Unionization, Innovation, and Licensing

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Abstract

In this paper we consider the game order of union-innovation-output, with the possibility of technology licensing and want to see whether the result obtained by Calabuig and Gonzalez-Maestre (2002) is robust with this game order. We show that (1) In the presence of union under G1 game, the R&D investment under licensing is lower (higher) than that under no-licensing if the R&D efficiency is high (low); the social welfare under licensing is lower than that under no-licensing; (2) The game order is irrelevant to the ranking of innovation and social welfare; (3) In the absence of technology licensing, the game order matters for R&D investment and social welfare. However, R&D investment and social welfare under technology licensing in G2 will be higher the one in G1.

1. Introduction

The existing works examining the effects of union on innovation mainly show the effects of union power on the incentives for innovation. Freeman and Medoff (1984) show that the effect of unionization is ambiguous on innovation. Using COMPUSTAT data, Bronas and Deere (1993) show that there is a significant negative relationship between firm-specific unionization rate and innovation. Using mainly aggregative industry level data, Ulph and Ulph (1989) find a negative relation for the high-tech industries in England, while Addison and Wagner (1994) find a positive but insignificant relation. It is documented in Menezes-Filho et al. (1998) that most U.S. studies show a negative effect between union power and innovation, while the evidence from some European studies is less compelling. Menezes-Filho and Van Reenen (2003) also show strong and negative effects of unions on innovation in North America, while that is generally not the case in the UK.

Given the diversity of unionised labour market and its effect on incentive to innovate, the purpose of this paper is to show the effects of labour union on the firms' incentives for cost-reducing innovation and licensing. Considering the case of no labour union as our benchmark, we compare the incentives for innovation and social welfare under labour union with and without technology licensing. The existing literature showing the effects of labour union on innovation has focused on process innovation.[1] Investment in process innovation is certainly a major part of the firms' R&D expenditures. While the earlier works have shown the impacts of union bargaining power[2], more recent contributions show the effects of different unionization structures on incentive to innovate (Calabuig and Gonzalez-Maestre,

[1] A notable exception is Lambertini and Mantovani (2009), which consider product innovation creating new products. However, they analyse a market with a monopolist with no labor union. Hence, they ignore strategic interactions in both the product market and in the input market, which we consider here.

[2] See Grout (1984) and Van der Ploeg (1987) for surveys, and Tauman and Weiss (1987) and Ulph and Ulph (1989, 1994 and 2001) for more recent contributions on this strand of literature. The monopoly input supplier in Degraba (1990), which shows the impact of upstream pricing strategy on downstream innovation, can be interpreted as a centralised union.

2002, Haucap and Wey, 2004, and Mukherjee and Pennings, 2011).[3]

Considering an innovating firm and a non-innovating firm, Mukherjee and Pennings (2011) show the implications of technology licensing ex-post innovation. They show that if the union's preferences for wage (compared to employment) are high, the innovator's incentive for innovation is higher under a centralised union irrespective of licensing ex-post innovation; however, if the unions's preferences for employment are high, the benefit from licensing may help to create higher incentive for innovation under decentralised unions. Recently, Chang et al. (2013) without considering the role of labor unions and demonstrate that when the R&D efficiency is high, R&D decreases under licensing and it is lower than no licensing scenario. The main reasoning is that when the R&D efficiency is high, the revenue effect generated by licensing is negative, while the sum of strategy effect, output effect and cost effect are positive. Accordingly, R&D under licensing will be lower than the one under no licensing.

We want to see whether the incentive for innovation is higher under labour union when the union bargaining occurs before innovation and technology licensing. Calabuig and Gonzalez-Maestre (2002) considers the move of the game: innovation-union structure-output, but without having the possibility of technology licensing. We consider the game order of union-innovation-output, with the possibility of technology licensing and want to see whether the result obtained by Calabuig and Gonzalez-Maestre (2002) is robust with this game order.

In this paper we show that (1) In the presence of union under G1 game, the R&D investment under licensing is lower (higher) than that under no-licensing if the R&D efficiency is high (low); the social welfare under licensing is lower than that under

[3] See Manasakis and Petrakis (2009) and Mukherjee (2005) for considering both non-cooperative R&D and cooperative R&D, and social welfare.

no-licensing; (2) The game order is irrelevant to the ranking of innovation and social welfare; (3) In the absence of technology licensing, the game order matters for R&D investment and social welfare. However, R&D investment and social welfare under technology licensing in G2 will be higher the one in G1.

This paper is organized as follows. Basic modeling and game order are provided in Section 2. Section 3 firstly examines G1 game while G2 game is explored in Section 4. Section 5 concludes the paper.

