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ISSN 1750-4171

**DEPARTMENT OF ECONOMICS**

**DISCUSSION PAPER SERIES**

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Oligopoly with Spillovers**

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**WP 2007 - 04**

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# The Temporal Dimension of Wage Contracts in Oligopoly with Spillovers

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## Abstract

This paper examines how the duration of wage contracts influences innovation incentives, wages and employment. We find that wages are non-monotone in the duration of wage contracts. Furthermore, a positive and one-to-one relation between innovation and union utility exists and both attain their highest value under a long-term contract. Profits may vary depending on the extent of R&D spillovers and the associated raising rivals' cost incentive, although they are highest when union/firms engage in a long-term contractual relation. Testable predictions to discriminate between short-term and long-term contracts are also discussed.

*Keywords:* Wage contracts; R&D; Spillovers; Raising rivals' cost.

*JEL Classification:* J41; J51; L13; O31.

## 1 Introduction

There is an ever increasing interest in the investigation of the relation between unionism and spending on R&D. However, despite the large body of theoretical and empirical studies on this issue, the findings so far seem to paint a mixed picture. On the one hand, slowed down growth rates have often been attributed to the unions rent-extraction (Grout 1984; Manning 1987; Ulph and Ulph 1994). On the other hand, unions are perceived as institutions with constructive presence. In this respect, they smooth industrial relations, encourage greater employee training

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and therefore, accelerate new technology adoption (Tauman and Weiss 1987; Ulph and Ulph 1998; Haucap and Wey 2004). Apart from such behavioural considerations that may occasionally encourage or deter innovation, equally as important are other factors in influencing innovation incentives: the *temporal dimension* of wage contracts may be regarded as such.

The large body of union-oligopoly literature has dealt extensively only with specific aspects of innovative activity and labour market organisation. First, most of the studies postulate that wage negotiations take place at firm-level. Haucap and Wey (2004) report that: “As this literature has focused exclusively on decentralised modes of wage setting...the relative performance of more centralised wage systems remains an open issue...”. Second, R&D has usually been modelled as a patent race, where the firm first to innovate is rewarded by a perfect patent.<sup>1</sup> Third, there is relatively scant attention on how the temporal dimension (or timing) of wage setting may affect innovation.

The main purpose of the present paper is to investigate how the duration of wage contracts affects innovation incentives by addressing these issues within a single model. Barcena-Ruiz and Campo (2004) examine the relation between the timing of wage setting and innovation under decentralised wage-setting at the firm-level. They found that when the size of the market is sufficiently large and the R&D technology is relatively efficient, then unions may choose to set wages simultaneously; in this case, the R&D investment becomes largest. Haucap and Wey (2004) analyse the effect of unionisation structures on innovation incentives and uncover a non-monotone relation between the level of wage setting and innovation incentives. Another study closely related to the present one is Banerjee and Lin (2003). They consider a two-tier market structure where the downstream firms engage in cost-reducing R&D. The focus of the analysis is the relation between input price contracts and innovation incentives. In line with our analysis, they obtain that long-term input price contracts promote innovation and enhance welfare. Although the case of (upstream) input suppliers encompasses labour unions as a special case, the study by Banerjee and Lin did not allow for R&D spillovers. Finally, Manasakis and Zikos (2007) explored the unions/firms incentives to form Research Joint Ventures (RJV), while allowing the possibility for rent-sharing. They found that firms have incentives to form an RJV when spillovers are sufficiently large and that unions will approve the RJV formation; however, if spillovers are relatively small, firms have to part with some rents to make the RJV attractive to unions and this will weaken their incentives.

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<sup>1</sup>See, for instance, Ulph and Ulph (1994, 2001) and Haucap and Wey (2004).

As a framework for analysing the relation between wage contracts and innovation, we consider a model with a central union<sup>2</sup> and  $n$  firms in vertical disposition. The basic set-up is, in principle, a straightforward extension of Banerjee and Lin (2003) by relaxing their (implicit) assumption of perfect patent protection with the addition of R&D spillovers. Furthermore, apart from exploring the desirable contract from each party's (union/firms) perspective, we address the issue of which contract is more likely to be adopted in equilibrium. In making such predictions we utilise the observable delay game of Hamilton and Slutsky (1990), where in stage one both parties simultaneously announce at which period they will move (and commit to this decision); at the following stage(s) both parties choose their decision variables according to their previous announcements and finally, all firms choose their output levels.

