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Absorptive capacity and R&D strategy of labor-managed firms

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Abstract: Taking absorptive capacity effects on research spillovers into consideration, this paper focuses on the R&D investment decisions and the output decisions of labor-managed firms. Based on the general model of the cost-reducing R&D, the strategic interactions of output and R&D investment between labor-managed firms in a duopoly are analyzed. Moreover, the impact of absorptive capacity effects on optimal output in the production stage is discussed. In the R&D stage, the impacts of absorptive capacity effects on the equilibrium R&D investment in cooperative and non-cooperative R&D are analyzed. Finally, the R&D strategy of labor-managed firms is compared with the behavior of profit-maximizing firms. The results show that equilibrium R&D investment is always higher than that in the exogenous spillover rate, which is similar to the behavior of the profit-maximizing firms. However, unlike the profit-maximizing firms, the impact of the absorptive capacity that affects the relationship between the optimal output and its own (rival's) R&D is shown to be dependent upon a return-to-scale of the production.

Key words: absorptive capacity; labor-managed firm; R&D; strategic interaction

Growing empirical evidence supports that a firm's own R&D, besides increasing its innovative ability, can also contribute to realizing spillovers from other firms' R&D efforts. This is the second face of R&D, namely absorptive capacity, which derives from its own R&D efforts as a measure of the ability to benefit from other firms' R&D activity[1]. Cockburn and Henderson[2] claimed that firms in the pharmaceutical industry must invest in absorptive capacity in order to be able to benefit from publicly funded basic research. Klette et al.[3] presented a more recent survey of the empirical literature on spillovers and on absorptive capacity. In addition, some researches focus on the theoretical study. Cohen and Levinthal[4] first set up a model with absorptive capacity effects to analyze the factors that influence absorptive capacity. Kamien et al.[5] set up a three-stage game in which the absorptive capacity is influenced by both the R&D approach and the R&D budget; they examined how to choose an R&D approach and an R&D budget. Grunfeld[6] analyzed how an R&D investment decision is affected by spillovers with absorptive capacity. Wiethaus[7] explored how the firms choose an R&D approach with absorptive capacity effects and found that competing firms can also adopt identical R&D approaches. Leahy and Neary[8] specified a general model of the absorptive capacity process and showed that costly absorption capacity can both raise the effectiveness of a firm's own R&D and lower the effective spillover coefficients.

There have been significant advances in theoretical modeling of the R&D behavior of firms when considering absorptive capacity. However, all these contributions focus on profit-maximizing firms (henceforth, PM firms, or PMF). There still exist some firms in Yugoslavia, America, England, France, Germany, China, and Italy, etc., who do not aim at maximizing profit, but strive to maximize share-per-worker, namely labor-managed firms (henceforth LM firms, or LMF). The LM firms range from all kinds of cooperatives, stock cooperative enterprises, and some enterprises derived from state-owned enterprise reform, such as Plywood cooperatives, the Spanish Mondragon cooperation complex, employee stock ownership plans.

In this paper, we analyze how R&D investment decisions are affected by R&D spillovers between labor-managed firms, considering that R&D investment improves absorptive capacity.

1 Model

The framework in our model of cost-reducing R&D with spillovers is according to Ref. [9]. Here firms choose their R&D investment level in the first stage, and play a regular Cournot game in output in the second stage. The subgame perfect equilibrium output and investment level are identified using backward induction.

Suppose that there is a well-behaved production function in which the output is only a function of labor: $q = f(l)$, $f'(l) > 0$ and $f''(l) \leqslant 0$. These restrictions on the production function imply that the average product rate of labor is greater than or equal to its marginal product (For example, with a production function of the form $f = l^{\xi}$). The output elasticity of employment $\varepsilon = lf'/f$. If the production function exhibits CRTS, $\varepsilon = 1$. Under increasing-return-to-scale (IRTS), $\varepsilon > 1$. Under decreasing-return-to-scale (DRTS), $\varepsilon < 1$. Given this set, based on the Ward model[10], the aim of the i-th LM firm has the following form,

$$\max_{x_i,\ l_i} V_i = \frac{\pi_i}{l_i} = \frac{[p_i - g_i(x_i,\ x_j)]f(l_i) - u_i(x_i)}{l_i} \qquad (1)$$

where p_i is the market price of the i-th firm's product, and x_i represents the R&D investment level. For simplicity, we assume that p_i is defined by a liner inverse demand function,

$$p_i = a - f_i(l_i) - df_j(l_j) \qquad (2)$$

where parameter d denotes cross-price effects. We assume that the products of the two firms are substitutes, namely 1