2. The Model

Assume that there is an innovator (firm 1) and an imitator (firm 2) producing homogenous goods. The inverse market demand function is given by $P = 1 - q$, where P is price and $q = q_1 + q_2$ is the total output. The marginal costs of firms 1 and 2 are c Assume firm 1 invests $g(x) = \frac{gx^2}{2}$ in R&D to reduce its marginal cost to $(c - x)$. We assume that knowledge spillover to firm 2 is zero under patent protection and firm 1 can license its technology to firm 2 after R&D.

Defined the utility function of the union in firm i as $V_i = (w_i - \overline{w})L_i$, where $\overline{w}$ is the reservation wage, which can be interpreted as the wage earned in the competitive sector, we assume $\overline{w} = 0$. That is, each union's objective is to maximize the total amount of rent, or the remuneration in excess of the reservation wage in each firm.

We will consider two different cases of decision sequential game. In the first scenario G1, we consider the following game in Figure 1. At stage 1, firms bargain with the union. At stage 2, firm 1 firm 1 determines R&D investment and decides whether to license the technology to firm 2. In the case of licensing, firm 1 gives a take-it-or-leave-it licensing offer to firm 2 with an up-front fixed-fee, F, and per-unit output royalty, r. At stage 3, firm 3 accepts the licensing offer if it is not worse off under licensing compared to no licensing. At stage 4, the firms compete like Cournot duopolist and the profits are realized. We solve the game through backward induction.

In the second scenario G2, we consider the following game in Figure 2.

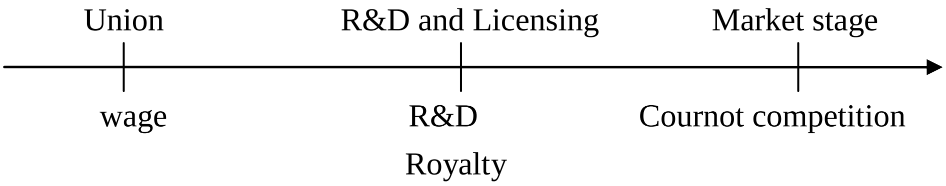

Figure 1 The G1 game

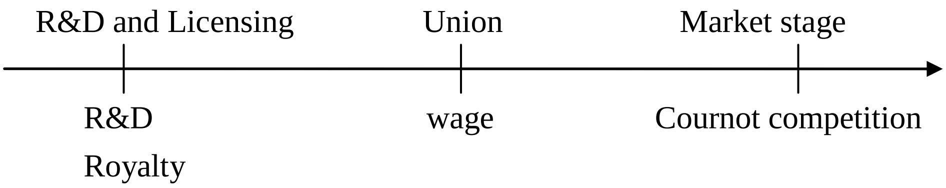

Figure 2 The G2 game

3. Union Wage-R&D-Quantity Competition (G1, Ex-ante Bargaining)

3.1 No Licensing

First, consider the equilibrium outputs and profits under no licensing. For each firms to maximize profit with R&D and no licensing, the profit are:

$$\pi_1^{NL} = (1 - q_1 - q_2 - c - w_1 + x)q_1 - \frac{gx^2}{2} \tag{1}$$

$$\pi_2^{NL} = (1 - q_1 - q_2 - c - w_2)q_2 \tag{2}$$

Since the marginal cost of firms 1 and 2 are $c - x$ and c respectively under no licensing, standard calculation show that the outputs and profits of firms 1 and 2 under no licensing are

$$q_1^{NL} = \frac{1}{3}(1 - c + 2x - 2w_1 + w_2), \tag{3}$$

$$q_2^{NL} = \frac{1}{3}(1 - c - x + w_1 - 2w_2), \tag{4}$$

$$\pi_1^{NL} = \frac{1}{9}(1 - c + 2x - 2w_1 + w_2)^2 - \frac{gx^2}{2}, \tag{5}$$

$$\pi_2^{NL} = \frac{1}{9}(1 - c - x + w_1 - 2w_2)^2. \tag{6}$$

Taking total derivative of Eqs. (5) and (6) with respect to *x*, we obtain

$$\frac{d\pi_1^{NL}}{dx} = \frac{\partial\pi_1^{NL}}{\partial q_1}\frac{dq_1}{dx} + \frac{\partial\pi_1^{NL}}{\partial q_2}\frac{dq_2}{dx} + \frac{\partial\pi_1^{NL}}{\partial x} = 0, \tag{7}$$

$$\frac{d\pi_2^{NL}}{dx} = \frac{\partial\pi_2^{NL}}{\partial q_2}\frac{dq_2}{dx} + \frac{\partial\pi_2^{NL}}{\partial q_1}\frac{dq_1}{dx} + \frac{\partial\pi_2^{NL}}{\partial x} < 0. \tag{8}$$