More precisely, the present paper assumes that there is a central union representing the industry workers. The union sets the wage whereas firms retain the right to choose employment (see Booth 1995; Haucap and Wey 2004). Firms compete both in the output and in the R&D market where they invest in cost reducing R&D with a two-fold perspective: (i) to reduce own costs in the first place and (ii) to raise their rivals' costs (RRC), if possible. The second innovation incentive may only arise under ex post (or short-term) contracting.<sup>3</sup> This case is modelled as a three-stage game. That is, the firms first choose their R&D levels. The union then chooses its wage level at the second stage<sup>4</sup> and firms compete in output at the third stage. In this situation, the wage contract is conditioned on the amount of R&D. Indeed, the implied flexibility over the terms of contract reduces the benefits from R&D, thus leading to a lower investment. On the other hand, a long-term contractual relation reflects a wage that is specified before the firms' investment decisions. More precisely, we consider that in the first stage the union sets the wage and in the second stage firms choose their R&D levels. Finally, as under a short-term contract, firms choose their output levels. A comparison of the two games reveals that although under long-term contracting the RRC effect vanishes, this type of contract promotes innovation, as it implies a disciplinary effect on the

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<sup>2</sup>Centralised wage-setting at an industry level is common practise eg., in the Nordic countries, in Germany and Ireland. In other instances, it is possible that wage negotiations take place at firm-level, although with certain elements of centralised negotiations, eg., UK and Spain (see, Mauleon and Vannetelbosch 2003).

<sup>3</sup>The reasons that justify a short-term relation are for instance, the absence of reputation effects or repeated interaction, as well as the inability to commit not to renegotiate an ex ante contract (see Ulph and Ulph 2001, for a more detailed discussion).

<sup>4</sup>Unions will generally behave with a shorter-term horizon compared with the firms' shareholders (Baldwin 1983). This observation suggests an opportunistic behaviour when short-term wage contracts are signed, which comes into effect after investment is sunk.

union wage demands. Moreover, a long-term contract may make all parties – firms and the trade union – better off by generating a greater cost reduction that will unambiguously expand available employment opportunities and improve welfare. We also show that a long-term contract will indeed be chosen in equilibrium when the union/firms respective decisions are endogenised.

The rest of the paper is organised as follows. The formal analytical framework is presented in section 2. Sections 3 and 4 deal, respectively, with the cases of short-term and long-term wage contracts, while section 4 compares them with a medium-term contract. Section 5 extends the basic model by endogenising the decision on the contract type. Finally, section 6 concludes and presents our testable predictions with a view to distinguishing in practice among the various types of contractual relations.

## 2 The model

We consider a unionised industry that consists of a single labour union and  $n$  firms indexed by  $i = 1, \dots, n$ , producing a homogeneous good. We postulate a two-tier industry where the union is at the upstream tier and the  $n$  firms at the downstream. The inverse demand function is of the standard form  $p = a - \sum_{i=1}^n q_i$ , for  $\sum_{i=1}^n q_i \leq a$ . The production process involves only labour as an input and one unit of a final good requires exactly one unit of labour. That is, all firms are endowed with linear one-factor technologies,  $q_i = \alpha_i L_i$ , where  $\alpha_i$  is firm  $i$ 's productivity of labour.<sup>5</sup> Without loss of generality, we assume that labour productivity is identical across firms and normalised to unity, i.e.,  $\alpha_i = 1$ .

The marginal cost of production is initially constant at  $c + w > 0$ , where  $w$  denotes the industry-wide wage and  $c$  is the uniform marginal cost of transforming one unit of labour input into one unit of the final product. However, firms have the opportunity to lower their marginal cost from  $c + w$  to  $c + w - x_i$ ,  $0 < x_i < c + w$ , via investing in process R&D. The cost of such activity is assumed to be quadratic,  $x_i^2$ , reflecting that process innovation takes place at decreasing returns.<sup>6</sup> In addition, there are inter-firm spillover effects that induce a further reduction in

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<sup>5</sup>This one-to-one form of technology is equivalent to a two-factor Leontief technology with the capital being fixed (in the short-run) and large enough to avoid driving the marginal product of labour to zero (see eg., Petrakis and Vlassis 2005; Manasakis and Zikos 2007).

<sup>6</sup>The adoption of a quadratic cost function alleviates to some extent the ‘hold-up’ problem that may arise in a unionized industry when firms have the opportunity to undertake an investment project (i.e., sink a specific amount of money) in order to implement a new technology that lowers their production cost. In our model, it remains in the firms’ discretion to decide how much to invest and therefore determine how severe the ‘hold-up’ will be.

a firm's marginal cost. Thus, the marginal cost borne by firm  $i$  is

$$c_i(x_i, x_{-i}) = w + c - x_i - \beta x_{-i}, \quad x_{-i} = \sum_{j \neq i} x_j, \quad (1)$$

where  $\beta$  captures the extent of spillover effects. The following assumption is made:

*Assumption 1.* Let  $A = a - c$  be a measure of the market size. Given that  $0 \leq \beta \leq 1$ , we have that (i)  $0 \leq w < A$  and (ii)  $x_i + \beta x_{-i} \leq w + c$ .