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$\leqslant d<0$. And the unit cost function g is

$$g_i(x_i, x_j) = c - x_i - \theta_i(x_i)x_j \qquad 0 \leqslant \theta_i(x_i) \leqslant 1 \qquad (3)$$

where c is the initial unit cost component. θ_i describes the proportion of R&D that spills over from firm j to firm i, contributing to a cost reduction. In the AJ approach[9], this variable is treated as a linear exogenous parameter, namely, $\theta(x) = \beta$. Here, it is a function of own R&D investment level.

From Eqs. (1) to (3), the objective of the i-th LMF can be written as

$$\max_{x_i, l_i} V_i = \frac{\pi_i}{l_i} = \frac{[a - c - f_i - df_j + x_i + \theta_i(x_i)x_j]f(l_i) - u_i(x_i)}{l_i} \qquad (4)$$

2 Absorptive Capacity Effects in Production Stage

In the production stage, the LM firms choose employment (consequently output) to maximize share-per-worker. This process can be derived from the first-order conditions for optimal employment as

$$\frac{\partial V_i}{\partial l_i} = \frac{[a - c - 2f_i - df_j + x_i + \theta_i(x_i)x_j)]f_i' - V_i}{l_i} = 0 \qquad (5)$$

2.1 Absorptive capacity effects on production reaction function

The i-th firm's marginal revenue is $\mathrm{MR}_i = [a - c - 2f_i - df_j + x_i + \theta_i(x_i)x_j]f_i'$, and its marginal cost is $\mathrm{MC}_i = V_i$. It follows from the first-order conditions that the firm's reaction function regarding employment is given as $l_i = l_i(l_j)$,

$$\frac{\mathrm{d}l_i}{\mathrm{d}l_j} = -\frac{\partial^2 V_i/\partial l_i \partial l_j}{\partial^2 V_i/\partial l_i^2} = \frac{df_j'(l_i f_i' - f_i)/l_i^2}{\partial^2 V_i/\partial l_i^2} \qquad (6)$$

Incidentally, the two LM firms' strategic interaction in employment can also be expressed as

$$\frac{\partial V_i}{\partial l_i \partial l_j} = \frac{-df_j'f_i'}{l_i} + \frac{df_j'f_i}{l_i^2} = \frac{-df_j'(l_i f_i' - f_i)}{l_i^2} \qquad (7)$$

where $-df_j'f_i'/l_i < 0$ represents the competitive effect; namely, when the rival j increases (or decreases) its output, firm i will decrease (or increase) its output. And $df_j'f_i/l_i^2 > 0$ represents the labor effect; namely, when rival j increases (or decreases) its output, firm i will also increase (or decrease) its output. When $\partial^2 V_i/\partial l_i \partial l_j > 0 (=0, <0)$, namely the labor effect $> (=, <)$ the competitive effect. This implies that the products of the two firms are strategically complementary (or strategically independent, strategic substitutes) as the production function is DRTS (or CRTS, IRTS).

Then both reaction curves are upward-sloping on the (l_i, l_j) plane as long as the production function is DRTS. However, the products of the two firms are strategic substitutes in the case of conventional PM firms involved in quantity competition. Why is there some difference between the LMF and the PMF? Since LM firms strive to maximize share-per-worker, it will decrease share-per-worker when they increase the output. Namely, they will increase the output depending on whether or not they increase share-per-worker. Usually, when the rival increases the output, share-per-worker of LMF will decrease. However, if the LMF increases its output, it will reduce the degree of the decrease of share-per-worker. Consequently, the optimal reaction of the LMF is also to increase its output when the rival increases its output. Moreover, when the production function is CRTS, no interaction between the firms exists, so each firm's reaction function is perpendicular to its coordinate axis and each firm's output is determined independently. This is also different from the PMF, where interaction among oligopolies is significant.

