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INNOVATION BY LEADERS
WITHOUT WINNER-TAKE-ALL

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Abstract: In innovative races with winner takes all, leading firms invest less than each follower, given exogenous entry (Reinganum, 1985). But with endogenous entry this result is reversed (Etro, 2004). It is argued here that sharing of rewards between the players may alter these predictions.

Keywords: Patent Race, Free Entry, Innovation, Market Sharing

JEL Classification Numbers: O31, L13

1. Introduction

A central feature of the neo-Schumpeterian analysis is the focus on the innovative role of first movers and followers. In so called race settings with technological uncertainty and winner-take-all, the leader invests less than each follower (Reinganum, 1985). This finding is consistent with empirical findings that, on average, challengers tend to invest more to enter a new market than incumbents (e.g. Czarnitzki and Kraft, 2004).

Refinements of the hypotheses are possible. With endogenous entry a leading firm anticipates that the equilibrium number of entrants will be affected by its own efforts (Etro, 2004). The first mover engages in more efforts than each of the followers, given winner-take-all. But what if the players have to share payoffs because of spillovers?

2. The model

Results on innovative races without winner-take-all have been analyzed by Stewart (1983) in a setting with simultaneous moves of all rivals. Here a stochastic leader–follower setting with market sharing is looked at. Let σ be a market sharing parameter ($\sigma \leq 1$). Two cases with asymmetric sharing define the minimum value of σ and the notation of payoffs, see Table 1.

<table>
<tr><td colspan="2" rowspan="2">One leader and
n entrants
(followers)</td><td>A

Leaders may share with
all entrants</td><td>B

Sharing may occur among all entrants</td></tr>
<tr><td>Winner takes all:
$\sigma = 1$
Equal sharing:
$\sigma = \frac{1}{1+n}$</td><td>Winner takes all:
$\sigma = 1$
Equal sharing:
$\sigma = \frac{1}{n}$</td></tr>
<tr><td rowspan="2">Payoff leader</td><td>P_1^L
(leaders wins)</td><td>$\sigma \times P$</td><td>P</td></tr>
<tr><td>P_2^L
(entrant wins)</td><td>0</td><td>0</td></tr>
<tr><td rowspan="3">Payoff entrant i</td><td>P_1^i
(entrant wins)</td><td>P</td><td>$\sigma \times P$</td></tr>
<tr><td>P_2^i
(leader wins)</td><td>$\left(\frac{1-\sigma}{n}\right) \times P$</td><td>0</td></tr>
<tr><td>P_3^i
(other entrant wins)</td><td>0</td><td>$\left(\frac{1-\sigma}{n-1}\right) \times P$</td></tr>
</table>

Table 1. Payoffs in two races with asymmetric market sharing.

Firm L is a Stackelberg leader in the innovative race and firms 1,2,…,n are entrants in the industry and followers. The development process is stochastic with the probability of success of any firm j by time t being equal to $1 - e^{-h(x_j)\times t}$, where $h(x_j)$ is the development intensity and x_j is the development intensity selected by firm j, at a cost of x_i euros per unit of time, with j=L,1,2,..,n. Moreover, $h'(.)>0$ and $h''(.)<0$. F is a fixed cost for each player, with $\sigma \times P - F > 0$. The expected value of discounted profits for the leader with interest rate r is:

$$V^L = \frac{h\left(z^L\right) \times P_1^L + \sum_{j=1}^{n} h\left(z^j\right) \times P_2^L + \pi - z^L}{r + \sum_{j=1}^{n} h\left(z^j\right) + h\left(z^L\right)} - F \tag{1}$$

and for each of the entrants i=1,2, …,n:

$$V^i = \frac{h\left(z^i\right) \times P_1^i + h\left(z^L\right) \times P_2^i + \sum_{\substack{j=1 \\ j \neq i}}^{n} h\left(z^j\right) \times P_3^i - z^i}{r + \sum_{j=1}^{n} h\left(z^j\right) + h\left(z^L\right)} - F \tag{2}$$

The discussion hereafter focuses on parameter values with $v^L>0$ and $V^i \geq 0$.

A symmetric equilibrium can be looked at with $z_i=z$, for all i. Concavity and existence conditions are assumed to be satisfied.

With exogenous entry the number of entrants is taken as given. The efforts of the followers are always strategic complements to the efforts of the leaders in setting B. In setting A, however, they are strategic complements for little sharing (high σ) but may be substitutes for high spillovers and more equal sharing (low σ).