The first, second and third term of Eqs. (7) is output effect, strategic effect and cost effect, respectively. R&D will increase output ($\frac{dq_1}{dx} > 0$) and raise firm1's profit ($\frac{\partial\pi_1^{NL}}{\partial q_1}\frac{dq_1}{dx} > 0$), so the sign of the first term is positive and due to that R&D will decrease the output of firm 2 ($\frac{\partial q_2}{\partial x} < 0$), raise firm1's profit ($\frac{\partial\pi_1^{NL}}{\partial q_2}\frac{\partial q_2}{\partial x} > 0$), so the sign of the second term is also positive. Because the R&D is expensive, the sign of cost effect is negative ($\frac{\partial\pi_1^{NL}}{\partial x} < 0$).

The firm 1 maximizes Eq. (5) to determine the R&D investment, and we obtain the equilibrium R&D investments as

$$x^{NL*} = \frac{4(1-c-2w_1+w_2)}{9g-8}. \tag{9}$$

Note that $g > \frac{8}{9}$ is needed for finding a positive interior solution of the equilibrium R&D investment and satisfy the second order condition.

Lemma 1: *The R&D investment is decreasing in the wage of union 1, but decreasing in the wage of union 2 under no licensing.*

Proof: $\frac{\partial x^*}{\partial w_1} < 0$ and $\frac{\partial x^*}{\partial w_2} > 0$.

If there is no consideration of licensing, the wage of firm 1 up and the marginal revenue of R&D down, so the R&D investment will be lower. But, because the wage of firm 2 up and the marginal revenue of R&D up as well, so the R&D investment will be higher.

In the first stage, it determines the equilibrium wage of unions 1 and 2 under no licensing. The objective function of union i can be written as:

$$V_i = (w_i - \bar{w})q_i^* \tag{10}$$

Straightforward calculation gives the respective equilibrium wages of unions 1 and 2 as:

$$w_1^{NL*} = \frac{(1-c)(15g-12)}{45g-32}, \tag{11}$$

$$w_2^{NL*} = \frac{(1-c)(15g-16)}{45g-32}. \tag{12}$$

From Eqs. (11) and (12), $\mathrm{w}_1^{\mathrm{NL}*} > \mathrm{w}_2^{\mathrm{NL}*}$ indicates that R&D investment makes firm 1 more competitive in product market and earns higher profit, and an increases in the derived demand for labor will push up the union wage and creates rent extracting effect。

Lemma 2: *The R&D investment increases the wage of union 1, decreases the wage of union 2, and* $w_1^{NL*} > w_2^{NL*}$.

The optimal R&D investment under no licensing is

$$x^{NL*} = \frac{24(1-c)(5g-4)}{(9g-8)(45g-32)}. \tag{13}$$

Also, straightforward calculation gives the equilibrium profit, union utility and social welfare under no licensing as:

$$V_1^{NL*} = \frac{54(1-c)^2(4-5g)^2 g}{(32-45g)^2(9g-8)},$$

$$V_2^{NL*} = \frac{2(1-c)^2(16-15g)^2(-2+3g)}{(32-45g)^2(9g-8)},$$

$$\pi_1^{NL*} = \frac{36(1-c)^2(4-5g)^2 g}{(32-45g)^2(9g-8)},$$

$$\pi_2^{NL*} = \frac{4(1-c)^2(32-78g+45g^2)^2}{(32-45g)^2(9g-8)^2},$$

$$W^{NL*} = \frac{4(1-c)^2(3584+9g(-2304+g(4902+5g(-913+315g))))}{(32-45g)^2(9g-8)^2}. \tag{14}$$

3.2 Licensing

For each firms to maximize profit with R&D and licensing, the profit are:

$$\pi_1^L = (1 - q_1 - q_2 - c - w_1 + x)q_1 - \frac{gx^2}{2} + L \tag{15}$$

$$\pi_2^L = (1 - q_1 - q_2 - c + x - r - w_2)q_2 - F \tag{16}$$

where $L = rq_2 + F$ is firm 1's licensing revenue, r is the royalty and F is the fixed fee payment.

