DEPARTMENT OF ECONOMICS
UNIVERSITY OF CRETE

BE.NE.TeC. Working Paper Series

Working Paper: 2007-05

Union structure and firms incentives for cooperative R&D investments

Constantine Manasakis, Emmanuel Petrakis

Business Economics & NEw TeChnologies Laboratory

www.soc.uoc.gr/benetec

Union structure and firms' incentives for cooperative R&D investments*

Constantine Manasakis† Emmanuel Petrakis‡

First Version: July 2004
This Version: January 2007

Abstract

This paper investigates the impact of alternative unionization structures on firms' incentives to spend on cost-reducing R&D activities as well as to form a Research Joint Venture, in the presence of R&D spillovers. We show that, in contrast to the "hold up" argument, if firms invest non-cooperatively and spillovers are low, R&D investments are higher when an industry-wide union sets a uniform wage rate than under firm-level unions. In contrast, investments are always higher under firm-level unions in the case of RJVs. Firms' incentives to form an RJV are non-monotonic in the degree of centralization of the wage-setting, with the incentives being stronger under an industry-wide union if and only if spillovers are low enough. Finally, centralized wage-setting as well as high unemployment benefits may hinder the formation of costly RJVs and their potential welfare benefits.

Keywords Unions, Oligopoly, Cost-reducing Innovations, Research Joint Ventures, Spillovers

JEL Classification J51; L13; O31

*We would like to thank Minas Vlassis as well as the participants at the CRETE 2004 Conference, Syros, Greece, the ASSET 2004 Meetings, Barcelona, Spain, and at Seminars Series, Department of Economics, University of Ioannina, for their helpful comments and suggestions. Full responsibility for all shortcomings is ours.

†Department of Economics, University of Crete; e-mail: manasakis@stud.soc.uoc.gr.

‡Corresponding author. Department of Economics, University of Crete, Univ. Campus at Gallos, Rethymnon 74100, Greece, Tel: +302831077407, Fax: +302831077406; e-mail: petrakis@ermis.soc.uoc.gr.

1 Introduction

It is well-established that labor market features, such as the level,[1] the agenda and the pattern of employers-employees negotiations, the bargaining power distribution between firms and unions, and the labor market institutions (minimum wages, unemployment benefits, etc.), are amongst the crucial determinants of firms' innovation activities (see e.g. Hirsch 2004).

In his seminal paper, Grout (1984) firstly introduced the "hold-up" argument in the literature. In a "one firm-one union" framework, Grout argues that in the absence of legally binding contracts, once the firm has incurred the sunk costs of investment, its union has incentives to extract a portion of the quasi-rents created by the firm's investment through higher wage demands. The union's hold-up behavior, in turn, leads the firm to underinvest. The higher the union's power is, the lower are the firm's incentives to innovate. However, unionization is not always associated with underinvestment. In a patent race for a labor savings innovation, Tauman and Weiss (1987) show that a unionized duopolist has stronger incentives to adopt the new technology than its non-unionized counterpart. Ulph and Ulph (1994, 1998), in a duopoly where firms bargain with their firm-level unions over employment and wages ("Efficient Bargaining"), show that a more powerful risk-averse union may encourage its firm to overinvest in order to win the patent race for a cost-reducing innovation. More recently, Calabuig and Gonzalez-Maestre (2002) show that if the market size is small, an industry-wide union provides stronger incentives for a firm to win a patent race than a firm-level union. Moreover, Haucap and Wey (2004) show that innovation incentives are not monotonic in the degree of centralization of wage-setting. Innovation incentives are the strongest when an industry-wide union sets a uniform wage rate, they are the weakest under an industry-wide union coordinating, via wage discrimination, its wage demands, while they lie in-between under perfectly decentralized firm-level union wage setting. Finally, these theoretical findings are, to a major

[1] Contemporary labor market institutions display substantial variability regarding the level of wage negotiations. In USA, Canada and Japan, collective and/or individual bargaining over wages occurs at the firm-level alone. In Europe, however, wage negotiations are often conducted at various levels. They are typically centralized at the sector-level in Italy, the Netherlands, Spain, France and Portugal, while they are centralized at both the national and the sector-level in Germany and the Scandinavian countries. Moreover, collective bargaining over wages is carried out at all three levels (national-, sector-, and firm-level) in Belgium and Greece. On the other hand, wage negotiations are mainly decentralized, at the firm-level, in UK and Ireland (see e.g. Flanagan, 1999; Hartog and Theeuwes, 1992).

extent, supported by the inconclusive empirical evidence on the impact of the unionization on the firms' incentives to innovate. Menezes-Filho and Van Reenen (2003), surveying the bulk of the empirical literature, conclude that, although there are consistently strong and negative impacts of unions on R&D expenditures in North America, this is not the case for Europe where no such clear pattern can be reached. In addition, Hirsch (2004) concludes that the existing empirical evidence does not allow us to establish, or reject, causal union effects on R&D investments.