In a long run symmetric equilibrium $V^i(z,z^L,n^*)=0$, with n^* the endogenous number of entrants. Combining this from (2) with the first order condition for an entrant allows verifying that:

Case A: $h'(z) \times (P - F) = 1$ (3)

Case B: $h'(z) \times (\sigma \times P - F) = 1$ (4)

So, in both cases, z is independent of the efforts of the leader z^L (Etro, 2004). The leader will however anticipate that n^* may be influenced by its own effort.

3. Comparing leader and entrant efforts.

The comparison of leader and follower efforts is driven by the sign of the function g(x) with $g(z^L)=0$ and $g'(.)<0$ in view of the concavity of V^L.

Case A.

$$g_A(x) = \begin{array}{l}\left[h'(x) \times \sigma \times P - 1\right] \times \left[r + n \times h(x) + h\left(z^L\right)\right] \\ -\psi^A \times \left[h(x) \times \sigma \times P + \pi - x\right]\end{array} \qquad (5)$$

$$\text{with } \psi^A = h'(x) + \frac{\partial\left(n \times h(z)\right)}{\partial z^L}. \qquad (6)$$

Case B.

$$g_B(x) = \left[h'(x) \times V - 1\right] \times \left[r + n \times h(x) + h\left(z^L\right)\right] - \psi^B \times \left[h(x) \times V + \pi - x\right] \qquad (7)$$

$$\text{with } \psi^B = h'(x) + \frac{\partial\left(n \times h(z)\right)}{\partial z^L}. \qquad (8)$$

Moreover, the following stability condition is assumed:

$$\psi^{\bullet} = h'(z) \times \left(1 + \frac{\partial(n \times z)}{\partial z^L}\right) > 0. \qquad (9)$$

With endogenous entry, $\frac{\partial z}{\partial z^L} = 0$ and $\psi^{\bullet} = h'(z) + h'(z) \times \frac{\partial n^*}{\partial z} > 0$, so

$$\psi^A = h'(x) + \frac{h(z) \times h'(x) \times \left[(1-\sigma) \times V - n^* \times F\right]}{h(x) \times \left(\frac{1-\sigma}{n}\right) \times V + n^* \times F \times h(z)}, \qquad (10)$$

$$\psi^B = h'(x) - h'(x) = 0. \qquad (11)$$

Now, it is possible to compare leader and follower efforts by deriving the sign of $g_{\cdot}(z)$. With $g_{\cdot}(z)>0$, the leader invests more than each follower. With $g_{\cdot}(z)<0$, the reverse applies.

Proposition 1: With exogenous entry and no market sharing (σ=1), the leader invests less than each follower (Reinganum, 1985). But with market sharing (σ<1), this tendency may be reversed in case B.

Sharing among all entrants tends to reduce their individual efforts in case B. A numerical example[1] confirms this reversal: V=100, F=10, π=20, r=0,10, n=4 and let $h(x) = \sqrt{x}$.

$$\sigma = 1 \quad \rightarrow \quad z^L = 1918 \;<\; z=1974$$

$$\sigma = 0,5 \quad \rightarrow \quad z^L = 1353 \;>\; z=332$$

$$\sigma = \frac{1}{n} = 0,25 \quad \rightarrow \quad z^L = 644 \;>\; z=43$$

Proposition 2: With endogenous entry and no market sharing (σ=1), the leader invests more than each follower (Etro, 2004). With market sharing (σ<1),

[1] All numerical examples are computed with Maple.

this tendency remains valid in case B but may be reversed in case A.

Losing part of the new market by the leader in case A tends to discourage its efforts, even if more could reduce the number of imitators. A numerical example[2] confirms this reversed prediction: V=100, F=10, π=20, r=0,10 and $h(x) = \sqrt{x}$.

$\sigma = 1 \quad \rightarrow \quad z^L = 2500 > z=2025$ and $n^* = 4{,}387$

$\sigma = 0{,}5 \quad \rightarrow \quad z^L = 571 < z=2025$ and $n^* = 5{,}454$

$\sigma = 0{,}2 = \frac{1}{5} \quad \rightarrow \quad z^L = 94 < z=2025$ and $n^* = 5{,}590$

These tendencies of case A were also found in a strategic investment game with leaders and followers, no uncertainty and exogenous entry (Vandekerckhove and De Bondt, forthcoming). Large spillovers from a leader to imitators may result in them investing less than each follower, even though a large effort could improve their subsequent Stackelberg profits.