2.2 Effects of changes in R&D on equilibrium output

Since our model is not a special functional formulation, but a general case, we determine the comparative-static effects of changes in the first-stage R&D on optimal second period employment in a game with absorptive capacity effects, and compare it with the one in the exogenous spillover rate. The effects of the i-th LMF's R&D investment x_i on its own equilibrium employment l_i is

$$\frac{\partial l_i}{\partial x_i} = -\frac{(\partial^2 V_i/\partial l_i \partial x_i)(\partial^2 V_j/\partial l_j^2) - (\partial^2 V_i/\partial l_i \partial l_j)(\partial^2 V_j/\partial l_j \partial x_i)}{(\partial^2 V_i/\partial l_i^2)(\partial^2 V_j/\partial l_j^2) - (\partial^2 V_i/\partial l_i \partial l_j)(\partial^2 V_j/\partial l_j \partial l_i)} \qquad (8)$$

Proposition 1 If the spillover rate $\theta(x)$ with absorptive capacity effects is the same as the exogenous spillover β, for the LMF, absorptive capacity effects have positive (no, negative) impact on the relationship between the optimal output and its own R&D as the production function is IRDS (CRTS, DRTS). Moreover, given a CRTS production, an increase in R&D raises the LMF's own equilibrium output.

Proof Supposing

$$g^{(s)} = \frac{-[(\partial^2 V_j/\partial l_j^2)(f_i' l_i - f_i)x_j \partial\theta_i/\partial x_i]/l_i^2}{(\partial^2 V_i/\partial l_i^2)(\partial^2 V_j/\partial l_j^2) - (\partial^2 V_i/\partial l_i \partial l_j)(\partial^2 V_j/\partial l_j \partial l_i)}$$

we obtain $(\partial l_i/\partial x_i)^{(s)} = (\partial l_i/\partial x_i)^{(n)} + g^{(s)}$. The superscript s denotes the case of the spillover rate with absorptive capacity effects, and n denotes the case of the spillover rate with no absorptive capacity effects.

1) When the production function is CRTS, $(\partial l_i/\partial x_i)^{(s)} = (\partial l_i/\partial x_i)^{(n)}$ since $g^{(s)} = 0$. Therefore, absorptive capacity effects have no impact on the relationship between the optimal employment and its own R&D. In addition, the relation between the i-th LMF's R&D investment and its own equilibrium employment can be expressed as

$$\left(\frac{\partial l_i}{\partial x_i}\right)^{(n)} = -\frac{(\partial^2 V_j/\partial l_j^2)u'_i(x_i)/l_i^2}{(\partial^2 V_i/\partial l_i^2)(\partial^2 V_j/\partial l_j^2) - (\partial^2 V_i/\partial l_i \partial l_j)(\partial^2 V_j/\partial l_j \partial l_i)} > 0 \qquad (9)$$

$$\left(\frac{\partial l_i}{\partial x_i}\right)^{(s)} = -\frac{(\partial^2 V_j/\partial l_j^2)u'_i(x_i)/l_i^2}{(\partial^2 V_i/\partial l_i^2)(\partial^2 V_j/\partial l_j^2) - (\partial^2 V_i/\partial l_i \partial l_j)(\partial^2 V_j/\partial l_j \partial l_i)} > 0 \qquad (10)$$

2) Under IRTS, $g^{(s)} > 0$. Furthermore, absorptive capacity effects have positive impact on the relationship between

the optimal employment and its own R&D.

3) Under DRTS, $g^{(s)} < 0$. Furthermore, absorptive capacity effects have a negative impact on the relationship between the optimal employment and its own R&D.

Similarly, the effects of the i-th LMF's R&D investment x_i on the rival's equilibrium employment l_j is

$$\left(\frac{\partial l_j}{\partial x_i}\right) = -\frac{(\partial^2 V_i/\partial l_i^2)(\partial^2 V_j/\partial l_j \partial x_i) - (\partial^2 V_i/\partial l_i \partial x_i)(\partial^2 V_j/\partial l_j \partial l_i)}{(\partial^2 V_i/\partial l_i^2)(\partial^2 V_j/\partial l_j^2) - (\partial^2 V_i/\partial l_i \partial l_j)(\partial^2 V_j/\partial l_j \partial l_i)}$$

Proposition 2 If the spillover rate $\theta(x)$ with absorptive capacity effects is the same as the exogenous spillover β, for the LMF, absorptive capacity effects have negative (no, negative) impact on the relationship between the optimal output and the rival's R&D as the production function is IRTS (CRTS, DTRS). Moreover, given a CRTS production, there is no correlation between the i-th LMF's R&D investment and the j-th LMF's equilibrium output.

