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Price competition and the effects of labour union on process innovation

by

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Abstract

We provide a new perspective to the literature on innovation in a unionised labour market by considering price competition in the product market. In contrast to the conventional wisdom, suggesting the presence of labour union reduces the incentive for innovation, we show that this view may not hold true if the firms compete in prices. We show that the incentive for innovation may be higher in the presence of labour unions if the goods are close substitutes. We also show that whether the incentive for innovation is higher under decentralised labour unions or under a centralised labour union may depend on product substitutability.

Key Words: Industry-wide union; Firm-specific union;
Process Innovation; Union Utility

JEL Classification: D43; J51; L13; O31

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1 Introduction

Labour unions differ substantially between countries with respect to the degree of wage setting centralisation (Calmfors and Driffill, 1988, Moene and Wallerstein, 1997, Flanagan, 1999 and Wallerstein, 1999). Decentralised wage setting is often contrasted with a centralised wage setting. In the former situation, wages are set between employers and firm-specific unions, while in the latter situation, an industry-wide union negotiates wages with all firms (Haucap and Wey, 2004). While the centralised argument is egalitarian in nature and generally makes the sufficiently substitutable workers better off (Horn and Wolinsky, 1988 and Davidson, 1988), the rigidity associated with this system is generally bad for overall economic performance (Nickell, 1997 and Siebert, 1997).

Given the diversity of unionised labour market, there is a growing interest in recent years for determining the effects of different labour unionisation structure on innovation (Calabuig and Gonzalez-Maestre, 2004, Haucap and Wey, 2004, Manasakis and Petrakis, 2009 and Mukherjee and Pennings, 2011),[1] which is often considered to be the vehicle of economic growth. In a patent race model, Haucap and Wey (2004) show that if a centralised labour union charges a uniform wage to all firms, the incentive for innovation is higher under the centralised labour union; however, in the case of wage discrimination by the centralised labour union, the incentive for innovation is higher under decentralised labour unions. In a model with R&D competition, Calabuig and Gonzalez-Maestre (2002) show that the incentive for innovation is higher under decentralised labour unions for non-drastic innovations; however, the incentive for innovation can be higher under a centralised labour union in the case of a drastic innovation. Manasakis and Petrakis (2009) show that, under non-cooperative R&D, the incentive for innovation is higher under decentralised labour unions if knowledge spillovers are high; however, the incentive for innovation is always higher under decentralised labour unions under cooperative R&D. 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 unions' preferences for wage (compared to employment) are high, the innovator's incentive for innovation is higher under a centralised labour union irrespective of licensing ex-post innovation; however, if the unions' preferences for employment are high, the benefit from licensing may help to create higher incentive for innovation under decentralised labour unions.

A common feature of the above-mentioned papers is to consider Cournot competition in the product market. However, it is well-known in the industrial organisation literature that the results are often affected by the type of product market competition. For example, the literature on horizontal mergers shows that whether the product market is characterised by Cournot or Bertrand competition may have significant implications on the merger's profitability (Salant et al., 1983 and Deneckere

[1] In contrast to these papers, earlier works have shown the impacts of union bargaining power. See Grout (1984) and Van der Ploeg (1987) for surveys, and Tauman and Weiss (1987) and Ulph and Ulph (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.

and Davidson, 1985).[2] The effect of type of product market competition is also examined in the context of strategic trade policy. Brander and Spencer (1983) and Eaton Grossman (1986) show that whether a country imposes ex-post subsidy or ex-post tax depends on whether the operating firm chooses profit maximising price rule or quantity rule in the product market. Similarly, the effect of trade liberalisation on unionised labour market also depends on the price or cournot competition in the product market (Munch and Skaksen, 2002 and Gürtzgen, 2002).

In what follows, section 2 considers a market with two innovating firms facing labour unions. Each firm can invest in process innovation, which reduces labour coefficient in the production process. We show that the decisions to invest in process innovation depend on the union structure as well as on the degree of product differentiation. If the goods are highly differentiated, which creates negligible competition in the product market, the presence of labour union reduces the incentive for innovation compared to the situation with no labour union, irrespective of the unionisation structure. Further the incentive for innovation in this situation is higher under decentralised labour unions than under a centralised labour union. However, if the goods are close substitutes, which creates intense competition in the product market, the incentive for innovation can be higher under decentralised labour unions compared to a centralised labour union and no labour union. Further, the incentive for innovation in this situation can be higher under a centralised labour union than under decentralised unions.

Our result comparing the incentive for innovation under no labour union to that of labour unions is in contrast to the existing literature (Calabuig and Gonzalez-Maestre, 2004 and Haucap and Wey, 2004), which shows under Cournot competition that the presence of labour unions reduces the incentive for innovation compared to the situation with no labour union. Our result comparing the incentive for innovation under decentralised labour unions to that of a centralised labour union also shows that the result of Calabuig and Gonzalez-Maestre (2002), which consider Cournot competition in an otherwise similar structure to ours, may not remain under Bertrand competition. They show that the incentive for innovation is higher under decentralised labour unions for non-drastic innovations, while our results show that, even under non-drastic innovations, the incentive for innovation can be higher under a centralised labour union if the goods are close substitutes.

The reasons behind our results are related to different types of constraints imposed by different unionisation structure affecting the *hold-up* problem. Haucap and Wey (2004) show that the uniformity rule under a centralised union is more effective in constraining the unions' hold-up potential and leads to higher incentives for innovation under a centralised union; however, if the centralised union discriminates wage, it helps the union to exploit its hold-up problem at the maximum level, and the innovation incentive can be lower under a centralised union. Calabuig and Gonzalez-Maestre (2002) show that the hold-up problems are affected by the nature of innovation, which may make production by the non-innovating firm unprofitable.

[2] Salant et al. (1983) show that horizontal merger in a Cournot oligopoly can be unprofitable if the number of merged firm is not large enough. In contrast, Deneckere and Davidson (1985) show that merger between any number of firms is profitable under Cournot competition.

Manasakis and Petrakis (2009) show that the degree of knowledge spillover and cooperation in R&D affect the hold-up problems created by the unionisation structures. In Mukherjee and Pennings (2010), the hold-up problems are present both in the innovation stage and in the technology licensing stage. Under licensing ex-post innovation, competition between the unions under decentralised unions is more effective in softening the hold-up problem, thus creating a stronger incentive for licensing under decentralised unions. The gain from licensing tends to increase the incentive for innovation under decentralised unions by reducing the negative effects of the hold-up problem under decentralised unions.