5. Conclusion

Existing theoretical and empirical work on innovative activities points to the need for a careful handling of the spillovers between participants. In leader follower race-settings, the incorporation of asymmetric spillovers can help the search for richer hypotheses to be tested in empirical work.

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[2] Integer constraint on n is ignored here.

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Appendix

INNOVATION BY LEADERS WITHOUT WINNER-TAKE-ALL

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The expected value of discounted profits for the leader:

$$V^L = \frac{h\left(z^L\right) \times P_1^L + \sum_{j=1}^{n} h\left(z^j\right) \times P_2^L + \pi - z^L}{r + \sum_{j=1}^{n} h\left(z^j\right) + h\left(z^L\right)} - F \,. \tag{A1}$$

The expected value of discounted profits for each follower:

$$V^i = \frac{h\left(z^i\right) \times P_1^i + h\left(z^L\right) \times P_2^i + \sum_{\substack{j=1 \\ j \neq i}}^{n} h\left(z^j\right) \times P_3^i - z^i}{r + \sum_{j=1}^{n} h\left(z^j\right) + h\left(z^L\right)} - F \,. \tag{A2}$$

Case A

Combining Table 1 with (A1) and (A2) results in the following expected profits functions for the leader and for each entrant in case A.

$$V^L = \frac{h\left(z^L\right) \times \sigma \times P + \pi - z^L}{r + \sum_{j=1}^{n} h\left(z^j\right) + h\left(z^L\right)} - F \tag{A3}$$

$$V^i = \frac{h\left(z^i\right) \times P + h\left(z^L\right) \times \left(\frac{1 - \sigma}{n}\right) \times P - z^i}{r + \sum_{j=1}^{n} h\left(z^j\right) + h\left(z^L\right)} - F \tag{A4}$$

For each of the n entrants, the first order condition needs to be satisfied, $\frac{\partial V^i}{\partial z^i} = 0$.

$$\frac{\partial V^i}{\partial z^i} = \frac{\left[h'\left(z^i\right) \times P - 1\right] \times \left[r + \sum_{j=1}^{n} h\left(z^j\right) + h\left(z^L\right)\right] - \left[h'\left(z^i\right)\right] \times \left[h\left(z^i\right) \times P + h\left(z^L\right) \times \left(\frac{1 - \sigma}{n}\right) \times P - z^i\right]}{\left[r + \sum_{j=1}^{n} h\left(z^j\right) + h\left(z^L\right)\right]^2} = 0 \tag{A5}$$

In a symmetric equilibrium, the following applies

$$\phi^i = \left[h'(z) \times P - 1\right] \times \left[r + n \times h(z) + h\left(z^L\right)\right] - \left[h'(z)\right] \times \left[h(z) \times P + h\left(z^L\right) \times \left(\frac{1 - \sigma}{n}\right) \times P - z\right] = 0 \tag{A6}$$

The sign of $\frac{dz}{dz^L}$ is equal to the sign of $\left[(r + n \times h(z)) \times \sigma \times P - n \times z - r \times P\right]$. So for $\sigma < \sigma°$, the efforts are strategic substitutes but for $\sigma° < \sigma \leq 1$, the efforts are strategic complements, with $\sigma° = \frac{r \times P + n \times z}{r \times P + n \times h(z) \times P}$.

The leader maximizes its profits by choosing z^L. Thus,

$$\frac{\partial V^L}{\partial z^L} = \frac{\left[h'\left(z^L\right) \times \sigma \times P - 1\right] \times \left[r + n \times h(z) + h\left(z^L\right)\right] - \left[h'\left(z^L\right) + \frac{\partial\left(n \times h(z)\right)}{\partial z^L}\right] \times \left[h\left(z^L\right) \times \sigma \times P + \pi - z^L\right]}{\left[r + \sum_{j=1}^{n} h\left(z^j\right) + h\left(z^L\right)\right]^2} = 0 \tag{A7}$$

or

$$\phi^L = \left[h'\left(z^L\right) \times \sigma \times P - 1\right] \times \left[r + n \times h(z) + h\left(z^L\right)\right] - \left[h'\left(z^L\right) + \frac{\partial\left(n \times h(z)\right)}{\partial z^L}\right] \times \left[h\left(z^L\right) \times \sigma \times P + \pi - z^L\right] = 0 \tag{A8}$$