Part (i) implies that firms have always an incentive to hire workers, while part (ii) ensures an economically meaningful investment level. This assumption is maintained throughout the rest of the paper.

The labour market is unionized and all workers are assumed to be identically skilled. Moreover, a central union represents all industry workers with the objective of *rent maximization* for its risk-neutral members, given fixed union membership (see Booth 1995 and Oswald 1982).<sup>7</sup> Hence, the utility function of the central union can be written as

$$U = \sum_{i=1}^n (w - w_0) L_i, \quad 0 < w_0 < A, \quad (2)$$

where  $w_0$  is the workers' reservation wage<sup>8</sup> and  $L_i$  is the employment level of firm  $i$ .

We analyse and compare two three-stage games.

(i) The *long-term wage contract* ( $l$ ). In this case, the union sets the wage in stage one. Firms then choose their R&D levels at the second stage and compete in output at the third stage.

(ii) The *short-term wage contract* ( $s$ ). The firms choose their R&D levels; then the union sets the wage and finally firms choose their output levels.

Under both scenarios, the union has all the power to decide the wage rate subject to the firms' labour demand curves, while each firm then simply determines from its labour demand curve the level of employment at the specified wage (so-

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<sup>7</sup>Fixed union membership amounts to saying that the central union operates as a *closed shop*, that is a worker displaced from a firm may be able to find a job in another firm. Furthermore, any worker employed in our model-industry will receive the wage rate being the outcome of the union-firms interaction. This latter observation gives rise to the raising rivals' cost potential between the downstream competitors via spending on R&D – as we shall see.

<sup>8</sup>In the union-oligopoly literature, a worker's outside option, given that all workers are identically skilled, is usually conceptualized as a weighted average of the competitive wage and unemployment benefits, where the respective weights are the probabilities of finding or not a job in the competitive sector. It is worth noting that within our model-economy, we do not treat explicitly the competitive (or numeraire) sector, as it is not crucial for our results.

called monopoly-union model). Our objective is to obtain a Subgame Perfect Nash Equilibrium (SPNE) of those games by backward induction.

The profit function of firm  $i$  is

$$\pi_i = (a - q_i - q_{-i})q_i - (c + w - x_i - \beta x_{-i})q_i, \quad q_{-i} = \sum_{j \neq i} q_j. \quad (3)$$

Maximizing profits with respect to  $q_i$  gives rise to the first order condition (foc)

$$A - 2q_i - q_{-i} - w + x_i + \beta x_{-i} = 0. \quad (4)$$

Introducing symmetry  $q_i = q_j$  and solving the system of the  $n$  focs as in (4), we obtain firm  $i$ 's equilibrium output

$$q_i(x_i, x_{-i}, w) = \frac{n(A - w) + (2 + n - 2\beta)x_i + [n\beta - \frac{2(1-\beta)}{n-1}]x_{-i}}{n(n+1)}. \quad (5)$$

Equilibrium profits and employment, given R&D investment and wage determined at the preceding stages of the game, are

$$\pi_i(x_i, x_{-i}, w) = [q_i(x_i, x_{-i}, w)]^2, \quad L_i(x_i, x_{-i}, w) = q_i(x_i, x_{-i}, w). \quad (6)$$

The solution to the firms' R&D maximization problem along with the union's choice of a wage are closely characterised in the next two sections.

### 3 Short-term wage contracts

In the second stage of the game, the central union chooses  $w$  to maximize its objective (2). Solving this maximization problem, we obtain the industry-wide equilibrium wage<sup>9</sup>

$$w(x_i, x_{-i}) = \frac{n(A + w_0) + [1 + (n - 1)\beta](x_i + x_{-i})}{2}. \quad (7)$$

The wage increases with the workers reservation income,  $w_0$ . More interestingly, it increases with the firms' R&D efforts,  $x_i$  and  $x_{-i}$ . That is, a greater R&D effort promotes the demand for labour and leads to a higher wage at higher level of employment. The following lemma summarizes.

**Lemma 1** *In an oligopoly ( $n \geq 2$ ) with linear demand and informational spillovers,*

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<sup>9</sup>The second order condition (soc) reads as  $-2n/(1+n) < 0$ .

under a short-term wage contract, the wage and each firm's R&D investment is a strategic complement from the central union's perspective.