Process innovation in our paper creates a direct negative effect on labour demand by reducing the labour requirement in the production process. A unionised labour market creates two opposing effects on the incentives of process innovation.[3] On one hand, a higher wage demand by the labour unions provides higher incentives for employing a more labour saving technology. On the other hand, the returns from innovation give rise to hold-up problems, as the labour unions intend to appropriate a part of the higher profit generated through innovation. This rent seeking behaviour of the unions reduces the innovation incentives. Hence, the overall incentive for process innovation depends on the relative strengths of these two opposing effects.

We show that whether labour union intervention increases the hold-up problem under decentralised unions or under a centralised union depends on the organisational mode of labour unions and the severity of product market competition. When the firms compete in a less competitive market, i.e., when the goods are highly differentiated and the firms are close to monopolists, a competitive labour market creates higher incentive for innovation compared to the situation with labour unions. The reason is that unions have high potentials to appropriate the monopoly rent and the hold-up problem is severe. However, this is not the case when the products are close substitutes and the product market competition is fierce. The union, in this case, is forced to moderate its wage demand to allow its hosting firm to maintain its market. Our results also reveal that, due to its monopolised wage bargaining structure a centralised labour union has greater hold-up ability than decentralised unions. Hence, investments in innovation are higher under decentralised labour unions than under a centralised labour union.

The remainder of the paper is organised as follows. Section 2 describes the model and derives equilibrium outputs. Section 3 considers the wage setting game under no labour union, and under decentralised and centralised unions. Section 4 demonstrates the investment game. Section 5 shows the effects of labour union and different labour unionisation structure on the incentive for innovation. Section 6 closes the paper with concluding remarks.

2 Model Outline

We consider an industry comprising of two firms, Firm 1 and Firm 2, competing like Bertrand duopolists. Firm 1 and 2 produce goods 1 and 2 respectively, where the products are imperfect substitutes. We assume for simplicity that production

[3] See Freeman and Medoff (1984, pp. 170–171) for a detailed discussion.

requires only labour and the technology is such that each firm requires one unit of labour (L_i) to produce one unit of output (q_i), where $i = 1, 2$. However, each firm can undertake process innovation to reduce its labour coefficient. We assume that each firm can invest k (> 0) to reduce its labour coefficient to $\phi \in (0, 1)$ from unity. Our framework is similar to Calabuig and Gonzalez-Maestre (2002) with the exception of Bertrand competition.

We assume that the workers are unionised and each firm needs to hire workers from the labour unions, which can be either decentralised or centralised. We consider a 'right-to-manage' model of labour union (see, e.g., Bughin and Vannini, 1995, López and Naylor, 2004, Calabuig and Gonzalez-Maestre, 2002 and Haucap and Wey, 2004 and Mukherjee and Pennings, 2011), where the firms and the union(s) bargain for wages and the firms hire workers according to their requirements. However, in order to capture the maximum effect of labour union, following Calabuig and Gonzalez-Maestre (2002) and Haucap and Wey (2004), we assume that the labour unions have full bargaining power in wage determination. As our benchmark, we assume a competitive labour market where the workers receive a competitive wage $c \in (0, 1)$.

For the demand side, we consider the representative consumer's utility function as

$$U(q, \xi) = \sum_i q_i - \frac{1}{2} \sum_i q_i^2 - \gamma \sum_{\substack{j \\ i \neq j}} q_i q_j + \xi \tag{1}$$

where ξ is the numeraire good and $\gamma \in (0, 1)$ measures the degree of product differentiation. Higher values of γ imply a lower degree of product differentiation. If $\gamma = 1$, the goods are perfect substitutes, and if $\gamma = 0$, the goods are isolated. The utility maximisation generates the following inverse demand function for good i and j ($i, j = 1, 2$ and $i \neq j$)

$$P_i = 1 - q_i - \gamma q_j \tag{2}$$

where P_i and q_i are price and output of product i, $i \in \{1, 2\}$.

We consider the following game. At stage 1, firms decide whether or not to invest in innovation. At stage 2, the wages are determined either by the decentralised unions or by a centralised union. At stage 3, the firms choose their prices simultaneously and the profits are realised. We solve the game through backward induction.

2.1 Bertrand Equilibrium

In order to solve the Bertrand game, we derive the direct demand function using expression (2). It takes the following form

$$q_i(P_i, P_j) = \frac{(1 - \gamma) - P_i + \gamma P_j}{1 - \gamma^2}. \tag{3}$$

Now, we will derive the equilibrium price levels and the corresponding output levels under three possible combinations: (i) neither firm innovates, (ii) only one firm innovates, and, (iii) both firms innovate.

First, we consider the case where neither firm invests in process innovation. In this situation, the equilibrium price charged by the i^{th} firm is:

$$\widehat{P}_i = \frac{(1-\gamma)(2+\gamma) + 2w_i + \gamma w_j}{4-\gamma^2} \tag{4}$$

and the corresponding output level is

$$\widehat{q}_i = \frac{(1-\gamma)(2+\gamma) - \left(2-\gamma^2\right) w_i + \gamma w_j}{(4-\gamma^2)(1-\gamma^2)}. \tag{5}$$

Now, consider the case where only one firm innovates. For notational ease we denote the innovating firm by $'iv'$ and the non-innovating firm by $'nv'$. In this case, the resulting equilibrium price and output levels are respectively

$$P_{iv} = \frac{(1-\gamma)(2+\gamma) + 2\phi w_{iv} + \gamma w_{nv}}{4-\gamma^2} \tag{6}$$

$$P_{nv} = \frac{(1-\gamma)(2+\gamma) + \phi\gamma w_{nv} + 2w_{iv}}{4-\gamma^2} \tag{7}$$

$$q_{iv} = \frac{(1-\gamma)(2+\gamma) - \left(2-\gamma^2\right)\phi w_{iv} + \gamma w_{nv}}{(4-\gamma^2)(1-\gamma^2)} \tag{8}$$

$$q_{nv} = \frac{(1-\gamma)(2+\gamma) + \gamma\phi w_{nv} - \left(2-\gamma^2\right) w_{iv}}{(4-\gamma^2)(1-\gamma^2)}. \tag{9}$$

Finally, there could be another possibility where both firms engage in process innovation. The equilibrium price and output are respectively

$$\overline{P}_i = \frac{(1-\gamma)(2+\gamma) + 2\phi w_i + \gamma\phi w_j}{4-\gamma^2} \tag{10}$$

$$\overline{q}_i = \frac{(1-\gamma)(2+\gamma) - \left(2-\gamma^2\right)\phi w_i + \gamma\phi w_j}{(4-\gamma^2)(1-\gamma^2)}. \tag{11}$$

3 Wage Determination

We now turn to stage 2 where we define and solve the wage setting game and derive the respective equilibrium wage rates conditional on the innovation strategies of the firms. To this extent, we will consider three different scenarios: no labour union, decentralised unions and a centralised union. For the ease of analysis, we use $r = n, fs, iw$ to indicate no union, decentralised unions and a centralised union respectively.