Although the impact of labor market features on firms' R&D investments have been extensively addressed in the literature, some key features regarding the nature and the organization of R&D activities, along with their interplay with the labor market features, have been ignored so far. Firstly, the spillover effects of a firm's R&D activities that may cause underinvestment problems.[2] And secondly, the organizational mode of R&D investments, i.e. whether firms invest non-cooperatively, or cooperatively by forming a Research Joint Venture (RJV). As Vonortas (1997) notes, RJVs are regarded as "the cure for a number of failures in innovation markets" as far as spillovers are internalized and thus incentives for R&D investments are restored.[3]

This paper aims to fill this gap by reconsidering the role of unions for the firms' incentives to invest in cost-reducing R&D activities when R&D spillovers are present and firms have the option to form an RJV. Our envisaged model is a homogeneous unionized Cournot duopoly, where firms can invest in cost-reducing R&D activities before adjusting their quantities in the market. Each firm's R&D output partially flows to its rival, contributing to the latter's unit cost reduction. Workers are organized either in two firm-level unions (*decentralized unionization structure*) or in an industry-wide union (*centralized unionization structure*). After firms have chosen their R&D expenditures and before the market competition stage, firm-level unions set

[2] As d'Aspremont and Jacquemin (1988) mention, "R&D externalities or spillovers imply that some benefits of each firm's R&D flow without payment to other firms" and this may cause free-riding behavior and underinvestment problems. Empirical findings suggest that spillovers have significant implications in real world situations, as they affect competitors' average cost (Bernstein and Nadiri, 1989), labor productivity and total factor productivity (Coe and Helpman, 1995; Frantzen, 2000).

[3] Recent papers establish the growing trends of RJVs formation (see e.g. Caloghirou et al., 2003; Hagedoorn and van Kranenburg, 2003). Benfratello and Sembenelli (2002) find a positive correlation between participation in RJVs, labor productivity and price-cost margins for European firms, sponsored under the EUREKA project during 1992-1996.

their firm-specific wage rates, or else the industry-wide union sets the uniform wage.[4] At an initial stage, firms have the option to form an RJV in order to invest cooperatively in the next stage, or to stay separately. We thus extend d'Aspremont and Jacquemin (1988) by adding alternative unionization structures to their non-union model. [5]

In the above setup we address the following three questions. First, how does the presence of R&D spillovers affect firms' R&D investments, employment and output levels, firms' profits and social welfare? Second, how does the unionization structure affect equilibrium market outcomes and welfare under alternative organizational forms of the R&D activity (RJVs or non-cooperative R&D spending)? Third, how does the unionization structure affect the firms' incentives to form an RJV, and in particular when the formation of the RJV is costly?

With respect to the first question, our results suggest that the effects of R&D spillovers on equilibrium market outcomes and welfare depend on both the unionization structure and the organizational form of the R&D activity. In particular, each individual firm's R&D investment increases in the spillover rate when firms form an RJV and internalize spillovers, while it decreases when firms invest non-cooperatively in R&D and free-riding behavior prevails, independently whether workers are organized in two-firm level unions or an industry-wide union. Nevertheless, employment and output levels, firms' profits and welfare increase in the spillover rate in most cases. The only exception is when firms invest non-cooperatively in R&D and the unionization structure is either centralized or coordinated, in which case employment and output levels, firms' profits and welfare increase in the spillover rate for spillovers below a critical value. Yet, this critical value differs not only across unionization structures but also it is specific to each variable under consideration. Under the centralized regime, for instance, this critical value is quite low for employment levels and quite high for firms' profits, implying that equilibrium profits are in most cases increasing in the spillover rate, while the opposite is true for employment levels. The driving forces behind the above results are as follows. On

[4] In the extensions Section 7 we also consider the case where the industry-wide union can set different wages for the two firms (*Coordinated unionization structure*, see Hawcap and Wey, 2004). Moreover, we briefly discuss the case where, instead of union(s) wage setting, we have wage negotiations between firms and union(s).

[5] These are the unionization structures that prevail in the countries where most of the RJV active firms operate. The decentralized regime of wage-setting fits well with the cases of U.S.A., U.K. and Japan, which are world-wide leaders in cooperative R&D partnerships (see Caloghirou et al., 2003); while the centralized regime fits well with collective bargaining systems in countries like Italy, Germany, France and Belgium, with the higher participation in RJVs across the European Union (see Benfratello and Sembenelli, 2002).

the one hand, the impact of an increase in the spillover rate on a firm's "effective R&D investment level", i.e. the aggregate R&D effort in the industry that contributes to its unitary cost reduction, is *ceteris paribus* positive. On the other hand, the union(s) hold-up behavior, i.e. the extra rents that a union can extract through higher wage demands, can be negatively or positively related with the spillover rate depending on the unionization structure. In particular, as in Hawcap and Wey (2004), we identify two types of the "hold-up" problem: the "wage-level hold-up" and the "wage-differentiation hold-up", referring respectively to the increase in the firm's wage rate and the firms' wage differential due to an individual firm's own R&D effort. When the unionization structure is decentralized, both the wage-level and the wage-differentiation hold-up become less severe as the spillover rate increases. In contrast, under centralized unionization, the wage-level hold-up becomes more severe as the spillover rate increases, while the wage-differentiation hold-up is null since both firms face a uniform wage. Furthermore, under the coordinated unionization structure, the wage-level hold-up is independent of the spillover rate, while the wage-differentiation hold-up becomes less pronounced as the spillover rate increases. Finally, the impact of the internalization of spillovers when firms form an RJV on market outcomes and welfare are *ceteris paribus* more pronounced when the spillover rate is high.

As far as the second question is concerned, we argue that the relation between R&D expenditures and unionization depends crucially on the organizational mode of R&D activities and the severity of the spillovers.[6] In particular, our results reveal a partial reversal of the "hold-up" argument. In fact, when firms invest non-cooperatively in R&D and spillovers are sufficiently low, R&D spending is higher when an industry-wide union sets a uniform wage than when firm-level unions set their firm-specific wages; moreover, they are higher in the latter case than when the industry-wide union coordinates its wage demands. In contrast, we reconfirm the "hold-up" argument when spillovers are sufficiently high, in which case R&D investments are the highest under a decentralized unionization structure, while they are higher under centralized than under coordinated unionization. On the other hand, when firms form an RJV and invest cooperatively, our results are always in line with the "hold-up" argument.