Substituting  $w$  into (5) and (6) yields equilibrium output, profits and employment. Then at the R&D stage of the game, the profit function of firm  $i$  is given by  $\pi_i(x_i, x_{-i}) = (q_i)^2 - x_i^2$ . Maximizing the relevant expression with respect to  $x_i$  and imposing symmetry  $x_i = x_j$ , yields the  $i$ -th firm's equilibrium investment<sup>10</sup>

$$x_i^s = \frac{(A - w_0)[1 + n(1 + n(1 - \beta)) - \beta]}{\Omega}, \quad (8)$$

where  $\Omega = -(1 - \beta)^2 + n(3 + \beta^2) + n^2(7 + \beta(1 - \beta)) + n^3(4 - \beta(1 - \beta)) > 0$ . Using (8) and the expressions for output and wage, (5) and (7), we obtain

$$q_i^s = \frac{2n(1 + n)(A - w_0)}{\Omega}, \quad (9)$$

$$w^s = \frac{2n(1 + n)^2 A + w_0 \Lambda}{\Omega}, \quad (10)$$

where  $\Lambda = -(1 - \beta)^2 + n(1 + \beta^2) + n^2(3 + \beta(1 - \beta)) + n^3(2 - \beta(1 - \beta)) > 0$ . Then from (9), (10) and (2) we can find union utility

$$U^s = \sum_{i=1}^n (w^s - w_0) q_i^s = \frac{4n^3(1 + n)^3(A - w_0)^2}{\Omega^2}. \quad (11)$$

Finally, each firm will make profit

$$\pi_i^s = \frac{(A - w_0)^2 \Delta}{\Omega^2}, \quad (12)$$

where  $\Delta = -2n(1 - \beta) - (1 - \beta)^2 + n^2(1 + 2\beta(2 - \beta)) + 2n^3(3 + \beta) + n^4(3 + \beta(2 - \beta)) > 0$ .

## 4 Long-term wage contracts

We now turn to investigate the case where the central union ex ante commits to a certain wage. The output selection stage of the game is the same as for the previous market arrangement. In the second stage, however, each firm maximizes

<sup>10</sup>The soc is  $-[4n^4 + 3(1 - \beta)^2 + na_1 + 2n^3a_2 - n^2a_3]/2n^2(1 + n)^2 < 0$ , where  $a_1 = 2 - 6\beta + 4\beta^2$ ,  $a_2 = 2 + 3\beta - \beta^2$ ,  $a_3 = 2 - 10\beta + 5\beta^2$ . It is readily verified that this requirement is always fulfilled.

profits with respect to  $x_i$  given  $x_{-i}$ . That is,

$$\max_{x_i} \left\{ \frac{n(A-w) + (2+n-2\beta)x_i + [n\beta - \frac{2(1-\beta)}{n-1}]x_{-i}}{n(n+1)} \right\}^2 - x_i^2.$$

The solution to the focs yields equilibrium investment as a function of the industry wage<sup>11</sup>

$$x_i(w) = \frac{(A-w)[(2+n^2)(1-\beta) + n(1+\beta)]}{L}, \quad (13)$$

where  $L = -2(1-\beta)^2 + n(1-\beta(2-3\beta)) + n^2(1+\beta)(3-2\beta) + n^3(2-\beta(1-\beta)) > 0$ . Notice that the R&D reaction function of each downstream firm has a negative slope: when the union opts for a higher wage, this reduces the rents available for spending on R&D, thereby leading to a lower investment.

**Lemma 2** *Given that  $n \geq 2$ , under a long-term wage contract, the wage and each firm's R&D investment is a strategic substitute from each firm's perspective.*

This result, in conjunction with the one in the previous lemma, portrays the union/firms conflicting objectives. Moreover, it suggests that an alternative order of moves (i.e., the duration of wage contracts) may give rise to different results, highlighting the importance of union/firm roles in the potential contractual agreements.

In the first stage, the union chooses the wage that maximizes its rents, anticipating how its decision will affect the firms' choice at the R&D selection stage. The solution to this problem is<sup>12</sup>

$$w^l = \frac{A + w_0}{2}. \quad (14)$$

Then the SPNE solutions of the entire game follow

$$x_i^l = \frac{(A-w_0)[(2+n^2)(1-\beta) + n(1+\beta)]}{2L} \quad (15)$$

$$q_i^l = \frac{n(1+n)(A-w_0)}{L} \quad (16)$$

$$U^l = \sum_{i=1}^n (w^l - w_0)q_i^l = \frac{n^2(1+n)(A-w_0)^2}{2L} \quad (17)$$

$$\pi_i^l = \frac{(A-w_0)^2 \Phi}{4L^2}, \quad (18)$$

<sup>11</sup>With soc  $-[2/n((1+n)^2)][n^3 + n^2(1+\beta) - n(1-3\beta+2\beta^2) - 2\beta(1-\beta)] < 0$ .