First consider the sub-game solution of R&D and licensing. Straightforward calculation gives the equilibrium outputs and profits of firms 1 and 2 as:

$$q_1^L = \frac{1-2(w_1+c-x)+(w_2+c-x+r)}{3}, \tag{17}$$

$$q_2^L = \frac{1-2(w_2+c-x+r)+(w_1+c-x)}{3}, \tag{18}$$

$$\pi_1^L = \frac{[1-2(w_1+c-x)+(w_2+c-x+r)]^2}{9}, \tag{19}$$

$$\pi_2^L = \frac{[1-2(w_2+c-x+r)+(w_1+c-x)]^2}{9}. \tag{20}$$

Now determine the equilibrium licensing contract. Firm 1 will determine the licensing contract by maximizing the following expression:

$$Max_{F,r}\, \pi_1^L = \frac{[1-2(w_1+c-x)+(w_2+c-x+r)]^2}{9} + \frac{r[1-2(w_2+c-x+r)+(w_1+c-x)]}{3} + F,$$

subject to $F, r \geq 0$.

$$\pi_2^L = \frac{[1-2(w_2+c-x+r)+(w_1+c-x)]^2}{9} - F \geq \pi_2^{NL} = \frac{1}{9}(1 - c - x + w_1 - 2w_2)^2,$$

Since firm 1 gives a take-it-or-leave-it offer, the equilibrium up-from fixed fee will be $F^* = \frac{[1-2(w_2+c-x+r)+(w_1+c-x)]^2}{9} - \frac{1}{9}(1 - c - x + w_1 - 2w_2)^2$. With the equilibrium up-front fixed-fee, the above maximization problem reduces to

$$Max_{F,r}\, \pi_1^L = \frac{[1-2(w_1+c-x)+(w_2+c-x+r)]^2}{9} + \frac{r[1-2(w_2+c-x+r)+(w_1+c-x)]}{3} + F^*,$$

subject to $r \geq 0$.

We get that the equilibrium royalty rate is given by $r^* = x$. Hence, the equilibrium up-front fixed-fee is $F^* = 0$. The total equilibrium profit of firm 1 under licensing contract is

$$\pi_1^L = \frac{[1-2(w_1+c-x)+(w_2+c-x+r)]^2}{9} + \frac{x[1-2(w_2+c-x+r)+(w_1+c-x)]}{3}.$$

Now, firm 1 maximises the following expression to determine its R&D investment:

$$\pi_1^L = \frac{[1-2(w_1+c-x)+(w_2+c-x+r)]^2}{9} + \frac{x[1-2(w_2+c-x+r)+(w_1+c-x)]}{3} - \frac{gx^2}{2}.$$

Taking total derivative of Eq. (15) with respect to *x*, we obtain

$$\frac{d\pi_1^L}{dx} = \frac{\partial\pi_1^L}{\partial q_1}\frac{dq_1}{dx} + \frac{\partial\pi_1^L}{\partial q_2}\frac{dq_2}{dx} + \frac{\partial\pi_1^L}{\partial L}\frac{dL}{dx} + \frac{\partial\pi_1^L}{\partial x} = 0, \quad (21)$$

The first, second and fourth terms are stated above, and the third term is the licensing revenue effect which has the ambiguous sign. We get the equilibrium R&D investment as

$$x^{L*} = \frac{5(1-c-w_1)+2(1-c-w_2)}{(9g-2)}, \quad (22)$$

Note that the second order condition for the above maximisation requires that $9g-2>0$.

Lemma 2: *The R&D investment is decreasing with the wage of union 1 and 2 under licensing.*

Proof: $\frac{\partial x^*}{\partial w_1} < 0$ and $\frac{\partial x^*}{\partial w_2} < 0$.

Under licensing, the wage of firm 2 up and the marginal revenue of R&D down, so the R&D investment will be lower. We also assume that $c - x^{L*} > 0$, which happens requiring $g \geq \underline{g} = \frac{5(1-c-w_1)+2(1-c-w_2)}{9c}$ which also satisfies the second order condition for maximisation, i.e., $g > \frac{2}{9}$.

Also, straightforward calculation gives the equilibrium wages, R&D investment, union utility, profit and social welfare under licensing as:

$w_1^{L*} = \frac{(1-c)(45g^2+21g-10)}{135g^2+3g-14}$, $w_2^{L*} = \frac{(1-c)(15g-8)}{45g \quad -14}$,

$x^{L*} = \frac{2(1-c)(315g^2-33g-16)}{(1+3g)(9g-2)(45g-14)}$,

$V_1^{L*} = \frac{2(1-c)^2(-10+21g+45g^2)^2}{(45g-14)^2(-2+3g+27g^2)}$, $V_2^{L*} = \frac{2(1-c)^2(8-15g)^2(3g-1)}{(14-45g)^2(9g-2)}$,