[6] In a different context, Mauleon et al. (2005) suggest that "the relationship between unions and R&D effort depends on the network architecture and on the spillovers".

Nevertheless, employment and output levels, firms' profits and welfare are always higher under a decentralized than under a centralized unionization structure, while they lie in-between under the coordinated unionization structure. Obviously, R&D expenses, employment and output levels, firms' profits and welfare are always higher in a non-unionized than in a unionized industry.

Coming back to the third question, we first show that if the formation of an RJV is costless, firms have *always* incentives to form an RJV, independently of the unionization structure. We thus reconfirm the finding obtained in the non-union case (see d'Aspremont and Jacquemin, 1988). Interestingly, RJVs lead to higher R&D investments than the non-cooperative R&D spending but only if spillovers are high enough. Moreover, the spectrum of spillover rates for which this holds depends crucially on the unionization structure. It is wider for the centralized unionization structure than for the coordinated one, and as for the latter it is wider than that of the decentralized unionization. An immediate consequence is that the firms' incentives to form an RJV differ across unionization structures for any given spillover rate. For instance, firms have stronger incentives to form an RJV under the centralized than under the decentralized unionization structure whenever spillovers are sufficiently low. Intuitively, each individual firm's incentives to participate in an RJV depend on two factors. The overall unit cost reduction effect and the R&D cost savings effect. When spillovers are low, the RJV formation leads to a relatively larger unit cost increase under the centralized rather than under the decentralized unionization structure. This negative effect is however dominated by the relatively larger R&D cost savings effect in the former than in the latter case. This reasoning is reversed if spillovers are high (in which case the RJV induces instead a reduction in unit costs and an increase in R&D expenditures). The above discussion implies that in the real world where the formation of an RJV is often costly, firms may have incentives to form an RJV under one unionization structure but not under another.

Our results further suggest that an increase in the unemployment benefits strengthens the unions' wage demands and thus hinder firms' R&D investments, leading to lower employment and output levels and firms' profits. Finally, although firms have always incentives to participate in a costless RJV, such RJVs are often welfare detrimental. In particular, under centralized unionization, an RJV reduces social welfare except if spillovers are quite high. In

contrast, an RJV is welfare enhancing under decentralized unionization provided that spillovers are not too low. Interestingly, the range of parameters for which welfare decreases due to the formation of an RJV in a non unionized industry lies in-between the centralized and the decentralized unionization structures. We thus add to d'Aspremont and Jacquemin (1988) by offering a welfare analysis of RJVs in the non-union case too. Our analysis thus points out that the alignment of market and social incentives for the formation of an RJV depends crucially on the unionization structure. As the formation of an RJV is welfare enhancing under various circumstances, policy measures that are intended to encourage RJVs should carefully be designed, taking into account all the features of the industry, namely its unionization structure, the severity of spillovers etc.

Our findings contribute to the existing literature on the impact of alternative unionization structures on firms' incentives to form an RJV. We reconfirm Calabuig and Gonzalez-Maestre (2002) result that union centralization, as compared with decentralization, may provide stronger incentives to firms to spend on R&D. This hold-up reversal occurs however for all market sizes whenever spillovers are low enough, and not only for small market sizes as Calabuig and Gonzalez-Maestre argue. Moreover, when spillovers are high enough, in line with the hold-up argument and contrary to Calabuig and Gonzalez-Maestre, union decentralization leads to stronger incentives than centralization. Furthermore, as Haucap and Wey (2004), we show that firms' investment incentives are not monotone in the degree of centralization. Firms' R&D incentives are the largest under the centralized unionization structure, the weakest under the coordinated one, while under the decentralized unionization structure they lie in-between. Nevertheless, this occurs only if spillovers are low enough. Otherwise, and in contrast to Haucap and Wey (2004), decentralization creates stronger R&D incentives for firms than an industry-wide union. Our analysis thus stresses the role of R&D spillovers for the magnitude of the hold-up problem and the ensuing incentives of firms to invest in R&D.

The rest of the paper is organized as follows. In section 2, we present the basic model and the analysis of the benchmark case with no unions. In section 3, the cases of non-cooperative R&D investments under firm-level unions and an industry-wide union are analyzed. In section 4, we study the respective cases when firms form an RJV and invest cooperatively. In section 5, the firms' incentives to form an RJV are analyzed. Section 6 includes the welfare analysis.

In Section 7 a number of extensions of the basic model are briefly discussed. Finally, Section 8 concludes.

2 The Basic Model

We consider a unionized homogenous good industry where two firms, denoted by $i, j = 1, 2, i \neq j$ compete in quantities. The (inverse) demand function for the final good is linear, and is given by $P(Q) = a - Q$, where $Q = q_1 + q_2$ is the aggregate output. Firms are endowed with constant returns to scale technologies that transform one unit of labor to one unit of output; that is, $q_i = L_i$ where q_i and L_i are respectively firm i's output and employment level. The unitary transformation cost of labor to output is constant and initially is equal to c for both firms. In addition to the transformation cost, each firm i incurs labor costs that are equal to w_i per unit of labor, where w_i is its wage rate. Hence, firm i's cost per unit of output initially equals $c + w_i$. However, firm i, by investing x_i^2 in R&D activities, can reduce its unitary transformation cost by x_i.[7] Moreover, due to technological spillovers, each firm benefits from its rival's investments. In particular, firm i's unitary transformation cost is reduced by δx_j,where x_j is firm j's investment level and δ is the spillover rate, $0 \leq \delta \leq 1$. Therefore, firm i's total cost function is given by $C_i(.) = (w_i + c - x_i - \delta x_j) L_i + x_i^2$. Note that this cost function reflects diminishing returns to scale to R&D expenditures.