3.1 No Labour Union: The Benchmark

If there is no labour union, there is no labour market distortions meaning that the workers earn a competitive wage rate $c \in (0,1)$.

3.2 Decentralised Labour Unions

If there are decentralised labour unions, the i^{th} firm-specific union, $i = 1, 2$, determines wage to maximise its utility, $U_i = (w_i - c) L_i$ with respect to the wage, w_i, where L_i is the labour demand faced by the i^{th} firm.

First, we consider the case where neither firm innovates. The resulting output levels are demonstrated in expression (5). The i^{th} union determines the wage w_i by maximising $U_i = (w_i - c) L_i = (w_i - c) \widehat{q}_i$. When neither firm innovates, the union's utility maximisation problem leads to the equilibrium wages as

$$\widehat{w}_i^{fs} = \widehat{w}_j^{fs} = \frac{(1-\gamma)(2+\gamma) + c(2-\gamma^2)}{4-\gamma-2\gamma^2}. \tag{12}$$

Next, we consider the case where one firm (say firm i) innovates and the other (firm j) does not. The corresponding output levels are shown in expressions (8)-(9). The innovating (non-innovating) firm determines its firm-specific wage $w_{iv}(w_{nv})$ by maximising the objective function $U_{iv} = (w_{iv} - c) L_i = (w_{iv} - c) \phi q_{iv}$ ($U_{nv} = (w_{nv} - c) L_j = (w_{nv} - c) q_{nv}$). Maximisation leads to the following equilibrium wages for the innovating and non-innovating firms respectively:

$$w_{iv}^{fs} = \frac{(1-\gamma)(2+\gamma)(4+\gamma-2\gamma^2) + c\left(2-\gamma^2\right)\left(\gamma+4\phi-2\gamma^2\phi\right)}{\phi(4+\gamma-2\gamma^2)(4-\gamma-2\gamma^2)} \tag{13}$$

$$w_{nv}^{fs} = \frac{(1-\gamma)(2+\gamma)(4+\gamma-2\gamma^2) + c(2-\gamma^2)(4-2\gamma^2+\gamma\phi)}{(4+\gamma-2\gamma^2)(4-\gamma-2\gamma^2)}. \tag{14}$$

Finally, when both firms innovate, the output levels are equivalent to the expressions stated in equation (11). The i^{th} firm determines the wage to maximise the expression $U_i = (w_i - c) L_i = (w_i - c) \phi \overline{q}_i$. The equilibrium wages are

$$\overline{w}_i^{fs} = \overline{w}_j^{fs} = \frac{(1-\gamma)(2+\gamma) + c\phi\left(2-\gamma^2\right)}{\phi\left(4-\gamma-2\gamma^2\right)}. \tag{15}$$

3.3 A Centralised Labour Union

If there is a centralised labour union, it determines the wage for both firms to maximise the utility of the centralised union. Like the case of no labour union and decentralised labour unions, we first consider the situation where neither firm innovates. The equilibrium wages are determined by maximising $U = \sum (w_i - c) \widehat{q}_i$ which yields the equilibrium wages as

$$\widehat{w}_i^{iw} = \widehat{w}_j^{iw} = \frac{1}{2}(1+c). \tag{16}$$

If only one firm (say firm i) innovates while the other (firm j) does not, the wages of the innovating and non-innovating firms are determined by maximising $U = (w_{iv} - c) \phi q_{iv} + (w_{nv} - c) q_{nv}$. The resulting equilibrium wages are

$$w_{iv}^{iw} = \left(\frac{1+c\phi}{2\phi}\right) \tag{17}$$

$$w_{nv}^{iw} = \left(\frac{1+c}{2}\right). \tag{18}$$

Finally, if both firms engage in process innovation, the maximisation problem $U = \sum (w_i - c) \phi \overline{q}_i$ gives the equilibrium wages as

$$\overline{w}_i^{iw} = \overline{w}_j^{iw} = \left(\frac{1 + c\phi}{2\phi} \right). \tag{19}$$

We now compare the equilibrium wages and the wage differentials (post-innovation wage minus pre-innovation wage) of the innovating firm(s) across the unionised structures. We summarise the results in the following proposition.

Lemma 1 *(a) The wage paid by the innovating firm under a centralised labour union is higher than that of under decentralised labour unions if either both firms innovate, i.e.,* $\overline{w}_i^{iw} > \overline{w}_i^{fs}$ *or only one firm innovates, i.e.,* $w_{iv}^{iw} > w_{iv}^{fs}$*.*

(b) The increase in the wage of the innovating firm ex-post innovation is always higher under a centralised labour union than under decentralised labour unions if either both firms innovate i.e., $\Delta w^{iw} > \Delta w^{fs}$ *or only one firm innovates,* $\not\Delta w^{iw} > \not\Delta w^{fs}$*.*

Proof. See Appendix (B.1). ∎

Lemma 1 is due to the fact that a centralised labour union internalises competition between the unions that remains under decentralised unions. The wage effects discussed in Lemma 1 helps us to investigate how the severity of *hold-up* problems across unions vary in accordance with the innovator's profit levels. In the next section, we demonstrate the investment game under the three regimes $r = n, fs, iw$ and find out respective profit levels of the firms.

4 The Investment Game

Let $\pi_i^r(.,.)$ denotes the i^{th} firm's profit in the product market where $i = 1, 2$ and the first (second) argument in $\pi_i^r(.,.)$ shows the labour coefficient of firm 1 (firm 2). For example, $\pi_i^r(\phi, 1)$ shows the i^{th} firm's profit in the product market when firm 1 innovates and firm 2 does not. Table 1 summarises the possible strategies of each firm and the realised profits conditional on the innovation decisions.

