial d} > 0, \frac{\partial \gamma_{\pi v2}(d)}{\partial d} > 0$ *and* $\gamma_{\pi v1}(1) = 0.068, \gamma_{\pi v2}(1) = 0.396, \gamma_{\pi v1}(0) = \gamma_{\pi v2}(0) = 0.$

The above proposition states that when the two (downstream) rivals obtain an input from an upstream supplier then our findings come in contrast with the previous ones (see Figure 2). The main reason for this divergence is the way that the downstream R&D investments affect the wholesale offers received by the supplier. In particular, as it is demonstrated in Banerjee and Lin (2003) there exists a positive relationship between the downstream R&D and the wholesale prices. Therefore, when $d \neq 0$ the R&D investments of the leader work in an additive way to the follower's investments and for this reason it pays a higher (marginal) price to the supplier. This effect is responsible for first mover advantages to be valid, since the higher wholesale price offsets the efficiency advantage due to the spillovers. In the previous case where this is not present, the spillovers are adequate for making the second mover better off.

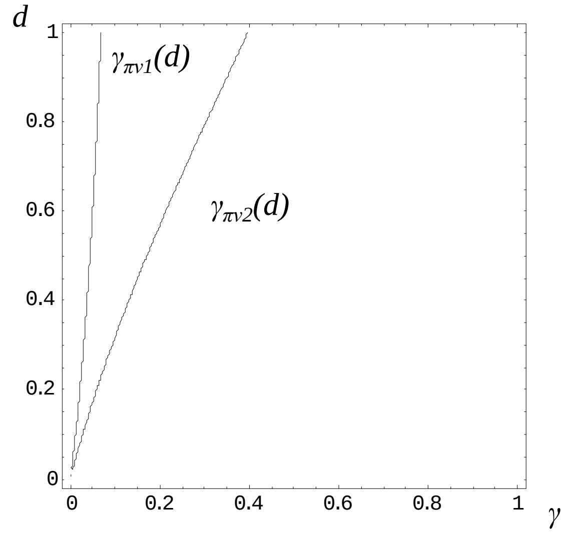

Figure 2: The critical values $\gamma_{\pi\nu1}(d)$ and $\gamma_{\pi\nu2}(d)$

4 Conclusion

This paper shows explicitly in a Stackelberg game where unidirectional R&D spillovers occur, from the leader to the follower, that under certain conditions in an one-tier industry the standard first mover advantages disappear. Furthermore, when we introduce an upstream sector with a monopolistic firm we find that although the spillovers exist in most of the cases the leader gets higher profits, that is first mover advantages are valid. This holds mainly due to the positive relationship between the R&D investments and the wholesale price contracts. Finally, we must note that when the R&D investments become less efficient as m increases (see footnote 4) then in the first (second) case the region where in Figure 1 (Figure 2) the second (first) mover benefits becomes smaller (higher). As we expected as the R&D becomes less efficient there are no strong incentives to undertake such investments and thus the effect on the efficiency of the follower that we described above is less severe[6].

[6] Note that for extremely inefficient R&D (very high values of m) then in both cases the first mover is better off.

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