In this industry R&D activities can be carried out under two alternative forms: (i) non-cooperatively (nc), where firms choose their R&D expenditures simultaneously and independently and (ii) cooperatively (c), where firms form a Research Joint Venture (RJV) and decide together their R&D expenditures in order to maximize their joint profits, while remaining competitors in the final good market.[8]

The industry is unionized and all workers have identical skills. Workers are organized either in two firm-level unions (Decentralized regime, D), or in one industry-wide union (Centralized regime, C). The unionization structure is exogenously given. Unions are assumed to maximize

[7] It can be shown that if one uses the labor saving process innovation, that has been employed in the bulk of the literature for the union effects on R&D investments for process innovations, the results will be qualitatively similar.

[8] Following d'Aspremont and Jacquemin (1988), we assume that pre-RJV spillovers and post-RJV spillovers are equal and are thus captured by the same spillover rate δ.

the rents of their members. In the decentralized regime, the union i's objective is $U_i(w_i, L_i) = (w_i - w_0) L_i$, where w_0 is the workers' *outside option*,[9] while in the centralized regime the industry-wide union's objective is $U(w, L_i, L_j) = (w - w_0)(L_i + L_j)$, where w is the uniform industry wage rate.[10] In our basic model, we assume that unions have all the power to set wages, while firms choose their employment level subsequently (Monopoly Union model).[11]

We consider the following four-stage game. In the first stage, firms decide whether to form an RJV (c) or stay separately (nc). In the second stage, if firms have chosen to form an RJV, they decide cooperatively their R&D expenses in order to maximize their joint profits. Otherwise, firms decide simultaneously and independently their R&D expenses. In the third stage, the industry-wide union sets the uniform industry wage rate in the Centralized regime (C); or the two unions set simultaneously and independently their firm-specific wage rates in the Decentralized regime (D). Finally, in the last stage, firms choose their employment and output levels. The equilibrium concept employed is the subgame perfect equilibrium.

2.1 The Benchmark Case: No Unions

Before considering non-cooperative and cooperative R&D investments under alternative unionized structures, we briefly present the analysis of the benchmark case with no unions (nU) in which firms face a labor cost equal to the workers' outside option, w_0.[12] In the last stage of the game, each firm i chooses its employment level L_i (and thus its output q_i) to maximize profits:

$$\max_{L_i} \pi_i = (a - L_i - L_j)L_i - (w_0 + c - x_i - \delta x_j) L_i - x_i^2 \tag{1}$$

Taking the first order conditions and solving the system of equations, we get the employment (and output) level:

[9] w_0 is typically a weighted average of the competitive wage and the unemployment benefits, the weights being respectively the probability of a worker to find a job or not in the competitive sector. As unemployment benefits influence the level of w_0, the latter can be considered in our setup as a labor market policy instrument.

[10] The case where the industry-wide union can set different wages for the two firms (Coordinated regime) is briefly presented in Section 7.

[11] Although in real life wages and, in some cases employment, is determined via firm-union negotiations, a standard simplifying assumption in the "union-oligopoly" literature is that the union has all the power in wage negotiations, while the firm has all the power to set the employment level (see e.g. Haucap and Wey, 2004; Petrakis and Vlassis, 2004; and the references therein). In Section 7 we extend our analysis to the more general case where wages are the outcome of negotiations between firm(s) and union(s) (Right-to-Manage model).

[12] See d'Aspermont and Jacquemin (1988) for details.

$$L_i(x_i, x_j) = q_i(x_i, x_j) = \frac{1}{3}\left[(a - c - w_0) + x_i\,(2 - \delta) + x_j\,(2\delta - 1)\right] \tag{2}$$

Observe that q_i increases with firm i's R&D effort x_i. It also increases with its rival firm's R&D effort x_j, but only if the spillover rate is high enough ($\delta > 0.5$); otherwise, q_i decreases with x_j.

In the previous stage, under non-cooperative R&D investments, each firm i chooses its R&D investment to maximize profits $\pi_i = L_i(x_i, x_j)^2 - x_i^2$. From the first order conditions, we get the firm's equilibrium R&D investment level,

$$x_{nc}^{nU} = \frac{(2 - \delta)(a - c - w_0)}{7 - \delta + \delta^2} \tag{3}$$

Then the equilibrium employment level and firm's profits are:

$$L_{nc}^{nU} = \frac{3(a - c - w_0)}{7 - \delta + \delta^2}; \qquad \pi_{nc}^{nU} = \frac{(5 - \delta)(1 + \delta)(a - c - w_0)^2}{(7 - \delta + \delta^2)^2} \tag{4}$$

If instead the two firms form an RJV, they choose (x_1, x_2) to maximize their joint profits $\pi_1 + \pi_2 = L_1(x_1, x_2)^2 + L_2(x_1, x_2)^2 - x_1^2 - x_2^2$. >From the first order conditions and symmetry we get the firm's equilibrium R&D investment level,

$$x_c^{nU} = \frac{(1 + \delta)(a - c - w_0)}{8 - 2\delta - \delta^2} \tag{5}$$

Then the equilibrium employment level and firm's profits are:

$$L_c^{nU} = \frac{3(a - c - w_0)}{8 - 2\delta - \delta^2}; \qquad \pi_c^{nU} = \frac{(a - c - w_0)^2}{8 - 2\delta - \delta^2} \tag{6}$$

Let firm i's '*effective R&D investment level*', e_i, be the aggregate R&D effort that contributes to its unitary transformation cost reduction, that is $e_i = x_i + \delta x_j$. One can then easily check the impact of an increase in technological spillovers δ on the equilibrium variables. The following Lemma summarizes the results for the non-unionized industry case.