Proof Supposing

$$h^{(s)} = \frac{[-df_i'(f_i' l_i - f_i)(f_j' l_j - f_j) x_j \partial\theta_i/\partial x_i]/(l_i^2 l_j^2)}{(\partial^2 V_i/\partial l_i^2)(\partial^2 V_j/\partial l_j^2) - (\partial^2 V_i/\partial l_i \partial l_j)(\partial^2 V_j/\partial l_j \partial l_i)}$$

we obtain $(\partial l_j/\partial x_i)^{(s)} = (\partial l_j/\partial x_i)^{(n)} + h^{(s)}$.

① Under CRTS, $(\partial l_j/\partial x_i)^{(s)} = (\partial l_j/\partial x_i)^{(n)} = 0$.

② Under IRTS, $h^{(s)} < 0$. Furthermore, absorptive capacity effects have a negative impact on the relationship between the optimal employment and the rival's R&D.

③ Under DRTS, $h^{(s)} < 0$. Furthermore, absorptive capacity effects have a negative impact on the relationship between the optimal employment and the rival's R&D.

3 Absorptive Capacity Effects in R&D Stage

d'Aspremont[9] first analyzed the equilibrium of cooperative R&D with a two-stage duopoly model. Later, Choi, Suzumura, Beath, Bondt, Kamien et al. explored research joint ventures (RJV) with a two-stage game based on d'Aspremont's study. And Nicholas, Katsoulacos, Kultti, Kamien, Atallah et al. proposed three-stage models by introducing new decision variables. However, besides the cooperative and non-cooperative R&D, the organization modes of R&D have other intermediate forms, such as a cost-sharing mode, an information-sharing mode. For the intermediate forms, Hu et al. [11] proposed spillover rate β as the collaboration degree of R&D. Therefore, we only need to analyze the non-cooperative and cooperative modes because the intermediate forms can be expressed by spillover rate β.

In a non-cooperative game, LM firms compete in both the research and production stages. However, in a cooperative game, they choose R&D efforts cooperatively, but compete in the output market.

3.1 Absorptive capacity effects on non-cooperative R&D

When the i-th LMF non-cooperatively chooses R&D in the first stage, the first-order conditions with respect to R&D investment are given by

$$\frac{\partial V_i}{\partial x_i} = \frac{\partial V_i}{\partial l_i}\frac{\partial l_i}{\partial x_i} + \frac{\partial V_i}{\partial l_j}\frac{\partial l_j}{\partial x_i} + \frac{\partial V_i}{\partial x_i} = \frac{\partial V_i}{\partial l_j}\frac{\partial l_j}{\partial x_i} + \frac{\partial V_i}{\partial x_i} =$$

$$\frac{[-df_j' f_i(\partial l_j/\partial x_i) + (1 + x_j(\partial\theta_i/\partial x_i))f_i - u_i']}{l_i} \tag{11}$$

Under CRTS, the equilibrium R&D investment level $\tilde{x}$ in a game with absorptive capacity effects can be computed by

$$\frac{\partial V_i}{\partial x_i} = \frac{[1 + x_j(\partial\theta_i/\partial x_i)]f_i - u_i'}{l_i} = 0 \tag{12}$$

Namely,

$$f_i[l_i(\tilde{x}_i)] - u_i'(\tilde{x}_i) + \tilde{x}_j \frac{\partial\theta_i}{\partial\tilde{x}_i} f_i[l_i(\tilde{x}_i)] = 0 \tag{13}$$

On the other hand, the equilibrium R&D investment level $\hat{x}$ in a game without absorptive capacity effects can be computed by $\partial V_i/\partial x_i = (f_i - u_i')/l_i = 0$, namely,

$$f_i[l_i(\hat{x}_i)] - u_i'(\hat{x}_i) = 0 \tag{14}$$

From Eqs. (13) and (14), we obtain

$$f_i[l_i(\hat{x}_i)] - u_i'(\hat{x}_i) = f_i[l_i(\tilde{x}_i)] - u'_i(\tilde{x}_i) + x_j(\partial\theta_i/\partial\tilde{x}_i)f_i[l_i(\tilde{x}_i)] = 0 \tag{15a}$$

$$[f_i(l_i(\hat{x}_i)) - u'_i(\hat{x}_i)] - [f_i(l_i(\tilde{x}_i)) - u'_i(\tilde{x}_i)] = \tilde{x}_j(\partial\theta_i/\partial\tilde{x}_i)f_i[l_i(\tilde{x}_i)] \tag{15b}$$

For $\partial^2 V_i/\partial x_i^2 < 0$, $f_i - u_i'$ will decrease with the increase in x. If $\hat{x} \geqslant \tilde{x}$, $[f_i(l_i(\hat{x}_i)) - u'_i(\hat{x}_i)] - [f_i(l_i(\tilde{x}_i)) - u_i'(\tilde{x}_i)] \leqslant 0$, which is inconsistent with $\tilde{x}_j(\partial\theta_i/\partial\tilde{x}_i)f_i[l_i(\tilde{x}_i)] > 0$. Consequently, $\hat{x} < \tilde{x}$.