<sup>12</sup>The soc requires  $-4n^2(1+n)/L < 0$ .

where  $\Phi = -4(1-\beta)^2 - 4n(1-\beta^2) - n^2(1-\beta(6-5\beta)) + 2n^3(3+\beta^2) + n^4(3+\beta(2-\beta)) > 0$ .

In order to facilitate comparison between the two contractual regimes presented so far, we proceed by computing the SPNE outcome of a game termed as *medium-term wage contract* ( $m$ ). That game has two stages. In stage one the union and firms act simultaneously so as to maximize their objectives and in the second stage firms compete in quantities à la Cournot. The solution of this game is relegated to the Appendix A1.

## 5 Comparing the wage contracts

We proceed to classify the wage and employment levels depending on the mode of the union/firms moves (i.e., type of wage contract). The following Proposition presents the result:

**Proposition 1** *For all  $n \geq 2$ , a long-term wage contract induces the lowest wage but the highest employment. That is, the following ordering obtains:*

- (i)  $w^l < w^s < w^m$ ,
- (ii)  $L_i^s < L_i^m < L_i^l$ .

Proposition 1 shows the different effects that the timing of wage-setting implies on wages and employment. Under a medium-term contract workers are entitled to the highest wage, while the lowest wage is due to a long-term contract. This ordering suggests that the relation between wages and the duration of wage contracts is non-monotone. That is, wages are intermediate for a short-term arrangement and highest for a medium-term one. Comparing the wage rates for a short-term and a long-term contract, we find that the former is always dominant. The rationale is simple: under a long-term arrangement the wage is not conditioned on the amount of R&D investment.<sup>13</sup> This means that a short-term contract reflects an opportunistic behaviour by the trade union – in response to downstream innovation. By raising the wage level after firms have invested in R&D, the central union is therefore able to extract some rents of the innovative activity. Regarding employment levels, our finding is also intuitively appealing, indicating that firms are willing to hire the most workers under the  $l$  structure.

These predictions may also suggest the type of contract that is most conducive to innovation. As firms recognize ex ante the opportunistic behaviour of the trade

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<sup>13</sup>In other words, under a long-term wage contract, the central union commits credibly to a wage level (which remains unaltered after firms have invested in R&D).

union under a short-term arrangement, they would be willing to undertake larger investments under a credible commitment on the wage level, namely a long-term contract. We can therefore state the following result:

**Proposition 2** *A long-term contract generates the largest innovation; i.e.,  $x_i^l > x_i^m > x_i^s$ .*

Proposition 2 shows that a long-term arrangement generates the largest incentives for R&D. The reason is that under this contractual regime, the problem arising due to the opportunistic behaviour of the trade union (i.e., setting a higher wage due to the firms' innovation) vanishes. In turn, this may suggest that a long-term settlement promotes innovation compared with any other type of (shorter-term) agreement, where the wage rate may not be ex ante guaranteed.

We are now in position to characterize the union's preferences over the set of wage contracts, were the union able to choose one. The next Proposition offers the result:

**Proposition 3** *Under a long-term contract the central union's wage bill is maximized; i.e.,  $U^l > U^m > U^s$ .*

From Proposition 1, the relevant forces to determine the size of the *wage bill* (above the reservation wage) are the wage and the employment levels. It turns out that the latter has a larger impact on union utility: although wages are the lowest under a long-term contract, employment is the highest among all possible regimes. This observation suggests that credible commitment over the terms of wage-setting is therefore the union's most preferred choice.

Combining Propositions 2 and 3, we can readily identify a positive and one-to-one relation between investment and union utility. That is, a long-term contract carries the largest innovation incentives and union utility levels. The reason for this is simple: the union recognising that firms will be willing to undertake larger investment projects under a long-term contract, decides to commit to a certain wage. This also means that the union anticipates to be 'compensated' for its commitment via higher employment. Finally, it is worth mentioning that the union will be granted these benefits on the basis of a simple 'mechanism': a larger amount invested in R&D will reduce the marginal cost, increase the demand for the final good, thus resulting in greater employment (and union utility).