Lemma 1 *In a non-unionized industry:*

(i) When firms invest non-cooperatively, individual firm's investments decrease in the spillover

rate δ. Effective R&D investment level, employment and output are increasing (decreasing) in δ when $\delta < 0.5$ ($\delta > 0.5$). Finally, firms' profits always increase in δ.

(ii) When firms form an RJV and invest cooperatively, individual firm's investments, effective R&D investment level, employment and output, and firms' profits are increasing in the spillover rate δ.

(iii) If the formation of an RJV is costless, firms have always incentives to form an RJV. Moreover, R&D investments are higher under an RJV than when firms invest non-cooperatively if and only if $\delta > 0.5$.

It is well known that when firms decide their R&D efforts in a non-cooperative way, technological spillovers have a negative impact on each firm's incentives to invest in R&D because its rival can free-ride on those investments. Clearly, firms can internalize spillovers by forming an RJV. The firms' joint (gross) profits increase with the spillover rate in this case, leading thus to higher individual firms' R&D investments as δ increases. An immediate consequence is that the effective R&D investment level, which is equal to each firm's unit cost reduction, increases with the spillover rate under an RJV.

In contrast, when firms invest non-cooperatively in R&D, the effective R&D investment level is not monotonic in δ. In fact, this relation is inverted U-shaped, with the maximum of the effective R&D investment level attained at $\delta = 0.5$. This implies that when the spillover rate is initially high enough, a further increase in δ leads to a lower unit cost reduction for the firms. This is so because when $\delta > 0.5$, R&D investment levels are strategic complements (using (2), one can see that $\partial^2 \pi_i / \partial x_i \partial x_j > 0$). As δ increases, an individual firm decreases its R&D effort, not only because its rival free-rides on its own investments, but also because it optimally responds to its rival's reduction of R&D effort (resulting in turn from the firm's free-riding on its rival's investments).

Clearly, employment and output levels follow the same pattern as the effective R&D investments both in the non-cooperative and the cooperative investment case. Yet, firms' profits always increase with the spillover rate δ, independently of the mode of R&D investments. When firms invest non-cooperatively in R&D, as δ becomes higher, an individual firm decreases its R&D investments and thus saves on R&D costs (*R&D cost savings effect*). It also obtains higher gross profits when $\delta < 0.5$, due to the increase in the effective R&D investment level

(*unit cost reduction effect*). This latter effect becomes negative for higher spillover rates, but it is dominated by the former positive effect and as a result profits are always increasing in δ. When firms form an RJV, as δ becomes higher, each firm increases its R&D investments, but at the same time its gross profits increase due to the increase in the effective R&D investment level. The positive unit cost reduction effect dominates the negative R&D cost savings effect and thus profits increase with δ in this case too.

Finally, one can easily check from (4) and (6) that firms have *always* incentives to form an RJV. This holds only if the formation of an RJV is *costless* for the firms, a condition which is however rarely met in reality. It is thus worth identifying the circumstances under which firms have stronger incentives to form an RJV. Defining $M^{nU} = \pi_c^{nU} - \pi_{nc}^{nU}$, one can check that an individual firm's incentives to form an RJV become weaker as the workers' outside option w_0 increases. More interestingly, they have a U-shaped relation with δ. An individual firm's incentives are null for $\delta = 0.5$, take their highest value in the full spillover case ($\delta = 1$) and the second highest value in the zero spillover case ($\delta = 0$). Finally, it is worth noting that an RJV leads to higher R&D investments, as compared with the non-cooperative R&D investment case as long as $\delta > \delta_{nU} \equiv 0.5$ (see d'Aspremont and Jacquemin, 1988).[13]

3 Non-cooperative R&D Investments

3.1 Firm-level Unions

We consider first the case in which firms invest non-cooperatively in R&D (nc) and unions are organized at the firm-level (D). In the last stage of the game, each firm i chooses its employment (and output) level to maximize profits:

$$\max_{L_i} \pi_i = (a - L_i - L_j)L_i - (w_i + c - x_i - \delta x_j)\, L_i - x_i^2 \tag{7}$$

Taking the first order conditions and solving the system of equations, employment and output levels are:

[13] It can be checked from (5) and (3) that $x_c^{nU} > x_{nc}^{nU}$ if and only if $\delta > 0.5$.

$$L_i(w_i, w_j, x_i, x_j) = \frac{1}{3}\left[(a-c) - 2w_i + w_j + x_i(2-\delta) + x_j(2\delta - 1)\right] \quad (8)$$

$$= \frac{1}{3}\left[(a-c) - w_i - \Delta w + x_i(2-\delta) + x_j(2\delta - 1)\right] \quad (9)$$

where $\Delta w = w_i - w_j$ is the firms' wage differential. Observe that L_i decreases with firm i's wage rate w_i and increases with its rival firm's wage w_j. More importantly, L_i decreases with the wage differential Δw (for any given w_i). Similar observations apply for the firm i's equilibrium profits, $\pi_i(.) = L_i(.)^2 - x_i^2$. In particular, firm i's profits decrease with its own wage rate w_i as well as with the firms' wage differential Δw. In the third stage, firm-level unions set wages simultaneously so as to maximize their rents:

$$\max_{w_i} U_i = \frac{1}{3}(w_i - w_0)\left[(a-c) - 2w_i + w_j + x_i(2-\delta) + x_j(2\delta - 1)\right] \quad (10)$$

>From the first order conditions of (10), firm i's wage rate is:

$$w_i(x_i, x_j) = \frac{1}{15}\left[5(a - c + 2w_0) + x_i(7 - 2\delta) + x_j(7\delta - 2)\right] \quad (11)$$