Table 1

Firm 2 $\rightarrow$ Firm 1 $\downarrow$	R&D	No R&D
R&D	$\pi_1^r(\phi, \phi) - k,$ $\pi_2^r(\phi, \phi) - k$	$\pi_1^r(\phi, 1) - k,$ $\pi_2^r(\phi, 1)$
No R&D	$\pi_1^r(1, \phi),$ $\pi_2^r(1, \phi) - k$	$\pi_1^r(1, 1),$ $\pi_2^r(1, 1)$

The respective pay-off tables under no labour union, decentralised labour unions and a centralised labour union are reported in Appendix A.1, A.2 and A.3 respectively.

The comparison of the above profit levels gives the following results immediately which we summarise in Lemma 2, 3 and 4.

Lemma 2 *If there is no labour union, we get that:*

(a) Both firms innovate if $k < k_L^n$

(b) Only one firm innovates if $k_L^n < k < k_H^n$

(c) Neither firm innovates if $k_H^n < k$

where, $k_L^n = \left[\frac{c\left(2-\gamma^2\right)(1-\phi)\left(2(1-\gamma)(2+\gamma)-c\left(\left(2-\gamma^2\right)(1+\phi)-2\gamma\phi\right)\right)}{\left(4-\gamma^2\right)^2\left(1-\gamma^2\right)}\right]$

and $k_H^n = \left[\frac{c\left(2-\gamma^2\right)(1-\phi)\left(2(1-\gamma)(2+\gamma)-c\left(\left(2-\gamma^2\right)(1+\phi)-2\gamma\right)\right)}{\left(4-\gamma^2\right)^2\left(1-\gamma^2\right)}\right]$.

Proof. See Appendix (B.2). ∎

If $k < k_L^n$, both firms innovate, and we denote this equilibrium by (RD,RD). If $k_H^n < k$, neither firm innovates, and we denote this equilibrium by (No RD,No RD). If $k_L^n < k < k_H^n$, only one firm innovates, and we denote the equilibrium by (RD, No RD) if only firm 1 innovates and by (No RD, RD) if only firm 2 innovates.[4]

We can describe the equilibrium R&D strategy of the firms in terms of non-strategic and strategic benefits from innovation (Roy Chowdhury, 2005). A firm's non-strategic (strategic) benefit from innovation is given by its payoff from innovation, net of its payoff from no innovation, when the competitor firm does not innovate (innovates).

Since the firms are symmetric, without any loss of generality, consider the case of firm 1. If firm 2 does not innovate, firm 1 innovates for $k < k_H^n$, i.e., if firm 1's gross non-strategic benefit from innovation, which is given by k_H^n, is greater than the cost of innovation. However, if firm 2 innovates, firm 1 innovates for $k < k_L^n$, i.e., if firm 1's gross strategic benefit from innovation, which is given by k_L^n, is greater than the cost of innovation.

The above results show that $k_H^n - k_L^n > 0$ i.e., the non-strategic benefit from innovation is higher than the strategic benefit from innovation. The intuition for this is as follows. Innovation has two effects on the profitability of the innovator. On the one hand, it tends to increase the profit of the innovator by reducing labour requirement in production. On the other hand, it tends to reduce the profit of the innovator by imposing an innovation cost that the innovator must incur while innovating. If the cost of innovation is small, the first effect dominates the second effect, and both firms find innovation profitable. As the cost of innovation increases, it reduces a firm's incentive for innovation, given that the other firm innovates, i.e., the strategic benefit from innovation reduces. Now consider that the cost of innovation is such that it is equal to the strategic benefit from innovation. If the cost of innovation increases further, it creates a firm's strategic benefit from innovation lower than the cost of innovation, thus encouraging only one firm to innovate in this situation. As the cost of innovation increases further, it reduces a firm's non-strategic benefit from innovation. If the cost of innovation is very high, a firm's non-strategic benefit from innovation becomes lower than the cost of innovation, and no firm innovates in this situation.

[4] There is also a mixed strategy equilibrium where the firms randomise on innovation and no innovation. However, we focus only on the pure strategy equilibria in this paper.

Lemma 3 *If there are decentralised unions, we get that:*
(a) Both firms innovate if $k < k_L^{fs}$
(b) Only one firm innovates if $k_L^{fs} < k < k_H^{fs}$
(c) Neither firm innovates if $k_H^{fs} < k$
where, $k_L^{fs} = \left[\frac{c\left(2-\gamma^2\right)^2(1-\phi)\left(8-9\gamma^2+2\gamma^4\right)\left(2(1-\gamma)(2+\gamma)\left(4+\gamma-2\gamma^2\right)-c\left(\left(8-9\gamma^2+2\gamma^4\right)+\phi\left(8-4\gamma-9\gamma^2+2\gamma^3+2\gamma^4\right)\right)\right)}{(1-\gamma^2)(4-\gamma^2)^2(16-17\gamma^2+4\gamma^4)^2}\right]$
and, $k_H^{fs} = \left[\frac{c\left(2-\gamma^2\right)^2(1-\phi)\left(8-9\gamma^2+2\gamma^4\right)\left(2(1-\gamma)(2+\gamma)\left(4+\gamma-2\gamma^2\right)-c\left(\left(8-4\gamma-9\gamma^2+2\gamma^3+2\gamma^4\right)+\phi\left(8-9\gamma^2+2\gamma^4\right)\right)\right)}{(1-\gamma^2)(4-\gamma^2)^2(16-17\gamma^2+4\gamma^4)^2}\right].$

Proof. See Appendix (B.3). ■

Knowing that $k_H^{fs} - k_L^{fs} > 0$, the intuition for the equilibrium innovation strategies in Lemma 3 is similar to that of Lemma 2. Like Lemma 2, k_H^{fs} and k_L^{fs} show a firm's gross non-strategic and gross strategic benefits from innovation respectively.

Lemma 4 *If there is a centralised union, we get that:*
(a) Both firms innovate if $k < k_L^{iw}$
(b) Only one firm innovates if $k_L^{iw} < k < k_H^{iw}$
(c) Neither firm innovates if $k_H^{iw} < k$
where, $k_L^{iw} = \left[\frac{c\left(2-\gamma^2\right)(1-\phi)\left(2(1-\gamma)(2+\gamma)-c\left(\left(2-\gamma^2\right)(1+\phi)-2\gamma\phi\right)\right)}{4(4-\gamma^2)^2(1-\gamma^2)}\right]$
and, $k_H^{iw} = \left[\frac{c\left(2-\gamma^2\right)(1-\phi)\left(2(1-\gamma)(2+\gamma)-c\left(\left(2-\gamma^2\right)(1+\phi)-2\gamma\right)\right)}{4(4-\gamma^2)^2(1-\gamma^2)}\right].$

Proof. See Appendix (B.4). ■

As $k_H^{iw} - k_L^{iw} > 0$, the intuition for Lemma 4 is analogous to Lemma 2. Like Lemma 2, k_H^{iw} and k_L^{iw} show a firm's gross non-strategic and gross strategic benefits from innovation respectively.