All contract types imply a *relative* cost advantage<sup>14</sup> for a firm (over its rivals) via spending on R&D. Restricting attention for a moment to a short-term and a long-

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<sup>14</sup>It is worth noting that an *absolute* cost advantage for a downstream firm under a short-term contract would only arise if innovation was fully protected against imitation, i.e.,  $\beta = 0$ .

term contract, we know that in the former case, it remains in the union's discretion to adjust the wage in response to R&D. Hence, as pointed out in the introduction, an R&D investment by firm  $i$  will affect its own profit in two ways: (a) by raising its rivals' costs (through the union's response to R&D) and (b) by lowering own costs. On the grounds of Proposition 1 (i) and 2, the effect described in (a) is largest under regime  $m$  (but lowest under regime  $l$ ), while regime  $l$  generates the largest effect in (b). It turns out, however, that the effect (on firms' profits) described in (b) will always dominate the effect in (a). This explains the content of part (i) in the following Proposition, which presents an ordering of firms' profits:

**Proposition 4** (i) *A long-term contract leads to the highest profits,  $\pi_i^l > \pi_i^s, \pi_i^l > \pi_i^m$ , and will be always preferred by firms.*

(ii) *There exists a threshold value  $\tilde{\beta}(n)$  such that  $\pi_i^s > \pi_i^m$  if  $\beta < \tilde{\beta}(n)$  and  $\pi_i^s < \pi_i^m$  if  $\beta > \tilde{\beta}(n)$ . The critical value is decreasing in the number of firms in the industry.*

Interestingly, the ranking in part (ii) depends on the extent of spillovers. As mentioned previously in (a), each downstream firm has an incentive to raise its rivals' costs. For a short-term contract this opportunity is present, while it vanishes both for a long-term and a medium-term contract. According to Proposition 4 (ii), a firm will choose a short-term contract if spillovers are relatively weak. The reason is that in this case a firm can raise its rivals costs – without hurting itself as much – due to increases in its own wage induced by R&D spillovers. (Refer also to the previous footnote.) On the other hand, when spillovers are relatively intense, an innovating firm will switch to a medium-term contract. A medium-term contract will generate a larger investment in R&D; in fact, wages will be higher, too. Hence, we can overall state that the RRC incentive (associated with a short-term contract) is relatively strong as long as spillovers are sufficiently weak: although innovation is lower under a short-term contract, also labour costs are lower and coexistent with the RRC potential. The content of Proposition 4 (ii) is presented in Figure 1.<sup>15</sup>

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<sup>15</sup>We have divided the relevant expressions by  $(A - w_0)^2$ .

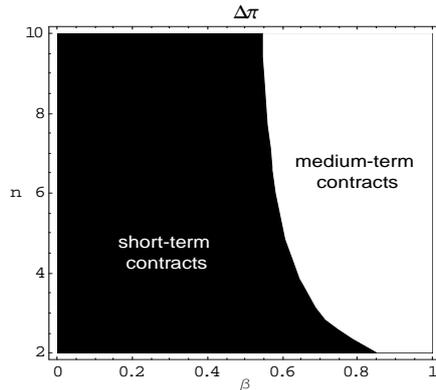


Figure 1: Contour plot of the difference in profits between short-term and medium-term wage contracts. Note that in the white area medium-term profits are higher; in the dark area they are lower.

From Propositions 3 and 4, the result presented below is immediate:

**Proposition 5** *The most preferred wage settlement both for the central union and firms is a long-term contract.*

Proposition 5 suggests that the union and firms will always prefer to engage in a long-term contractual relation – independently of the extent of spillovers. Under a long-term contract the union will act as a Stackelberg leader while firms will be the followers. Recall from Proposition 2 that this type of contract promotes innovation compared with any other arrangement. A higher investment in R&D will lower firms’ marginal cost and in turn, reduce the market price and expand output, thus leading to higher consumer surplus. In addition, according to Propositions 3 and 4, union utility and firms’ profits are higher when wages are settled for a long-term period. Therefore, a long-term contract will not only be preferred by firms and the labour union but will also lead to higher welfare than a short-term or a medium-term arrangement.<sup>16</sup>

## 6 Extension to endogenous wage contracts

In this section, we endogenise the firms’ decision on the type of wage contract to examine whether our main result in Proposition 5 remains robust to this alternative specification. Thus we adopt the observable delay game of Hamilton and Slutsky (1990) in the context of a unionised industry. In the first stage firms and the labour union announce simultaneously and independently in which period (or stage) they

<sup>16</sup>The relevant expressions are presented in the Appendix A2. It is worth noting that the medium-term regime generates lower welfare compared with both the long-term and the short-term regimes.

will choose their actions and commit to this decision.<sup>17</sup> Each party then takes its own action, while knowing when the other party will move. This means that a simultaneous move game will arise if the union and firms act in the same time period; otherwise, the game will be sequential. A simultaneous move game (for which both parties act in period 2 or 3) corresponds to a medium-term contract. By contrast, if all firms act in period 2 and the union acts in period 3, then a short-term contract will arise; and the contract will be a long-term one if the order of these moves is reversed.<sup>18</sup> Finally, firms choose their output levels. For simplicity, we restrict attention to the duopoly case. Our objective is to solve for the SPNE of this extended form game.<sup>19</sup>