Clearly, w_i increases with the workers' outside option w_0. More importantly, w_i increases with the firm i's own R&D effort x_i. The latter reflects the well-known *wage-level hold-up* problem. Since a higher R&D effort will lead, via its union's future claims on extra rents, to a higher wage rate for the firm, a unionized firm has weaker incentives to spend on R&D than its non-union counterpart. Moreover, w_i increases with the rival firm's R&D effort but only if the spillover rate is not too low (i.e. for all $\delta > 0.286$). In contrast, if $\delta < 0.286$, an increase in firm j's R&D effort has a positive impact on firm i because it reduces the wage rate set by its own union. Yet, there is an additional hold-up problem, *the wage-differentiation hold-up* (see Haucap and Wey, 2004). In particular, from (11) $\Delta w^D(x_i, x_j) \equiv w_i(.) - w_j(.) = \frac{3(1-\delta)}{5}(x_i - x_j)$; hence the wage differential is positively related to the firm i's R&D effort. As a consequence, a higher R&D effort will lead to a higher wage differential between the two firms and thus to weaker incentives for firm i to spend on R&D.

In the second stage, firms invest simultaneously in R&D efforts, each to maximize its own

profits, which after substituting (11) into (7), are given by:

$$\max_{x_i} \pi_i = \frac{4\left[5\left(a-c-w_0\right)+x_i\left(7-2\delta\right)+x_j\left(7\delta-2\right)\right]^2}{2025} - x_i^2 \tag{12}$$

Taking the first order conditions of (12) and exploiting symmetry, we get the equilibrium R&D investment level:

$$x_{nc}^D = \frac{4\left(7-2\delta\right)\left(a-c-w_0\right)}{8\delta^2-20\delta+377} \tag{13}$$

Using (13), we get respectively each firm's equilibrium wage rate, employment and output level, and profits:

$$w_{nc}^D = w_0 + \frac{135\left(a-c-w_0\right)}{8\delta^2-20\delta+377} \tag{14}$$

$$L_{nc}^D = \frac{90\left(a-c-w_0\right)}{8\delta^2-20\delta+377} \tag{15}$$

$$\pi_{nc}^D = \frac{4\left(59-4\delta\right)\left(31+4\delta\right)\left(a-c-w_0\right)^2}{\left(8\delta^2-20\delta+377\right)^2} \tag{16}$$

As in the non-unionized industry case, here too, technological spillovers have a negative impact on the individual firms' incentives to invest in R&D due to the free-riding effect. From (13) it can be seen that the higher the spillover rate δ is, the lower is a firm's R&D effort in equilibrium. Yet, the effective R&D investment level, $e_{nc}^D = (1+\delta)x_{nc}^D$, increases *always* with δ. The intuition is as follows. Consider an increase in the spillover rate when $\delta > 0.5$. For exogenously given wage rates, such an increase would have lead to a decrease in e_{nc}^D (Lemma 1). However, when wages are endogenous, future wage claims by its union discourage a firm from spending on R&D. Yet, as δ increases, both the wage-level and the wage-differentiation hold-up problems become less severe, since from (11) $\frac{\partial w_i^D}{\partial x_i} = \frac{7-2\delta}{15}$ and $\frac{\partial \Delta w^D}{\partial x_i} = \frac{3(1-\delta)}{5}$. As a result, an individual firm's R&D effort reduction due to its own union's rent seeking behavior becomes less pronounced. This positive feedback effect in turn implies that an individual firm's R&D effort decreases with δ by less when wages are endogenous than when they are exogenously given. In fact, by (13) and (5), $\mid \partial x_{nc}^D/\partial\delta \mid < \mid \partial x_{nc}^{nU}/\partial\delta \mid$. Therefore, when wages are set by

firm-level unions, effective R&D investment level is increasing in the spillover rate for all values of δ.

An immediate consequence is that a firm's transformation cost reduction is larger when the spillover rate is higher. This, in turn, allows unions to push for higher wages in the subsequent wage-setting stage as δ increases. Nevertheless, labor costs rise by less than the reduction of the transformation costs, and as a result, *overall cost reduction,* $e_{nc}^D - w_{nc}^D$, turns out to be increasing in the spillover rate. In fact, by (13) and (14), one can check that $\partial(e_{nc}^D - w_{nc}^D)/\partial\delta > 0$. Therefore, employment level, output and firms' profits increase as technological spillovers become more prominent. The following Lemma summarizes:

Lemma 2 *When firms invest non-cooperatively in R&D and wage-setting is decentralized, an individual firm's R&D investment decreases with the spillover rate δ. Effective R&D investment, wage rates, overall cost reduction, employment and output levels, and firms' profits are increasing in δ.*

It can also be checked that an increase in the workers' outside option - for instance, an increase in the unemployment benefits set by the government - has a negative impact on the individual and the effective R&D investments, as well as on the overall cost reduction, the employment and output levels and the firms' profits. This is because the increase in w_0 leads to a higher wage paid by the firms to their employees.