Proposition 3 Under CRTS, if the spillover rate $\theta(x)$ with absorptive capacity effects is the same as the exogenous spillover β in a non-cooperative game, the equilibrium R&D investment in the game with absorptive capacity effects will always be higher than the one in the exogenous spillover rate.

Incidentally, $\partial^2 V_i/\partial x_i \partial x_j = f_i(\partial\theta_i/\partial x_i)/l_i > 0$. This implies that the R&D investments of the two LM firms are strategically complementary when considering absorptive capacity effects. So both reaction curves are upward-sloping on the (x_i, x_j) plane as long as the production function is CRTS. However, the R&D investments of the two LM firms have no interaction under the exogenous spillover rate. Thus, under CRTS, the R&D reaction curve of the i-th LMF becomes perpendicular to the coordinate axis on the R&D plane (x_i, x_j) in the game without absorptive capacity effects.

3.2 Absorptive capacity effects on cooperative R&D

When the i-th LMF cooperatively chooses R&D to maximize the joint profits with respect to R&D investment in the first stage,

$$\max_{x_i, x_j} V = \max_{x_i, x_j}(V_i + V_j) \tag{16}$$

Similarly, the equilibrium R&D investment can be computed by

$$\frac{\partial V}{\partial x_i} = \frac{\partial V_i}{\partial l_j}\frac{\partial l_j}{\partial x_i} + \frac{\partial V_j}{\partial l_i}\frac{\partial l_i}{\partial x_i} + \frac{\partial V_i}{\partial x_i} + \frac{\partial V_j}{\partial x_i} = 0 \tag{17}$$

Under CRTS, $\partial l_j/\partial x_i = 0$. And Eq. (17) is reduced to

$$\frac{\partial V}{\partial x_i} = \frac{f_j[\theta_j - df_i' f_j(\partial l_i/\partial x_i)]}{l_j} + \frac{[1 + x_j(\partial\theta_i/\partial x_i)]f_i - u_i'}{l_i} = 0 \tag{18}$$

We denote $\tilde{x}$ as the equilibrium R&D investment in a game with absorptive capacity effects. And the equilibrium R&D investment $\hat{x}$ in a game without absorptive capacity effects can be computed by

$$\frac{\partial V}{\partial x_i} = \frac{f_j[\theta_j - df_i' f_j(\partial l_i/\partial x_i)]}{l_j} + \frac{f_i - u_i'}{l_i} = 0 \tag{19}$$

From Eqs. (18) and (19), we obtain

$$\frac{f_j[\theta_j - df_i' f_j(\partial l_i/\partial \tilde{x}_i)]}{l_j} + \frac{[1 + \tilde{x}_j(\partial\theta_i/\partial \tilde{x}_i)]f_i - u_i'}{l_i} = \frac{f_j[\theta_j - df_i' f_j(\partial l_i/\partial \hat{x}_i)]}{l_j} + \frac{f_i - u_i'}{l_i} = 0$$

Defining $g(x) = \dfrac{f_j[\theta_j - df_i' f_j(\partial l_i/\partial x_i)]}{l_j} + \dfrac{f_i - u'_i}{l_i}$, we obtain

$$g(\hat{x}) - g(\tilde{x}) = \frac{\tilde{x}_j(\partial\theta_i/\partial\tilde{x}_i)f_i}{l_i} \tag{20}$$

For $g'(x) = \partial^2 V/\partial x_i^2 < 0$, $g(x)$ will decrease with the increase of x. If $\hat{x} \geqslant \tilde{x}$, $g(\hat{x}) - g(\tilde{x}) \leqslant 0$, which is inconsistent with $[\tilde{x}_j(\partial\theta_i/\partial\tilde{x}_i)f_i]/l_i > 0$. Consequently, $\hat{x} < \tilde{x}$.