Now define the following function:

$$g_A(x) = \left[h'(x) \times \sigma \times P - 1\right] \times \left[r + n \times h(z) + h\left(z^L\right)\right] - \psi^A \times \left[h(x) \times \sigma \times P + \pi - x\right] \tag{A9}$$

with $g_A\left(z^L\right) = 0$ and $\psi^A = h'(x) + \frac{\partial\left(n \times h(z)\right)}{\partial z^L}$

Then,

$$g'(x) = \frac{\partial^2 V^L}{\partial x^{L^2}} - h'(z) \times \left(h'\left(z^L\right) \times \sigma \times P - 1\right) < 0 \tag{A10}$$

Combining (A9) and (A6) and evaluating in x=z,

$$g(z) = -h'(z) \times (1-\sigma) \times P \times \left(r + n \times h(z) + h\left(z^L\right)\right) - \psi^A \times \left[h(z) \times \sigma \times P + \pi - z\right] + h'(z) \times \left[h(z) \times \sigma \times P + h\left(z^L\right) \times \left(\frac{1-\sigma}{n}\right) \times P - z\right] \tag{A11}$$

The sign of (A11) drives the comparison of z and z^L.

- Exogenous entry

  - With $\sigma = 1$, $g_A(z)\big|_{\sigma=1} = -\frac{\partial\left(n \times h(z)\right)}{\partial z^L} \times \left[h(z) \times P + \pi - z\right] - h'(z) \times \pi < 0$ (A12)

    Since z and z^L are strategic complements for $\sigma = 1$, $\frac{\partial z}{\partial z^L} > 0$, from A6.

  - The sign of $g_A(z)$ for $\sigma < 1$ is unclear in general. Numerical analysis suggests that in a wide range of cases, the sign remains negative.

- Endogenous Entry

With endogenous entry, the zero profit condition states that $V^i = 0$ for i=1,2,…,n. From (A4):

$$ZPC = h(z) \times P + h\left(z^L\right) \times \left(\frac{1-\sigma}{n}\right) \times P - z - F \times \left[r + n \times h(z) + h\left(z^L\right)\right] = 0 \qquad \text{(A13)}$$

Combining (A6) and (A13) yields

$$h'(z) \times (P - F) = 1 \qquad \text{(A14)}$$

From (A14), z can be derived and it is clear that z is not dependent on z^L.

From the Zero Profit Condition of the followers, $\psi^A = h'\left(z^L\right) + \frac{\partial\left(n \times h(z)\right)}{\partial z^L}$ can be calculated, as

$$\psi^A = h'\left(z^L\right) + \frac{\partial\left(n \times h(z)\right)}{\partial z^L} = h'\left(z^L\right) + \frac{\partial n}{\partial z^L} \times h(z) + n \times h'(z) \times \frac{dz}{dz^L} = h'\left(z^L\right) + \left(-\frac{\partial ZPC/\partial z^L}{\partial ZPC/\partial n}\right) \times h(z) + 0 = h'\left(z^L\right) + \frac{h'\left(z^L\right) \times \left[\left(\frac{1-\sigma}{n}\right) \times P - F\right]}{\frac{h\left(z^L\right)}{h(z)} \times \left(\frac{1-\sigma}{n^2}\right) \times P + F}. \qquad \text{(A15)}$$

Finally, A(15) should be introduced in A(11). For $\sigma = 1$, $g(z) > 0$, thus $z^L > z$. For $\sigma < 1$, the sign of g(z) can be positive or negative.

Case B

Combining Table 1 with (A1) and (A2) results in the following expected profits functions for the leader and for each entrant in case A.

$$V^L = \frac{h\left(z^L\right) \times P + \pi - z^L}{r + \sum_{j=1}^{n} h\left(z^j\right) + h\left(z^L\right)} - F \tag{A16}$$

$$V^i = \frac{h\left(z^i\right) \times \sigma \times P + \sum_{\substack{j=1 \\ j \neq i}}^{n} h\left(z^j\right) \times \left(\frac{1 - \sigma}{n - 1}\right) \times P - z^i}{r + \sum_{j=1}^{n} h\left(z^j\right) + h\left(z^L\right)} - F \tag{A17}$$

For each of the n entrants, the first order condition needs to be satisfied, $\frac{\partial V^i}{\partial z^i} = 0$.