$\pi_1^{L*} = \frac{2(-1+c)^2(28+g(98+3g(-373+9g(-14+5g(43+30g)))))}{(9g-2)(-14+3g+135g^2)^2}$, $\pi_2^{L*} = \frac{4(-1+c)^2(8-39g+45g^2)^2}{(28-216g+405g^2)^2}$,

$W^{L*} = \frac{2(1-c)^2(260+g(188+3g(-1996+9g(33+g(668+15g(-137+630g))))))}{(45g-14)^2(9g-2)^2(1+3g)^2}$.   (23)

Next, compared the R&D investment and social welfare under licensing and no licensing, we obtain

$x^{NL*} - x^{L*} < 0$, if $g \geq \overline{g}_x = 1.71156$,

$w_1^{NL*} - w_1^{L*} < 0$, $w_2^{NL*} - w_2^{L*} < 0$,

$\pi_1^{NL*} - \pi_1^{L*} < 0$, $\pi_2^{NL*} - \pi_2^{L*} < 0$,

$V_1^{NL*} - V_1^{L*} < 0$, if $g > \bar{g}_{V1} \equiv 1.16217$,

$V_2^{NL*} - V_2^{L*} < 0$, if $g > \bar{g}_{V2} \equiv 0.97841$,

$W^{NL*} - W^{L*} > 0$.

Corollary 1 (Chang et al., 2013): *In the absence of union, that is* $w_1^{NL*} = w_1^{L*} = 0$, *the R&D investment under the licensing regime is lower (higher) than that under no-licensing regime if the R&D efficiency is high (low). The social welfare with licensing is lower (higher) than that with no licensing, if the R&D efficiency is high (low).*

Chang et al. (2013) argue that when the R&D efficiency is high, R&D decreases under licensing and it is lower than no licensing scenario. The main reasoning is that when the R&D efficiency is high, the revenue effect generated by licensing is negative, while the sum of strategy effect, output effect and cost effect are positive. Accordingly, R&D under licensing will be lower than the one under no licensing. From Figure 3, we see that under technology licensing, firm 1's profit function moves up and when the R&D efficiency is high, profits become higher and hence, R&D investment will be lower than no licensing one.

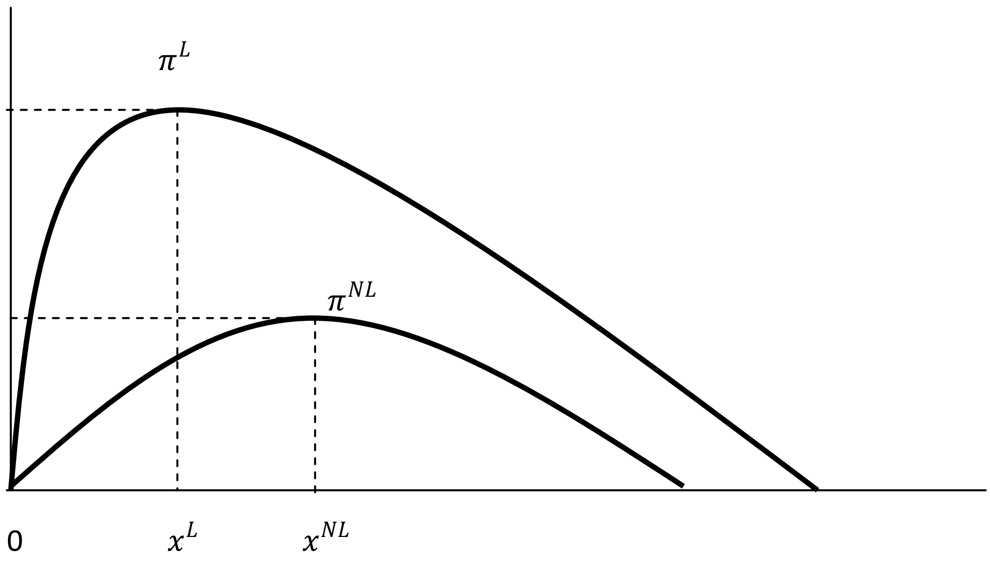

Figure. 3 The case when R&D efficiency is high

On the other hand, when the R&D efficiency is low, the licensing revenue effect turns to be positive and the sum of strategic effect, output effect and cost-reducing effect is negative. Accordingly, R&D investment under licensing will be higher than the one under no licensing. See Figure for the illustration.