5 The effects of the unionisation structure

We now focus on the effects of labour union and the labour unionisation structure on innovation. However, the complexity of the critical values of investment shown in Lemmas 2−4 do not allow us to provide a general comparison. Hence, in order to simplify the matter and to make an effective comparison, we take different values of $\gamma \in (0, 1)$ to reflect how product substitutability (which affects the magnitude of product market competition) affects the firm's incentive for innovation. Table 2 shows the resulting outcomes at one-tenth intervals.

Table 2

		Investment rankings
Regime I	$\gamma \to 0$ $\gamma = 0.1$ $\gamma = 0.2$ $\gamma = 0.3$ $\gamma = 0.4$	$k_L^{iw} < k_H^{iw} < k_L^{fs} < k_H^{fs} < k_L^n < k_H^n$
Regime II	$\gamma = 0.43$ $\gamma = 0.5$ $\gamma = 0.6$	$k_L^{iw} < k_L^{fs} < k_H^{iw} < k_H^{fs} < k_L^n < k_H^n$
Regime III	$\gamma = 0.68$ $\gamma = 0.7$ $\gamma = 0.8$ $\gamma = 0.9$ $\gamma \to 1$	$k_L^{iw} < k_L^n < k_L^{fs} < k_H^{fs} < k_H^{iw} < k_H^n$

Table 2 clearly illustrates that no labour union creates higher incentive for innovation if the goods are sufficiently differentiated (i.e. regime I and II) However, if the goods are close substitutes (i.e. regime III), the presence of labour union may create higher incentive for innovation. The outcomes depicted in Table 2 are summarised in Propositions 1−3.

Proposition 1 *If $\gamma \to 0$ and $\gamma \in \{0.1; 0.2; 0.3; 0.4\}$, we get that $k_L^{iw} < k_H^{iw} < k_L^{fs} < k_H^{fs} < k_L^n < k_H^n$.*

Proposition 1 shows that if the products are sufficiently differentiated, the presence of labour unions reduces R&D investments and the incentive for innovation is higher under decentralised labour unions than under a centralised labour union. While innovation helps the innovating firm to increase its market share by stealing business from its competitor, innovation also increases its wage charged by the labour union. If the products are very much differentiated, the business stealing effect is not significant and the wage effects dominate this. Since the wage effect is higher under labour union compared to no labour union and it is higher under a centralised labour unions than under decentralised unions, we get higher incentive for innovation under no labour union followed by decentralised labour unions and a centralised labour union respectively.

Proposition 2 *If $\gamma \in \{0.43; 0.5; 0.6\}$, we get that $k_L^{iw} < k_L^{fs} < k_H^{iw} < k_H^{fs} < k_L^n < k_H^n$.*

The above result considers the case where the products are moderately differentiated. Like Proposition 1, Proposition 2 also shows that the incentive for innovation is higher under no labour union than under any unionisation structure. A comparison across the two unionisation structures shows that the incentive for innovation is higher under decentralised labour unions than under a centralised labour union. The intuition is similar to that of Proposition 1.

Proposition 3 *If* $\gamma \in \{0.68; 0.7; 0.8; 0.9\}$ *and* $\gamma \to 1$*, we get that* $k_L^{iw} < k_L^n < k_L^{fs} < k_H^{fs} < k_H^{iw} < k_H^n$.

Proposition 3 depicts the scenario where the goods are close substitutes. It shows that the incentive for innovation is maximum under no labour union followed by a centralised labour union and decentralised labour unions respectively if at most one firm innovates and innovation occurs at least under no labour union, which occurs for $k \in (k_L^{fs}, k_H^n)$. However, if $k < k_L^{fs}$, i.e., both firms innovate at least under decentralised labour unions, the presence of labour union reduces (increases) the incentive for innovation compared to decentralised labour unions (a centralised labour union). These results suggest that the non-strategic benefit is maximum under no labour union followed by a centralised labour union and decentralised labour unions respectively. However, the strategic benefit for innovation is maximum under decentralised unions followed by no labour union and a centralised labour union respectively.

As mentioned above, innovation creates both the business stealing effect and wage effect even if the goods are close substitutes. However, if the goods are close substitutes, a cost reduction by the innovator helps it to steal a significant amount of the market share from the non-innovator. This strong business stealing effect may play an important role in creating higher incentive for innovation under decentralised labour unions compared to no labour union and under a centralised labour union compared to decentralised labour unions, depending on the number of innovating firms.

To sum up from what follows from above discussions, whether the innovation incentive is higher under no labour union or under decentralised labour unions depends on the degree of product differentiation. It is easy to check that profit increases ex-post innovation under both scenarios $-$ no union and decentralised unions and the profit increases more under no union case than under decentralised unions, i.e., $\overline{\pi}^n - \overline{\pi}^{fs} > 0$. However, this profit difference varies inversely with the degree of product differentiation, i.e., $\frac{\partial(\overline{\pi}^n - \overline{\pi}^{fs})}{\partial\gamma} < 0$.[5] The intuition can be articulated in the following way. γ serves as a proxy of product market competition. When product differentiation reduces, it increases product market competition which has significant effect on the (labour) productivity of the firms. In this situation, decentralised unions bring forth a bigger profit share which is high enough to compensate the bargained wage rate and it restalls the firms' competitiveness in the product market. Hence, the innovation incentives are higher under decentralised unions than under no union case when the goods are homogenous to each other.

The severity of *hold-up* problem across the unions, on the other hand, can be explained in terms of wage effects and profit shares under the two unionised structures. It is straight forward to show that post-innovation profits are higher under decentralised unions than a centralised union irrespective of the degree of product differentiation. Also, recall that innovating firm pays a lower wage rate under decentralised unions (discussed in Lemma 1). Hence, it is obvious that hold-up problem is less severe under decentralised unions which makes innovation more attractive than

[5] The proof is documented in Appendix C.

a centralised union.

The main result of the paper, shown in the following corollary follows immediately from Propositions 1, 2 and 3.