3.2 An Industry-wide Union

When an industry-wide union sets a uniform wage (C unionization structure), in the last stage of the game, output and employment are given by (8) when $w_i = w_j = w$. In the third stage, the industry-wide union chooses w to maximize its overall rents $(w - w_0)[L_1(.) + L_2(.)]$, i.e.:

$$\max_w U = \frac{1}{3}(w - w_0)[2(a - c) - 2w + (x_i + x_j)(1 + \delta)] \tag{17}$$

>From the first order condition of (17), the uniform wage rate is:

$$w(x_i, x_j) = \frac{1}{4}[2(a - c + w_0) + (x_i + x_j)(1 + \delta)] \tag{18}$$

As expected, the wage rate increases with the workers' outside option. Interestingly, it increases with both firms' R&D efforts. This reflects the wage-level hold up problem. An increase in firm i's R&D effort leads, via the industry-wide union's future claims on extra rents, to a higher industry wage w, i.e. $\frac{\partial w}{\partial x_i} = \frac{1+\delta}{4}$. Knowing this, firm i has weaker incentives to spend on R&D. Obviously, there is no wage-differentiation hold-up in the centralized regime, because both firms face the uniform wage rate set by the industry-wide union.

In the second stage, firms simultaneously invest in R&D, each maximizing its profits, which after substituting (18) into (7) are given by:

$$\max_{x_i} \pi_i = \frac{\left[2\left(a-c-w_0\right)+x_i\left(7-5\delta\right)+x_j\left(7\delta-5\right)\right]^2}{144} - x_i^2 \tag{19}$$

>From the first order conditions of (19) and symmetry, the equilibrium R&D investment is:

$$x_{nc}^C = \frac{\left(7-5\delta\right)\left(a-c-w_0\right)}{5\delta^2-2\delta+65} \tag{20}$$

Using (20), we get respectively the equilibrium wage, and each firm's employment level and profits:

$$w_{nc}^C = w_0 + \frac{36\left(a-c-w_0\right)}{5\delta^2-2\delta+65} \tag{21}$$

$$L_{nc}^C = \frac{12\left(a-c-w_0\right)}{5\delta^2-2\delta+65} \tag{22}$$

$$\pi_{nc}^C = \frac{5\left(1+\delta\right)\left(19-5\delta\right)\left(a-c-w_0\right)^2}{\left(5\delta^2-2\delta+65\right)^2} \tag{23}$$

In this case too, due to the rival's free-riding, an individual firm's incentives to invest in R&D become weaker as δ increases. However, in contrast to the decentralized regime, when an industry-wide union sets a uniform wage rate the effective R&D investment, $e_{nc}^C = (1+\delta)x_{nc}^C$, decreases with the spillover rate whenever δ is not too low (i.e. for all $\delta > 0.2$). In fact, the relation between e_{nc}^C and δ is inverted U-shaped, with its maximum attained at $\delta = 0.2$. The intuition is as follows. Consider an increase in the spillover rate when $\delta < 0.5$. For an

exogenously given wage rate, such an increase would have lead to an increase in e_{nc}^C (Lemma 1). Yet, when the wage rate is endogenous, wage claims by the industry-wide union in the subsequent stage discourage firms from spending on R&D. In addition, as δ increases, the wage-level hold-up problem becomes more severe, since from (18) $\frac{\partial w^C}{\partial x_i} = \frac{1+\delta}{4}$ (recall that in this case, there is no wage-differentiation hold-up). Therefore, the individual firm's R&D effort reduction due to industry-wide union's rent seeking behavior becomes larger. This, in turn, implies that an individual firm's R&D effort decreases with δ by more when the wage is endogenous than when it is exogenously given. In fact, by (20) and (3), $\mid \partial x_{nc}^C/\partial\delta \mid > \mid \partial x_{nc}^{nU}/\partial\delta \mid$. As a result, when a uniform wage rate is set by an industry-wide union, effective R&D investment level decreases for a wider spectrum of values of δ, i.e. for all $\delta > 0.2$.

Clearly then, the uniform industry wage rate w_{nc}^C, the overall cost reduction $(e_{nc}^C - w_{nc}^C)$, and the employment and output levels follow the same pattern as the effective R&D investment level. Finally, firms' profits are not monotonic in the spillover rate; they are increasing with δ for all $\delta < 0.861$ and decreasing for higher spillover rates. This is so because if δ is not too high, the positive R&D cost savings effect (due to the individual firm's R&D investments being decreasing in δ) dominates the negative unit cost reduction effect (due to the firm's overall cost reduction being decreasing in δ for all $\delta > 0.2$). The former effect dominates the latter for higher values of δ and the firm's profits decrease with the spillover rate if $\delta > 0.861$. The following Lemma summarizes:

Lemma 3 *When firms invest non-cooperatively in R&D and wage-setting is centralized, an individual firm's R&D investment decreases with the spillover rate δ. Effective R&D investments, the wage rate, overall cost reduction, employment and output levels are decreasing (increasing) in δ for all $\delta > 0.2$ ($\delta < 0.2$). Finally, firms' profits are decreasing (increasing) in δ for all $\delta > 0.861$ ($\delta < 0.861$).*

As in the decentralized wage setting case, in this case too, an increase in w_0 leads to a higher uniform industry wage rate and as a result, it has a negative impact on the individual and effective R&D investments, as well as on the overall cost reduction, the employment and output levels and the firms' profits.

3.3 A Comparison

We turn now to the comparison of the equilibrium outcomes of the decentralized and the centralized wage-setting regime when firms invest non-cooperatively in R&D. Our discussion above reveals that the individual firm's investment, as a function of the spillover rate, is steeper when an industry-wide union sets the uniform wage rate than when two firm-level unions set the firm specific wages. This is because $\mid \partial x_{nc}^{C}/\partial\delta \mid > \mid \partial x_{nc}^{nU}/\partial\delta \mid > \mid \partial x_{nc}^{D}/\partial\delta \mid$. Moreover, it can be checked that $x_{nc}^{C}(0) > x_{nc}^{D}(0)$, while $x_{nc}^{C}(1) < x_{nc}^{D}(1)$. As a consequence, we have the following result:

Proposition 1 *(i) R&D investments in the industry are higher under a centralized rather than under a decentralized regime if and only if technological spillovers are low enough, i.e.* $\delta < 0.565$.