**Claim 1** *A medium-term contract cannot be sustained as a SPNE outcome.*

**Proof.** Assume, to the contrary, that a medium-term contract can be sustained in equilibrium. Note that the union can increase its utility by deciding to move in an earlier time period (i.e., switch to a long-term contract).<sup>20</sup> This contradiction establishes the claim. ■

In line with our previous findings, the claim above shows that the labour union is better off being a wage-setting leader than acting simultaneously with the downstream firms. The main reason is that a long-term contract carries the largest innovation incentives and, in turn, promotes the demand for labour and union utility compared with a medium-term contract.

**Claim 2** *A short-term contract cannot be sustained as a SPNE outcome.*

**Proof.** According to Proposition 3, the labour union has an incentive to deviate and choose its wage in an earlier time period (i.e., simultaneously with the firms), rather than being the follower. This proves our claim. ■

We proceed to present our key result:

**Claim 3** *The unique SPNE outcome of the contract game is a long-term contract.*

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<sup>17</sup>As noted by Pal (1998) who used the observable delay game in a different context, the assumption of “commitment” is not restrictive in the sense that both parties will have no incentive to deviate from their decision in a later time period.

<sup>18</sup>The assumption that firms are symmetric practically eliminates the possibility that firms announce different time periods to choose their R&D levels, in which case a mixture of a simultaneous and a sequential move game would arise.

<sup>19</sup>The detailed derivations are available from the author on request.

<sup>20</sup>A similar argument applies to the firms.

**Proof.** Under a long-term contract the SPNE outcomes for union utility and per-firm profits are:

$$U^{l*} = \frac{3(A-w_0)^2}{2(7-\beta+\beta^2)}; \pi_i^{l*} = \frac{(A-w_0)^2(5+4\beta-\beta^2)}{4(7-\beta+\beta^2)^2}, i = 1, 2.$$

Suppose now that, say firm 2, decides to move in an earlier time period and act simultaneously with the labour union in setting the amount of its R&D. The corresponding SPNE solutions are:

$$U^* = \frac{(A-w_0)^2 ER}{T^2}; \pi_1^* = \frac{(A-w_0)^2(5+4\beta-\beta^2)Z^2}{T^2}; \pi_2^* = \frac{(A-w_0)^2(4+11\beta-7\beta^2+\beta^3)^2 Y}{T^2},$$

where  $E = 40 + 237\beta - 94\beta^2 + 19\beta^3 - 12\beta^4 + 2\beta^5$ ;  $R = 32 + 188\beta - 85\beta^2 + 17\beta^3 - 10\beta^4 + 2\beta^5$ ;  $T = 76 + 452\beta - 206\beta^2 + 65\beta^3 - 48\beta^4 + 25\beta^5 - 8\beta^6 + \beta^7$ ;  $Z = 4 + 39\beta - 30\beta^2 + 17\beta^3 - 7\beta^4 + \beta^5$  and  $Y = 9 + 56\beta - 14\beta^2 + 8\beta^3 - 7\beta^4 + 4\beta^5 - \beta^6$ .

It can be checked that  $\pi_2^* - \pi_i^{l*} < 0$  for all  $\beta$ . That is, firm 2 cannot increase its profit by switching its decision in an earlier period. Note that the result for firm 1 choosing to deviate (instead of firm 2) follows by analogy. Hence, there is no *unilateral* incentive for firm  $i$  ( $i = 1, 2$ ) to invest in R&D at the earlier wage-setting stage of the game. Moreover, according to the proof of claim 1 (and Proposition 3), the labour union has no incentive to deviate, as it cannot increase utility by acting simultaneously with the firms. This completes the proof of our claim. ■

As we mentioned previously, under a long-term contract the labour union commits ex ante to a certain wage which remains unaltered after firms have conducted their R&D investments. In this respect, a long-term contract eliminates the opportunistic behaviour of the labour union and therefore increases R&D and the firms' profit relative to all other regimes. Overall, we showed that our main result carries over in a setting where the decision over the type of wage contract is endogenous. Although this was shown to be true for the case of duopolistic competition, we conjecture that it may also hold for an  $n$ -firm oligopoly for reasons similar to those outlined within our main framework.