Corollary 1 *(a) The incentive for innovation is higher under no labour union compared to any unionisation structure if the goods are sufficiently differentiated, whereas, the incentive for innovation can be higher under decentralised labour unions than under no labour union if the goods are close substitutes.*

(b) The incentive for innovation is always higher under decentralised labour unions compared to a centralised labour union if the goods are sufficiently differentiated, whereas, the incentive for innovation can be higher under a centralised labour union compared to decentralised labour unions if the goods are close substitutes.

6 Conclusion

In this paper, we show the effects of the labour union and the unionisation structure on the incentive for innovation when the firms compete in prices. The firms' costs are determined endogenously due to the strategic wage determination by the labour unions. We show that the standard conclusion of the literature under Cournot competition showing higher incentive for innovation in the absence of labour unions (Calabuig and Gonzalez-Maestre, 2004) may not hold under Bertrand competition. If the goods are close substitutes, the incentive for innovation can be higher under decentralised labour unions compared to no labour union. Whether the incentive for innovation is higher under decentralised labour unions or under a centralised labour union may also depend on the product substitutability and whether either both firms or only one firm innovate in equilibrium.

To conclude, we note a few possible extensions of this paper. First, there is a possibility where one can assume a mixed duopoly structure where the firms may choose to compete in prices or in quantities. Wage bargaining may have different effects on mixed duopoly model. Secondly, we kept our model simple by assuming that unions bargain over the wage rates only. It will be interesting to investigate the effects of efficient bargaining (i.e. bargaining over wage and employment level) in a similar framework. We leave these for future research.

7 Appendix

In this Appendix, we report the specific profit levels and investment cut-offs under no union, decentralised unions and centralised union respectively and summarise the proofs of Lemma 1−4.

Appendix A: Pay-off tables of the firms

Table A.1: NO UNION CASE

Firm 2 $\rightarrow$ Firm 1 $\downarrow$	R&D	No R&D
R&D	$\left[\left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{1-c\phi}{2-\gamma}\right)^2-k\right]$, $\left[\left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{1-c\phi}{2-\gamma}\right)^2-k\right]$	$\left[\frac{\left((1-\gamma)(2+\gamma)+c\left(\gamma+\gamma^2\phi-2\phi\right)\right)^2}{(4-\gamma^2)^2(1-\gamma^2)}-k\right]$, $\left[\frac{\left((1-\gamma)(2+\gamma)+c\left(\gamma^2+\gamma\phi-2\right)\right)^2}{(4-\gamma^2)^2(1-\gamma^2)}\right]$
No R&D	$\left[\frac{\left((1-\gamma)(2+\gamma)+c\left(\gamma^2+\gamma\phi-2\right)\right)^2}{(4-\gamma^2)^2(1-\gamma^2)}\right]$, $\left[\frac{\left((1-\gamma)(2+\gamma)+c\left(\gamma+\gamma^2\phi-2\phi\right)\right)^2}{(4-\gamma^2)^2(1-\gamma^2)}-k\right]$	$\left[\left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{1-c}{2-\gamma}\right)^2\right]$, $\left[\left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{1-c}{2-\gamma}\right)^2\right]$

Table A.2: DECENTRALISED UNION

Firm 2 $\rightarrow$ Firm 1 $\downarrow$	R&D	No R&D
R&D	$\left[\left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{(2-\gamma^2)(1-c\phi)}{(2-\gamma)(4-\gamma-2\gamma^2)}\right)^2-k\right]$, $\left[\left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{(2-\gamma^2)(1-c\phi)}{(2-\gamma)(4-\gamma-2\gamma^2)}\right)^2-k\right]$	$[\eta_1-k]\,,[\eta_2]$
No R&D	$[\eta_2]\,,[\eta_1-k]$	$\left[\left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{(1-c)\left(2-\gamma^2\right)}{(2-\gamma)(4-\gamma-2\gamma^2)}\right)^2\right]$, $\left[\left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{(1-c)\left(2-\gamma^2\right)}{(2-\gamma)(4-\gamma-2\gamma^2)}\right)^2\right]$

where, $\eta_1=\left[\frac{\left(2-\gamma^2\right)^2\left((1-\gamma)(2+\gamma)(4+\gamma-2\gamma^2))-c\left(8\phi-\gamma\left(2-\gamma^2+9\gamma\phi-2\gamma^3\phi\right)\right)\right)^2}{(1-\gamma^2)(4-\gamma^2)^2(16-17\gamma^2+4\gamma^4)^2}\right]$

and, $\eta_2=\left[\frac{\left(2-\gamma^2\right)^2\left((1-\gamma)(2+\gamma)(4+\gamma-2\gamma^2))-c\left(8-\gamma\left(9\gamma-2\gamma^3+2\phi-\gamma^2\phi\right)\right)\right)^2}{(1-\gamma^2)(4-\gamma^2)^2(16-17\gamma^2+4\gamma^4)^2}\right]$

Table A.3: CENTRALISED UNION

Firm 2 $\rightarrow$ Firm 1 $\downarrow$	R&D	No R&D
R&D	$\left[\frac{1}{4}\left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{1-c\phi}{2-\gamma}\right)^2-k\right],$ $\left[\frac{1}{4}\left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{1-c\phi}{2-\gamma}\right)^2-k\right]$	$\left[\frac{\left(\left(2-\gamma-\gamma^2\right)+c\left(\gamma-\left(2-\gamma^2\right)\phi\right)\right)^2}{4(4-\gamma^2)^2(1-\gamma^2)}-k\right],$ $\left[\frac{\left(\left(2-\gamma-\gamma^2\right)-c(2-\gamma(\gamma+\phi))\right)^2}{4(4-\gamma^2)^2(1-\gamma^2)}\right]$
No R&D	$\left[\frac{\left(\left(2-\gamma-\gamma^2\right)-c(2-\gamma(\gamma+\phi))\right)^2}{4(4-\gamma^2)^2(1-\gamma^2)}\right],$ $\left[\frac{\left(\left(2-\gamma-\gamma^2\right)+c\left(\gamma-\left(2-\gamma^2\right)\phi\right)\right)^2}{4(4-\gamma^2)^2(1-\gamma^2)}-k\right]$	$\left[\frac{1}{4}\left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{1-c}{2-\gamma}\right)^2\right],$ $\left[\frac{1}{4}\left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{a-c}{2-\gamma}\right)^2\right]$