Proposition 4 Under CRTS, if the spillover rate $\theta(x)$ with absorptive capacity effects is the same as the exogenous spillover β in cooperative game, the equilibrium R&D investment in the absorptive capacity game will always be higher than the one in the exogenous spillover rate.

3.3 Comparison of R&D investments between non-cooperative and cooperative R&D

In the Brander-Spencer model[12], there exist over-investment effects whenever there are no spillovers. As shown in the AJ model[9], the over-investment effect is not necessarily valid in the game with spillovers since spillovers force down the equilibrium R&D investment level. But in the model of Grunfeld[6] with spillovers affected by absorptive capacity effects, whether PMF will over-invest or under-invest depends on the learning effect. How about the case of the LMF?

Under CRTS, using the first-order conditions (12) and (18), and further evaluating (12) at the optimal point of (18), we obtain the following equation:

$$\left(\frac{\partial V}{\partial x_i}\right)^{\text{cn}} - \left(\frac{\partial V_i}{\partial x_i}\right)^{\text{nn}} = \frac{f_j[\theta_j - df_i' f_j(\partial l_i/\partial x_i)]}{l_j} \tag{21}$$

where $f_j[\theta_j - df_i' f_j(\partial l_i/\partial x_i)]/l_j$ is the external effect, which appears in cooperative R&D. The superscript nn denotes the case of non-cooperation both in the R&D and the production stages, cn denotes the case of cooperative R&D and Cournot competition in output. The sign of this effect may be positive or negative. If $\theta_j \gtreqqless df_i' f_j(\partial l_i/\partial x_i)$, $(\partial l_i/\partial x_i)^{\text{cn}} \gtreqqless (\partial l_i/\partial x_i)^{\text{nn}}$, i.e., $(x_i)^{\text{cn}} \gtreqqless (x_i)^{\text{nn}}$.

Proposition 5 Under CRTS, the equilibrium R&D investment in the cooperative game can exceed the one of a non-cooperative game for a large spillover with absorptive capacity. And it will be less than the one of a non-cooperative game for a small spillover.

4 Comparison of LM Firms with PM Firms

For the sake of convenience when comparing the differences between the LMF and the PMF under same conditions, we set up a similar model of profit-maximizing firms as

$$\max_{x_i, l_i} \pi_i = (p_i + x_i + \theta_i x_j)f_i - u_i(x_i) - w_i l_i \tag{22}$$

where w_i is the wage per worker. The first-order conditions for optimal employment are as follows:

$$\frac{\partial \pi_i}{\partial l_i} = [a - c - 2f_i - df_j + x_i + \theta_i(x_i)x_j]f_i' = 0 \tag{23}$$

The two PM firms' strategic interaction in employment can be expressed as

$$\frac{\partial^2 \pi_i}{\partial l_i \partial l_j} = -\frac{df_j' f_i'}{l_i} < 0$$

Consequently, the products of the two firms are strategic substitutes in the case of a PMF involved in Cournot competition. However, the strategic interaction of the output between LMFs depends upon return to scale of the production.

4.1 Effects of changes in R&D on equilibrium output

The effect of the i-th PMF's R&D investment x_i on its own equilibrium employment l_i is

$$\left(\frac{\partial l_i}{\partial x_i}\right)^{(\text{s})} = -\frac{(\partial^2\pi_i/\partial l_i \partial x_i)(\partial^2\pi_j/\partial l_j^2) - (\partial^2\pi_i/\partial l_i\partial l_j)(\partial^2\pi_j/\partial l_j\partial x_i)}{(\partial^2\pi_i/\partial l_i^2)(\partial^2\pi_j/\partial l_j^2) - (\partial^2\pi_i/\partial l_i\partial l_j)(\partial^2\pi_j/\partial l_j\partial l_i)} \tag{24}$$

Supposing

$$g^{(\text{s})} = -\frac{(\partial^2\pi_j/\partial l_j^2)f_i' x_j \partial\theta_i/\partial x_i}{(\partial^2\pi_i/\partial l_i^2)(\partial^2\pi_j/\partial l_j^2) - (\partial^2\pi_i/\partial l_i\partial l_j)(\partial^2\pi_j/\partial l_j\partial l_i)}$$

when $\theta(x) = \beta$, we obtain $(\partial l_i/\partial x_i)^{(\text{s})} = (\partial l_i/\partial x_i)^{(\text{n})} + g^{(\text{s})}$. Due to $g^{(\text{s})} > 0$, absorptive capacity effects have a positive impact on the relationship between the optimal employment and its own R&D.