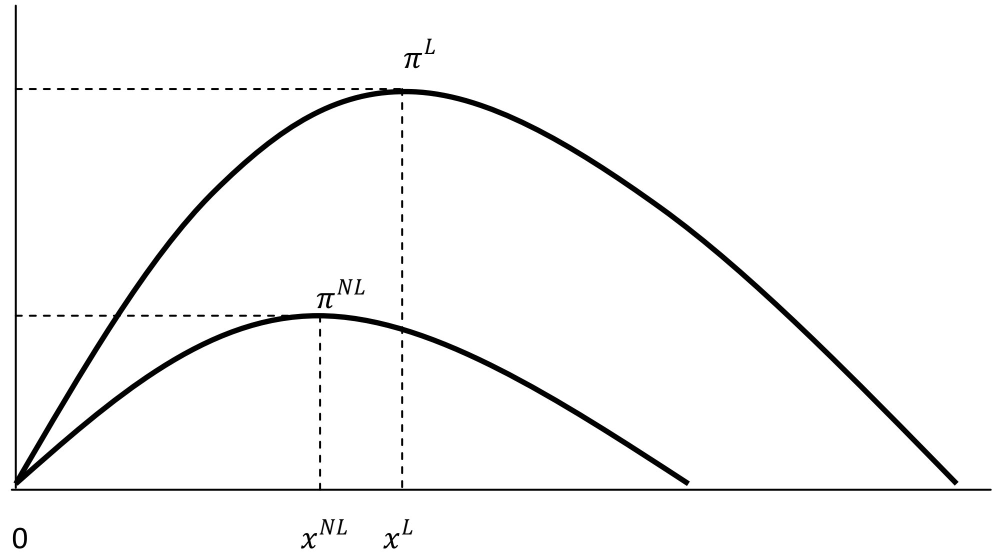

Figure. 4 The case when R&D efficiency is low

In Chang et al. (2013), social welfare is a monotonic increasing function of innovation regardless of technology licensing, i.e.,

$$\frac{dW^{NL}}{dx} = \frac{d\pi_1^{NL}}{dx} + \frac{d\pi_2^{NL}}{dx} + \frac{dCS_1^{NL}}{dx} > 0, \quad (23)$$

$$\frac{dW^{L}}{dx} = \frac{d\pi_1^{L}}{dx} + \frac{d\pi_2^{L}}{dx} + \frac{dCS_1^{L}}{dx} > 0 \quad (24)$$

The impact of R&D on social welfare can be decomposed into three parts: raise the profit of firm 1, increase consumer's surplus, while decline the profit of firm 2. Substituting Eqs. (7) and (21) into Eqs. (23) and (24), we obtain that

$$\frac{dW^{NL}}{dx} = \left[\frac{\partial\pi_1^{NL}}{\partial q_1}\frac{dq_1}{dx} + \frac{\partial\pi_1^{NL}}{\partial q_2}\frac{dq_2}{dx} + \frac{\partial\pi_1^{NL}}{\partial x}\right] + \frac{d\pi_2^{NL}}{dx} + \frac{dCS_1^{NL}}{dx} > 0, \quad (25)$$

$$\frac{dW^{L}}{dx} = \left[\frac{\partial\pi_1^{L}}{\partial q_1}\frac{dq_1}{dx} + \frac{\partial\pi_1^{L}}{\partial q_2}\frac{dq_2}{dx} + \frac{\partial\pi_1^{L}}{\partial L}\frac{dL}{dx} + \frac{\partial\pi_1^{L}}{\partial x}\right] + \frac{d\pi_2^{L}}{dx} + \frac{dCS_1^{L}}{dx} > 0. \quad (26)$$

From Eqs. (25) and (26), when the R&D efficiency is low, the licensing revenue effect is positive, that is $\frac{\partial\pi_1^L}{\partial L}\frac{dL}{dx} > 0$. Note that $\left.\frac{dW^L}{dx}\right|_{x^L = x^{NL}} > \left.\frac{dW^{NL}}{dx}\right|_{x^L = x^{NL}}$, represents the marginal social benefit of R&D investment with licensing is higher than that with no licensing. Concurrently, when the R&D efficiency is low, R&D investment under licensing will be higher than the one under no licensing. The social welfare with licensing is higher than that with no licensing, if the R&D efficiency is low.

We have the following proposition.

Proposition 1: *In the presence of union under G1 game, the R&D investment under licensing is lower (higher) than that under no-licensing if the R&D efficiency is high (low); the social welfare under licensing is lower than that under no-licensing.*

We find that the R&D investment under licensing is lower (higher) than that under no-licensing if the R&D efficiency is high (low) which is the same as Chang et al. (2013), but the welfare ranking is different from the outcome without considering labor union as in Chang et al. (2013). The main reasoning is that when firm 1 license its technology, it will add on its profit, and union will then have the rent extracting effect. Besides that, union wage of both firms go up and rent extracting effect will have negative impact on social welfare.