Appendix B: Proofs of Lemma 1–4

(B.1) Proof of Lemma 1

(B.1a) Proof of Lemma 1(a)

$$
\begin{aligned}
\overline{w}_i^{iw}-\overline{w}_i^{fs} &= \tfrac{1+c\phi}{2\phi}-\tfrac{(1-\gamma)(2+\gamma)+c\phi\left(2-\gamma^2\right)}{\phi(4-\gamma-2\gamma^2)} \\
&= \tfrac{\gamma(1-c\phi)}{2\phi(4-\gamma-2\gamma^2)}>0
\end{aligned}
$$

$$
\begin{aligned}
w_{iv}^{iw}-w_{iv}^{fs} &= \tfrac{1+c\phi}{2\phi}-\tfrac{(1-\gamma)(2+\gamma)(4+\gamma-2\gamma^2)+c(2-\gamma^2)(\gamma+4\phi-2\gamma^2\phi)}{\phi(4+\gamma-2\gamma^2)(4-\gamma-2\gamma^2)} \\
&= \tfrac{\gamma\left(2(1-c)(2-\gamma^2)+\gamma(1-c\phi)\right)}{2\phi(4+\gamma-2\gamma^2)(4-\gamma-2\gamma^2)}>0
\end{aligned}
$$

(B.1b) Proof of Lemma 1(b)

First, we consider the wage difference of the innovating firm across the two unionised structures when no firm innovates and both firms innovate.

$$
\begin{aligned}
\Delta w^{iw} &= \overline{w}_i^{iw}-\widehat{w}_i^{iw}=\tfrac{1+c\phi}{2\phi}-\tfrac{1+c}{2}=\tfrac{1-\phi}{2\phi} \\
\Delta w^{fs} &= \overline{w}_i^{fs}-\widehat{w}_i^{fs}=\tfrac{(1-\gamma)(2+\gamma)+c\phi\left(2-\gamma^2\right)}{\phi(4-\gamma-2\gamma^2)}-\tfrac{(1-\gamma)(2+\gamma)+c\left(2-\gamma^2\right)}{(4-\gamma-2\gamma^2)}=\tfrac{(1-\gamma)(2+\gamma)(1-\phi)}{\phi(4-\gamma-2\gamma^2)}
\end{aligned}
$$

Hence, $\Delta w^{iw}-\Delta w^{fs}=\tfrac{\gamma(1-\phi)}{2\phi(4-\gamma-2\gamma^2)}>0$

Next, we consider the wage differential of the innovating firm across the unions when no firm innovates and only firm innovates.

$$
\begin{aligned}
\not\Delta w^{iw} &= w_{iv}^{iw}-\widehat{w}_i^{iw}=\tfrac{1+c\phi}{2\phi}-\tfrac{1+c}{2}=\tfrac{1-\phi}{2\phi} \\
\not\Delta w^{fs} &= w_{iv}^{fs}-\widehat{w}_i^{fs}=\tfrac{(1-\gamma)(2+\gamma)(4+\gamma-2\gamma^2)+c(2-\gamma^2)(\gamma+4\phi-2\gamma^2\phi)}{\phi(4+\gamma-2\gamma^2)(4-\gamma-2\gamma^2)}-\tfrac{(1-\gamma)(2+\gamma)+c\left(2-\gamma^2\right)}{(4-\gamma-2\gamma^2)} \\
&= \tfrac{\left(8-2\gamma+2c\gamma-9\gamma^2+\gamma^3-c\gamma^3+2\gamma^4\right)(1-\phi)}{\phi(4+\gamma-2\gamma^2)(4-\gamma-2\gamma^2)}
\end{aligned}
$$

Hence, $\not\Delta w^{iw} - \not\Delta w^{fs} = \frac{\gamma(1-\phi)\left(2\left(2-\gamma^2\right)(1-c)+\gamma\right)}{2\phi(4+\gamma-2\gamma^2)(4-\gamma-2\gamma^2)} > 0$

(B.2) Proof of Lemma 2

Under *no union case*, we use the profit levels of firm 1 and firm 2 stated in *Table A.1* to derive the following equilibrium conditions:

(RD,RD), i.e., both firms innovating is an equilibrium when

$$\begin{aligned} k < k_L^n &= \left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{1-c\phi}{2-\gamma}\right)^2 - \frac{\left((1-\gamma)(2+\gamma)+c\left(\gamma^2+\gamma\phi-2\right)\right)^2}{(4-\gamma^2)^2(1-\gamma^2)} \\ &= \frac{c\left(2-\gamma^2\right)(1-\phi)\left(2(1-\gamma)(2+\gamma)-c\left(\left(2-\gamma^2\right)(1+\phi)-2\gamma\phi\right)\right)}{(4-\gamma^2)^2(1-\gamma^2)} \end{aligned}$$

(No RD,No RD), i.e., neither firm innovating is an equilibrium when

$$\begin{aligned} k > k_H^n &= \frac{c\left(2-\gamma^2\right)(1-\phi)\left(2(1-\gamma)(2+\gamma)-c\left(\left(2-\gamma^2\right)(1+\phi)-2\gamma\phi\right)\right)}{(4-\gamma^2)^2(1-\gamma^2)} - \frac{c\left(2-\gamma^2\right)(1-\phi)\left(2(1-\gamma)(2+\gamma)-c\left(\left(2-\gamma^2\right)(1+\phi)-2\gamma\right)\right)}{(4-\gamma^2)^2(1-\gamma^2)} \\ &= \frac{c\left(2-\gamma^2\right)(1-\phi)\left(2(1-\gamma)(2+\gamma)-c\left(\left(2-\gamma^2\right)(1+\phi)-2\gamma\right)\right)}{(4-\gamma^2)^2(1-\gamma^2)} \end{aligned}$$

(RD,No RD) or (No RD,RD), i.e., either firm innovating is an equilibrium when

$k_L^n < k < k_H^n$ where, $k_H^n - k_L^n = \frac{2c^2\gamma\left(2-\gamma^2\right)(1-\phi)^2}{(4-\gamma^2)^2(1-\gamma^2)} > 0$

(B.3) Proof of Lemma 3

Under *decentralised union case*, we use the profit levels of firm 1 and firm 2 stated in *Table A.2* to derive the following equilibrium conditions:

(RD,RD), i.e., both firms innovating is an equilibrium when

$$\begin{aligned} k < k_L^{fs} &= \left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{(2-\gamma^2)(1-c\phi)}{(2-\gamma)(4-\gamma-2\gamma^2)}\right)^2 - \eta_2 \\ &= \left[\frac{c\left(2-\gamma^2\right)^2(1-\phi)\left(8-9\gamma^2+2\gamma^4\right)\left(2(1-\gamma)(2+\gamma)\left(4+\gamma-2\gamma^2\right)-c\left(\left(8-9\gamma^2+2\gamma^4\right)+\phi\left(8-4\gamma-9\gamma^2+2\gamma^3+2\gamma^4\right)\right)\right)}{(1-\gamma^2)(4-\gamma^2)^2(16-17\gamma^2+4\gamma^4)^2}\right] \end{aligned}$$

(No RD,No RD), i.e., neither firm innovating is an equilibrium when

$$\begin{aligned} k > k_H^{fs} &= \left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{(1-c)\left(2-\gamma^2\right)}{(2-\gamma)(4-\gamma-2\gamma^2)}\right)^2 - \eta_1 \\ &= \left[\frac{c\left(2-\gamma^2\right)^2(1-\phi)\left(8-9\gamma^2+2\gamma^4\right)\left(2(1-\gamma)(2+\gamma)\left(4+\gamma-2\gamma^2\right)-c\left(\left(8-4\gamma-9\gamma^2+2\gamma^3+2\gamma^4\right)+\phi\left(8-9\gamma^2+2\gamma^4\right)\right)\right)}{(1-\gamma^2)(4-\gamma^2)^2(16-17\gamma^2+4\gamma^4)^2}\right] \end{aligned}$$

(RD,No RD) or (No RD,RD), i.e., either firm innovating is an equilibrium when

$k_L^{fs} < k < k_H^{fs}$ where, $k_H^{fs} - k_L^{fs} = \frac{2c^2\gamma\left(2-\gamma^2\right)^3(1-\phi)^2\left(8-9\gamma^2+2\gamma^4\right)}{(1-\gamma^2)(4-\gamma^2)^2(16-17\gamma^2+4\gamma^4)^2} > 0$

(B.4) Proof of Lemma 4

Under a *centralised union*, we use the profit levels of firm 1 and firm 2 stated in *Table A.3* to derive the following equilibrium conditions:

(RD,RD), i.e., both firms innovating is an equilibrium when

$$k < k_L^{iw} = \frac{1}{4}\left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{1-c\phi}{2-\gamma}\right)^2 - \frac{\left((1-\gamma)(2+\gamma)+c\left(\gamma^2+\gamma\phi-2\right)\right)^2}{4(4-\gamma^2)^2(1-\gamma^2)}$$
$$= \frac{c\left(2-\gamma^2\right)(1-\phi)\left(2(1-\gamma)(2+\gamma)-c\left(\left(2-\gamma^2\right)(1+\phi)-2\gamma\phi\right)\right)}{4(4-\gamma^2)^2(1-\gamma^2)}$$

(No RD,No RD), i.e., neither firm innovating is an equilibrium when

$$k > k_H^{iw} = \frac{c\left(2-\gamma^2\right)(1-\phi)\left(2(1-\gamma)(2+\gamma)-c\left(\left(2-\gamma^2\right)(1+\phi)-2\gamma\phi\right)\right)}{4(4-\gamma^2)^2(1-\gamma^2)} - \frac{c\left(2-\gamma^2\right)(1-\phi)\left(2(1-\gamma)(2+\gamma)-c\left(\left(2-\gamma^2\right)(1+\phi)-2\gamma\right)\right)}{4(4-\gamma^2)^2(1-\gamma^2)}$$
$$= \frac{c\left(2-\gamma^2\right)(1-\phi)\left(2(1-\gamma)(2+\gamma)-c\left(\left(2-\gamma^2\right)(1+\phi)-2\gamma\right)\right)}{4(4-\gamma^2)^2(1-\gamma^2)}$$

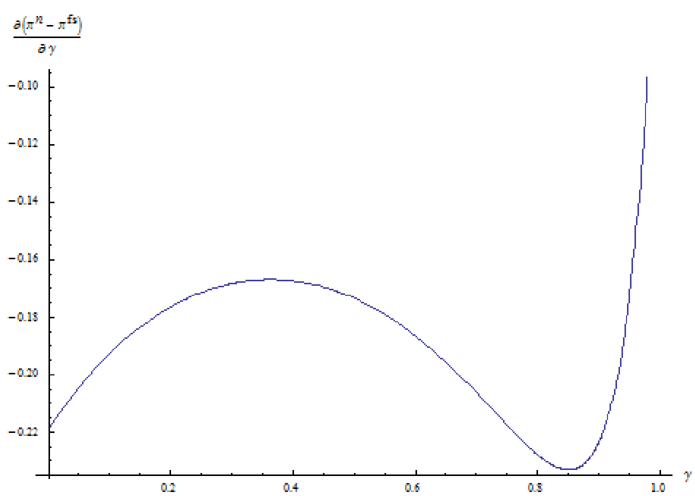
(RD,No RD) or (No RD,RD), i.e., either firm innovating is an equilibrium when $k_L^{iw} < k < k_H^{iw}$ where, $k_H^{iw} - k_L^{iw} = \frac{c^2\gamma\left(2-\gamma^2\right)(1-\phi)^2}{2(4-\gamma^2)^2(1-\gamma^2)} > 0$

Appendix C

Appendix C: Proof of $\frac{\partial(\overline{\pi}^n-\overline{\pi}^{fs})}{\partial\gamma} < 0$

$$\overline{\pi}^n - \overline{\pi}^{fs} = \left[\left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{1-c\phi}{2-\gamma}\right)^2 - k\right] - \left[\left(\frac{1-\gamma}{1+\gamma}\right)\left(\frac{(2-\gamma^2)(1-c\phi)}{(2-\gamma)(4-\gamma-2\gamma^2)}\right)^2 - k\right]$$
$$= \frac{\left(1-\gamma^2\right)(2+\gamma)\left(6-\gamma-3\gamma^2\right)(1-c\phi)^2}{(2-\gamma^2)(1+\gamma)(4-\gamma-2\gamma^2)^2} > 0$$

$$\frac{\partial(\overline{\pi}^n-\overline{\pi}^{fs})}{\partial\gamma} = -\frac{2(1-\gamma)\left(56-40\gamma-16\gamma^2+47\gamma^3-28\gamma^4-25\gamma^5+12\gamma^6+6\gamma^7\right)}{(2-\gamma)^3(1+\gamma)^2(4-\gamma-2\gamma^2)^3} < 0$$



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