Similarly, the effects of the i-th PMF's R&D investment x_i on a rival's equilibrium employment l_j is

$$\left(\frac{\partial l_i}{\partial x_i}\right)^{(\text{s})} = -\frac{(\partial^2\pi_i/\partial l_i^2)(\partial^2\pi_j/\partial l_j \partial x_i) - (\partial^2\pi_i/\partial l_i\partial x_i)(\partial^2\pi_j/\partial l_j\partial l_i)}{(\partial^2\pi_i/\partial l_i^2)(\partial^2\pi_j/\partial l_j^2) - (\partial^2\pi_i/\partial l_i\partial l_j)(\partial^2\pi_j/\partial l_j\partial l_i)} \tag{25}$$

Supposing

$$h^{(\text{s})} = \frac{-d(f_i')^2 f_j' x_j \partial\theta_i/\partial x_i}{(\partial^2\pi_i/\partial l_i^2)(\partial^2\pi_j/\partial l_j^2) - (\partial^2\pi_i/\partial l_i\partial l_j)(\partial^2\pi_j/\partial l_j\partial l_i)}$$

when $\theta(x) = \beta$, we obtain $(\partial l_j/\partial x_i)^{(\text{s})} = (\partial l_j/\partial x_i)^{(\text{n})} + h^{(\text{s})}$.

Due to $h^{(s)} < 0$, absorptive capacity effects have a negative impact on the relationship between the optimal employment and a rival's R&D investment.

Result 1 If the spillover rate $\theta(x)$ with absorptive capacity effects is the same as the exogenous spillover β, for the PMF, absorptive capacity effects have a positive impact on the relationship between the optimal output and its own R&D, and a negative impact on a rival's R&D; for the LMF, however, the impact of absorptive capacity effects on the relationship between the optimal output and its own (or a rival's) R&D is shown to be dependent upon return to scale of the production.

4.2 Effects of absorptive capacity on R&D investment

4.2.1 Absorptive capacity on non-cooperative R&D

For the PMF, the equilibrium R&D investment level $\tilde{x}$ in a game with spillovers affected by absorptive capacity effects can be computed by $\frac{\partial \pi_i}{\partial \tilde{x}_i} = \frac{\partial \pi_i}{\partial l_j}\frac{\partial l_j}{\partial \tilde{x}_i} + \frac{\partial \pi_i}{\partial \tilde{x}_i} = 0$. And the equilibrium R&D investment level $\hat{x}$ in a game without absorptive capacity effects can be computed by $\frac{\partial \pi_i}{\partial \hat{x}_i} = \frac{\partial \pi_i}{\partial l_j}\frac{\partial l_j}{\partial \hat{x}_i} + \frac{\partial \pi_i}{\partial \hat{x}_i} = 0$. Accordingly,

$$\frac{\partial \pi_i}{\partial \tilde{x}_i} = \frac{\partial \pi_i}{\partial l_j}\frac{\partial l_j}{\partial \tilde{x}_i} + \frac{\partial \pi_i}{\partial \tilde{x}_i} = \frac{\partial \pi_i}{\partial l_j}\left(\frac{\partial l_j}{\partial \hat{x}_i} + h^{(s)}\right) + \frac{\partial \pi_i}{\partial \hat{x}_i} + f_i' \frac{\partial \theta_i}{\partial \tilde{x}_i} \tag{26}$$

Defining $A(\hat{x}_i) = \partial\pi_i / \partial\hat{x}_i$, we obtain $A(\hat{x}_i) - A(\tilde{x}_i) = -df_i f_j' h^{(s)} + f_i' \partial\theta_i / \partial\tilde{x}_i > 0$ since $h^{(s)} < 0$. Consequently, $\hat{x} < \tilde{x}$.

Result 2 If the spillover rate $\theta(x)$ with absorptive capacity effects is the same as the exogenous spillover β in the non-cooperative game, for the PMF, the equilibrium R&D investment in the game with absorptive capacity is always higher than the one in the exogenous spillover rate. For the LMF, there are the same results as for the PMF under CRTS. Under IRTS or DRTS, however, the results are uncertain.