## 7 Conclusions

We constructed a simple non-tournament R&D model with spillovers in order to treat some of the gaps in the union-oligopoly literature within a unified framework. The main focus of our analysis was to uncover how the temporal dimension of wage contracts influences innovation incentives, wages and employment. Our major findings are the following:

- (i) Wages are non-monotone with respect to the duration of wage contracts: they are lowest under a long-term contract and highest under a medium-term one.

(ii) The wage bill is maximized under a long-term contract and exhibits a positive and one-to-one relation with investment levels; both are the lowest under a short-term arrangement.

(iii) The firms' profits are highest in the case of a long-term contract.

In light of (ii) and (iii), the central union and firms prefer to engage in a long-term contractual relation. This outcome remains also valid within the context of the observable delay game. As a long-term contract carries the largest innovation incentives, it also improves consumer surplus and, in turn, increases the level of welfare.

Due to practical difficulties in distinguishing among the different types of wage contracts, we proceed to present some testable predictions, which may facilitate further research in this direction:

(i) Wages are lower and less volatile with long-term contracts as compared with short-term contracts. Because long-term contracts smooth wages, innovation is expected to exhibit a similar behaviour.

(ii) Employment is higher and less volatile under long-term contracts than under short-term contracts.

All in all, although the relation between unionism and spending on R&D may still remain context-dependent (Keefe 1992; Menezes-Filho, Ulph and Van Reenen 1998), our purpose was nevertheless to highlight a new aspect of this relation, namely how the duration of wage contracts affects union wage demands and the associated incentives for R&D investments.

## Appendix

### A1. Medium-term wage contracts

The equilibrium output in last stage of the game is given by (5). Then in the first stage, the union and the firms, respectively, decide simultaneously on the wage and the R&D level. The equilibrium wage-R&D pair for the medium-term contract game is<sup>21</sup>

$$x_i^m = \frac{(A - w_0)[(2 + n^2)(1 - \beta) + n(1 + \beta)]}{N}, \quad (19)$$

$$w^m = \frac{2nA(1 + n)^2 + w_0G}{N}, \quad (20)$$

where  $N = -2(1 - \beta)^2 + n(3 - \beta(2 - 3\beta)) + n^2(7 + \beta(1 - 2\beta)) + n^3(4 - \beta(1 - \beta)) > 0$  and  $G = -2(1 - \beta)^2 + n(1 - \beta(2 - 3\beta)) + n^2(3 + \beta(1 - 2\beta)) + n^3(2 - \beta(1 - \beta)) > 0$ .

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<sup>21</sup>The socs are all satisfied.

The remainder SPNE solutions obtain

$$q_i^m = \frac{2n(1+n)(A-w_0)}{N} \quad (21)$$

$$U^m = \frac{4n^3(1+n)^3(A-w_0)^2}{N^2} \quad (22)$$

$$\pi_i^m = \frac{(A-w_0)^2 K}{N^2}, \quad (23)$$

where  $K = -4(1-\beta)^2 - 4n(1-\beta^2) - n^2(1-\beta(6-5\beta)) + 2n^3(3+\beta^2) + n^4(3+\beta(2-\beta)) > 0$ .

## A2. Welfare

Define social welfare as the sum of consumers surplus, firms profits and union utility. That is,

$$SW = \frac{1}{2} \left( \sum_{i=1}^n q_i \right)^2 + \sum_{i=1}^n \pi_i + \sum_{i=1}^n (w - w_0) q_i$$

Using the SPNE solutions in sections 3 and 4, we can obtain the following expressions for the cases of the short-term, long-term and medium-term contracts

$$SW^s = \frac{n(A-w_0)^2 J}{\Omega^2} \quad (24)$$

$$SW^l = \frac{n(A-w_0)^2 M}{4L^2}, \quad (25)$$

$$SW^m = \frac{(A-w_0)^2 n \Psi}{N^2} \quad (26)$$

where  $J = -(1-\beta)^2 - 2n(1-\beta) + n^2(5+2\beta(2-\beta)) + 2n^3(10+\beta) + n^4(19+\beta(2-\beta)) + 6n^5 > 0$ ,  $M = -4(1-\beta)^2 - 8n(1-\beta) + n^2(-3+\beta(10-3\beta)) + n^3(16-2\beta(1-2\beta)) + n^4(17+\beta(2-3\beta)) + 2n^5(3-\beta(1-\beta)) > 0$ ,  $\Psi = -4(1-\beta)^2 - 4n(1-\beta^2) + n^2(3+\beta(6-5\beta)) + 2n^3(10+\beta^2) + n^4(19+\beta(2-\beta)) + 6n^5 > 0$  and  $\Omega, L$  are defined as previously. Comparing the relevant SPNE solutions, we have that:  $SW^l - SW^s > 0$  and  $SW^m - SW^s < 0$ .

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