4. R&D-Union Wage-Quantity Competition (G2, Ex-post Bargaining)

4.1 No Licensing

In the market stage, the results are the same as Eqs. (3) and (4). In the second stage of the game, it determines the equilibrium wage of unions 1 and 2 under licensing. Straightforward calculation gives the respective equilibrium wages of unions 1 and 2 as:

$w_1^{NL} = \frac{1}{15}(5 - 5c + 7x)$,

$w_2^{NL} = \frac{1}{15}(5 - 5c - 2x)$.

In the R&D stage, the firm 1 maximizes Eq. (5) to determine the R&D investment, we obtain the equilibrium R&D investments are

$$x^{NL**} = \frac{280(1-c)}{2025g-392}. \qquad (27)$$

Note that $g > \frac{392}{2025}$ is needed for finding a positive interior solution of the equilibrium R&D investment and satisfy the second order condition.

Also, straightforward calculation gives the respective equilibrium R&D investment and social welfare under no licensing as:

$V_1^{NL**} = \frac{303750(1-c)^2 g^2}{(2025g-392)^2}$,

$V_2^{NL**} = \frac{6(1-c)^2(56-225g)^2}{(2025g-392)^2}$,

$\pi_1^{NL**} = \frac{100(1-c)^2 g}{2025g-392}$,

$\pi_2^{NL**} = \frac{4(1-c)^2(56-225g)^2}{(2025g-392)^2}$,

$W^{NL**} = \frac{28(1-c)^2(1344+125g(-112+405g))}{(2025g-392)^2}$. (28)

4.2 Licensing

In the market stage, the results are the same as Eqs. (10) and (11). In the second stage, it determines the equilibrium wage of unions 1 and 2 under licensing. Straightforward calculation gives the respective equilibrium wages of unions 1 and 2 as:

$w_1^L = \frac{1}{15}(5 - 5c + 2r + 5x)$,

$w_2^L = \frac{1}{15}(5 - 5c - 7r + 5x)$.

In the R&D stage, the firm 1 maximizes Eq. (5) to determine the R&D investment, we obtain the equilibrium R&D investments are

$x^{L**} = \frac{730(1-c)}{2025g-32}$. (29)

Note that $g > \frac{32}{2025} \cong 0.0158$ is needed for finding a positive interior solution of the equilibrium R&D investment and satisfy the second order condition.

Also, straightforward calculation gives the respective equilibrium wages, R&D investment and social welfare under licensing as:

$w_1^{L**} = \frac{15(1-c)(22+45g)}{2025g-32}$,

$w_2^{L**} = \frac{27(1-c)(-4+25g)}{2025g-32}$,

$V_1^{L**} = \frac{150(1-c)^2(22+45g)^2}{(2025g-32)^2}$,

$V_2^{L**} = \frac{486(1-c)^2(4-25g)^2}{(2025g-32)^2}$,

$\pi_1^{L**} = \frac{10(1-c)^2(13+10g)}{2025g-32}$,

$\pi_2^{L**} = \frac{324(1-c)^2(4-25g)^2}{(2025g-32)^2}$,

$$W^{L**} = \frac{2(1-c)^2(46176+125g(2113+5670g))}{(2025g-32)^2}. \quad (30)$$

Next, compared the R&D investment and social welfare under licensing and no licensing, we obtain

$x^{NL**} - x^{L**} < 0$, $w_1^{NL**} - w_1^{L**} < 0$, and $w_2^{NL**} - w_2^{L**} < 0$, if $g > \frac{616}{2025}$.

$\pi_1^{NL**} - \pi_1^{L**} < 0$, $\pi_2^{NL**} - \pi_2^{L**} < 0$,

$V_1^{NL**} - V_1^{L**} < 0$ and $V_2^{NL**} - V_2^{L**} < 0$, if $g > \frac{616}{2025}$.

$W^{NL**} - W^{L**} > 0$.

We then have the following proposition.