4.2.2 Absorptive capacity on cooperative R&D

If the PMFs coordinate their R&D investments, in the first stage the objective is to maximize joint profits, i. e.,

$$\max_{x_i}(\pi_i + \pi_j) \qquad i = 1,\ 2;\ i \neq j$$

The first-order condition is

$$\frac{\partial \pi}{\partial x_i} = \frac{\partial \pi_i}{\partial l_j}\frac{\partial l_j}{\partial x_i} + \frac{\partial \pi_j}{\partial l_i}\frac{\partial l_i}{\partial x_i} + \frac{\partial \pi_i}{\partial x_i} + \frac{\partial \pi_j}{\partial x_i} = 0$$

Each firm internalizes the externality, namely, $\frac{\partial \pi_i}{\partial l_j}\frac{\partial l_j}{\partial x_i} + \frac{\partial \pi_j}{\partial x_i}$. With absorptive capacity effects, the equilibrium R&D investment level $\tilde{x}$ can be computed by

$$\left(\frac{\partial \pi}{\partial \tilde{x}_i}\right)^{(s)} = -df_i f_j' \left(\frac{\partial l_j}{\partial \tilde{x}_i}\right) - df_i' f_j \left(\frac{\partial l_i}{\partial \tilde{x}_i}\right) + f_i\left[1 + \tilde{x}_j\left(\frac{\partial \theta_i}{\partial \tilde{x}_i}\right)\right] - u_i'(\tilde{x}_i) + \theta_i f_j = 0$$

On the other hand, the equilibrium R&D investment level $\hat{x}$ in the exogenous spillover rate can be computed by

$$\left(\frac{\partial \pi}{\partial \hat{x}_i}\right)^{(s)} = -df_i f_j' \left(\frac{\partial l_j}{\partial \hat{x}_i}\right) - df_i' f_j \left(\frac{\partial l_i}{\partial \hat{x}_i}\right) + f_i - u_i'(\tilde{x}_i) + \beta_i f_j = 0$$

Defining $A(\hat{x}_i) = \partial\pi_i / \partial\hat{x}_i$, for $\theta(x) = \beta$, we obtain $A(\hat{x}_i) - A(\tilde{x}_i) = -df_i f'_j h^{(s)} - df'_i f_j g^{(s)} + f'_i \partial\theta_i / \partial\tilde{x}_i > 0$. Consequently, $\hat{x} < \tilde{x}$.

Therefore, in cooperative R&D, the results of the PMF and the LMF is the same as those in the case of non-cooperation, namely result 2.

5 Conclusion

In this paper, we have explored the intrinsic quality of R&D spillovers. R&D directly increases the firm's absorptive capacity as well as its profitability. Focusing on the behavior of labor-managed firms, we discuss the impact of absorptive capacity effects on the output decision and the R&D investment decision. Our research shows that the existence of absorptive capacity can encourage LMF's R&D investment in order to benefit from other firms' R&D activity; namely, the equilibrium R&D investment in the absorptive capacity game is always higher than the one in the exogenous spillover rate, which is the same as the behaviors of the PMF. The main reason is that the benefits from R&D investment are always higher than the benefits without absorptive capacity effects. And absorptive capacity effects have positive impact on the relationship between the optimal output and its own R&D in the PMF. However, the results are uncertain in the LMF. Because in the PMF, R&D investment is in proportion to its own output, absorptive capacity effects increase the benefits from the R&D investment, and, consequently, raise its own output. On the other hand, the R&D investments are in inverse proportion to a rival's output, so absorptive capacity effects increase the benefits from the R&D investments, and, consequently, reduce a rival's output. But the result is uncertain for the LMF due to the difference in objective functions.

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共营企业的吸收能力和 R&D 战略

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摘要：当技术溢出存在吸收能力效应时，讨论了共营企业的产量和 R&D 决策. 通过建立通用的基于成本降低的 R&D 模型，分析了在双寡头市场上共营企业之间关于产品产出和 R&D 投资水平的战略互动；探讨了产品阶段吸收能力效应对共营企业均衡产出的影响；在 R&D 阶段分别分析了合作和非合作 R&D 情况下吸收能力对 R&D 投资水平的影响；最后比较了共营企业和传统的利润最大化企业在产品产出和 R&D 战略方面的不同表现. 结果表明：当存在吸收能力效应时，与利润最大化企业相同，共营企业的均衡 R&D 投资水平高于不存在吸收能力效应的水平；然而吸收能力对共营企业中 R&D 投入和对其自身(或竞争对手)产出的影响却表现出不同的效应，其结果视规模经济收益而定，这与利润最大化企业形成较大的差别.

关键词：吸收能力；共营企业；研发；战略互动

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