$$\frac{\partial V^i}{\partial z^i} = \frac{\left[h'\left(z^i\right) \times \sigma \times P - 1\right] \times \left[r + \sum_{j=1}^{n} h\left(z^j\right) + h\left(z^L\right)\right] - \left[h'\left(z^i\right)\right] \times \left[h\left(z^i\right) \times \sigma \times P + \sum_{\substack{j=1 \\ j \neq i}}^{n} h\left(z^j\right) \times \left(\frac{1 - \sigma}{n - 1}\right) \times P - z^i\right]}{\left[r + \sum_{j=1}^{n} h\left(z^j\right) + h\left(z^L\right)\right]^2} = 0 \tag{A18}$$

In a symmetric equilibrium, the following applies

$$\phi^i = \left[h'(z) \times \sigma \times P - 1\right] \times \left[r + n \times h(z) + h\left(z^L\right)\right] - \left[h'(z)\right] \times \left[h(z) \times P - z\right] = 0 \tag{A19}$$

The leader maximizes its profits by choosing z^L. Thus,

$$\frac{\partial V^L}{\partial z^L} = \frac{\left[h'\left(z^L\right) \times P - 1\right] \times \left[r + n \times h(z) + h\left(z^L\right)\right] - \left[h'\left(z^L\right) + \frac{\partial\left(n \times h(z)\right)}{\partial z^L}\right] \times \left[h\left(z^L\right) \times P + \pi - z^L\right]}{\left[r + \sum_{j=1}^{n} h\left(z^j\right) + h\left(z^L\right)\right]^2} = 0 \tag{A20}$$

or

$$\phi^L = \left[h'\left(z^L\right) \times P - 1\right] \times \left[r + n \times h(z) + h\left(z^L\right)\right] - \left[h'\left(z^L\right) + \frac{\partial\left(n \times h(z)\right)}{\partial z^L}\right] \times \left[h\left(z^L\right) \times P + \pi - z^L\right] = 0 \tag{A21}$$

Now define the following function:

$$g_B(x) = \left[h'(x) \times P - 1\right] \times \left[r + n \times h(z) + h\left(z^L\right)\right] - \psi^B \times \left[h(x) \times P + \pi - x\right] \tag{A22}$$

with $g_B\left(z^L\right) = 0$ and $\psi^B = h'(x) + \frac{\partial\left(n \times h(z)\right)}{\partial z^L}$

Then,

$$g_B'(x) = \frac{\partial^2 V^L}{\partial x^{L^2}} - h'(z) \times \left(h'\left(z^L\right) \times P - 1\right) < 0 \tag{A23}$$

The sign of (A22) drives the comparison of z and z^L.

- Exogenous entry

  - With $\sigma = 1$, $g_B(z)\big|_{\sigma=1} = -\psi^B \times \left[h(z) \times P + \pi - z\right] < 0$, by which $z^L < z$.

  - With $\sigma < 1$, it is possible that $g_B(z) > 0$, by which $z^L > z^F$. The example in the text is a proof of this.

- Endogenous entry

  With endogenous entry, the zero profit condition states that $V^i = 0$ for i=1,2,…,n. From (A17)

$$ZPC = h(z) \times P + -z - F \times \left[r + n \times h(z) + h\left(z^L\right)\right] = 0 \tag{A24}$$

  Combining (A19) and (A24) yields

$$h'(z) \times (\sigma \times P - F) = 1 \tag{A25}$$

  From (A26), z can be derived and it is clear that z is not dependent on z^L.

  From the Zero Profit Condition of the followers, $\psi^B = h'\left(z^L\right) + \frac{\partial\left(n \times h(z)\right)}{\partial z^L}$ can be calculated, as

$$\psi^{B} = h'\left(z^{L}\right) + \frac{\partial\left(n \times h(z)\right)}{\partial z^{L}} = h'\left(z^{L}\right) + \frac{\partial n}{\partial z^{L}} \times h(z) + n \times h'(z) \times \frac{dz}{dz^{L}} = h'\left(z^{L}\right) + \left(-\frac{\partial ZPC/\partial z^{L}}{\partial ZPC/\partial n}\right) \times h(z) + 0 = h'\left(z^{L}\right) + h(z) \times \left(-\frac{-h'\left(z^{L}\right) \times F}{-h\left(z^{L}\right) \times F}\right) = 0. \quad \text{(A26)}$$

Consequently,

$$g_{B}(z) = \left[h'(z) \times P - 1\right] \times \left[r + n \times h(z) + h\left(z^{L}\right)\right] > 0, \text{ by which } z^{L} > z \text{ for } \frac{1}{n} \leq \sigma \leq 1. \quad \text{(A27)}$$