Proposition 2: *The game order is irrelevant to the ranking of innovation and social welfare with and without licensing.*

However, the game order will influence the activity of R&D investment. In G2 game, the optimal R&D with and without licensing is determined by

$$\frac{d\pi_1^{NL}}{dx} = \frac{\partial\pi_1^{NL}}{\partial q_1}\frac{dq_1}{dx} + \frac{\partial\pi_1^{NL}}{\partial q_2}\frac{dq_2}{dx} + \frac{\partial\pi_1^{NL}}{\partial w_1}\frac{dw_1}{dx} + \frac{\partial\pi_1^{NL}}{\partial w_2}\frac{dw_2}{dx} + \frac{\partial\pi_1^{NL}}{\partial x} = 0, \quad (31)$$

$$\frac{d\pi_1^{L}}{dx} = \frac{\partial\pi_1^{L}}{\partial q_1}\frac{dq_1}{dx} + \frac{\partial\pi_1^{L}}{\partial q_2}\frac{dq_2}{dx} + \frac{\partial\pi_1^{NL}}{\partial w_1}\frac{dw_1}{dx} + \frac{\partial\pi_1^{NL}}{\partial w_2}\frac{dw_2}{dx} + \frac{\partial\pi_1^{L}}{\partial L}\frac{\partial L}{\partial x} + \frac{\partial\pi_1^{L}}{\partial x} = 0, \quad (32)$$

In Eq. (31), $\frac{\partial\pi_1^{NL}}{\partial w_1} < 0$, $\frac{dw_1}{dx} > 0$, $\frac{\partial\pi_1^{NL}}{\partial w_2} < 0$, and $\frac{dw_2}{dx} < 0$. Because $\frac{\partial\pi_1^{NL}}{\partial w_1}\frac{dw_1}{dx} <$

0 and $\frac{\partial \pi_1^{NL}}{\partial w_2}\frac{dw_2}{dx}$>0 will offset each other, the effect of game order is ambiguous under no technology licensing. However, in Eq. (320), $\frac{dw_2}{dx} > 0$, $\frac{\partial \pi_1^{NL}}{\partial w_1}\frac{dw_1}{dx} < 0$ and $\frac{\partial \pi_1^{NL}}{\partial w_2}\frac{dw_2}{dx}$ <0，the sing of $\frac{\partial \pi_1^{L}}{\partial q_1}\frac{dq_1}{dx} + \frac{\partial \pi_1^{L}}{\partial q_2}\frac{dq_2}{dx} + \frac{\partial \pi_1^{L}}{\partial L}\frac{\partial L}{\partial x} + \frac{\partial \pi_1^{L}}{\partial x}$ is positive. Hence, R&D investment under technology licensing in G2 will be higher the one in G1.

We have the following proposition.

Proposition 3: *In the absence of technology licensing, the game order matters for R&D investment. However, R&D investment under technology licensing in G2 will be higher the one in G1.*

Next, we compare the social welfare with and without licensing between G1 and G2,

$$\frac{dW^{NL}}{dx} = \frac{d\pi_1^{NL}}{dx} + \frac{d\pi_2^{NL}}{dx} + \frac{dV_1^{NL}}{dx} + \frac{dV_2^{NL}}{dx} + \frac{dCS_1^{NL}}{dx} > 0, \tag{33}$$

$$\frac{dW^{L}}{dx} = \frac{d\pi_1^{L}}{dx} + \frac{d\pi_2^{L}}{dx} + \frac{dV_1^{L}}{dx} + \frac{dV_2^{L}}{dx} + \frac{dCS_1^{L}}{dx} > 0 \tag{34}$$

In Eq. (33), the effect of game order on social welfare is ambiguous under no technology licensing, the same reasoning is provided as proposition 3. In Eq. (34), due to that R&D investment under technology licensing in G2 will be higher the one in G1, and $\left.\frac{dW^{L}(G2)}{dx}\right|_{x^{L*}=x^{L**}} > \left.\frac{dW^{L}(G1)}{dx}\right|_{x^{L*}=x^{L**}}$, the social welfare under technology licensing in G2 will be higher the one in G1.

We immediate have the following proposition.

Proposition 4: *In the absence of technology licensing, the game order matters for social welfare. However, social welfare under technology licensing in G2 will be higher the one in G1.*

5. Conclusions

In this paper, we considered the game order of union-innovation-output, with the possibility of technology licensing and want to see whether the result obtained by

Calabuig and Gonzalez-Maestre (2002) is robust with this game order and the validity of Chang (2013) et al. in the context of union-innovation-output game. Our main findings are that (1) In the presence of union under G1 game, the R&D investment under licensing is lower (higher) than that under no-licensing if the R&D efficiency is high (low); the social welfare under licensing is lower than that under no-licensing; (2) The game order is irrelevant to the ranking of innovation and social welfare; (3) In the absence of technology licensing, the game order matters for R&D investment and social welfare. However, R&D investment and social welfare under technology licensing in G2 will be higher the one in G1.

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