(ii) Firms' employment level, overall cost reduction and profits are always higher, while wages are always lower, under a decentralized rather than under a centralized regime.

The intuition goes as follows. Due to wage under-cutting between firm-level unions, wage rates are always lower under a decentralized regime rather than when an industry-wide union sets a uniform wage. Nevertheless, under the decentralized regime, the most severe wage-level and wage-differentiation hold-up problems occur when there are no spillovers ($\delta = 0$). This is so, because as we have seen above, the wage-level and wage-differentiation hold-up decrease in δ under the decentralized regime. In contrast, under the centralized regime, the wage-level hold-up increases in δ, and thus it is the least severe when $\delta = 0$ (Recall that there is no wage-differentiation hold-up in this case).

The relative severity of the hold-up under firm-level union wage-setting overturns the relatively softer *unions' rent-extracting effect* and as a result, individual firms have stronger incentives to spend on R&D under the centralized regime whenever spillovers are low enough. The opposite is true when the spillover rate is relatively high. In fact, if $\delta = 1$, the wage-differentiation hold-up is null in the decentralized regime too. Moreover, the wage-level hold-up takes its lowest (highest) value under the decentralized (centralized) regime. Therefore, as the unions' rent-extracting effect is weaker under the decentralized regime, firms have stronger incentives to spend on R&D rather than under the centralized regime.

Interestingly enough, our findings reveal a partial reversal of the hold-up problem. Although firms' incentives to invest in R&D are always lower in a unionized than in a non-unionized industry (from (3), (13) and (20), one can see that $x_{nc}^{C} < x_{nc}^{nU}$ and $x_{nc}^{D} < x_{nc}^{nU}$ for all δ), Proposition 1 tells us that a more centralized unionization structure provides stronger R&D incentives to firms than a less centralized one whenever spillovers are low enough ($\delta < 0.565$). This is in contrast to the conventional wisdom according to which the more severe is the unions' rent-extracting behavior, the lower are the firms investments in R&D.

Finally, overall cost reduction and employment are higher under firm-level wage setting than when an industry-wide union sets a uniform wage rate. This is because, firstly, wage rates are always lower under the decentralized rather than under the centralized regime; and secondly, R&D investments are higher for all $\delta > 0.565$ in this case. Nevertheless, even if δ is low, the negative effect due to lower R&D investments is dominated by the former positive effect and thus overall cost reduction and employment and output levels are higher under firm-level wage setting. As a consequence, firms' profits are higher under the decentralized than under the centralized regime. The lower overall cost reduction effect is reinforced by the R&D cost savings effect for low spillover rates, while for higher spillover rates, the negative effect on profits due to higher R&D spending is dominated by the positive overall cost reduction effect.

4 Cooperative R&D investments

4.1 Firm-level unions

We turn next to the case where firms form an RJV and invest cooperatively in R&D under a decentralized wage-setting regime. The last two stages of the game are as in Subsection 3.1 and employment levels and wage rates are given by (8) and (11) respectively. In the second stage, firms choose R&D investments (x_i, x_j) so as to maximize their joint profits:

$$\begin{aligned} \max_{x_i,x_j}(\pi_i+\pi_j) &= \frac{4\left[5\left(a-c-w_0\right)+x_i\left(7\delta-2\right)+x_j\left(7-2\delta\right)\right]^2}{2025} \\ &+\frac{4\left[5\left(a-c-w_0\right)+x_i\left(7-2\delta\right)+x_j\left(7\delta-2\right)\right]^2}{2025}-x_i^2-x_j^2 \end{aligned} \tag{24}$$

Taking the first order conditions and solving the system of equations, we get the (symmetric) equilibrium R&D investment for each firm:

$$x_c^D = \frac{4\,(1+\delta)\,(a-c-w_0)}{77-8\delta-4\delta^2} \tag{25}$$

Using (25), we obtain the equilibrium wage rates, the employment levels and the firms' profits, respectively,

$$w_c^D = w_0 + \frac{27\,(a-c-w_0)}{77-8\delta-4\delta^2} \tag{26}$$

$$L_c^D = \frac{18\,(a-c-w_0)}{77-8\delta-4\delta^2} \tag{27}$$

$$\pi_c^D = \frac{4\,(a-c-w_0)^2}{77-8\delta-4\delta^2} \tag{28}$$

When firms form an RJV and decide jointly their R&D expenditures, firms' strategic R&D spending in order each to increase its market share is absent. Furthermore, due to the internalization of spillovers, the firms' incentives to invest in R&D become stronger as technological spillovers rise. This is so because the wage-level and the wage-differentiation hold-up problems under decentralized wage-setting become less severe as δ increases (see Subsection 3.1). As a result, the firms' joint profits are increasing in δ for all symmetric firms' R&D expenditures (i.e. for all $x_i = x_j$, see (24)). Clearly then, the effective R&D investment level, $e_c^D = (1+\delta)x_c^D$, increases with δ. Furthermore, although unions push for higher wages as the spillover rate increases, overall cost reduction, employment and output levels as well as firms' gross profits increase with δ. The positive unit cost reduction effect dominates the negative R&D cost savings effect due to higher R&D expenditures and thus firms' profits increase with the spillover rate. The following Lemma summarizes:

Lemma 4 *When firms form an RJV and wage-setting is decentralized, individual firm's R&D investment, effective R&D investment level, wage rates, overall cost reduction, employment and output levels, and firms' profits are increasing in the spillover rate* δ.

Finally, the impact of the workers' outside option on the equilibrium outcome is qualita-

tively similar to that in the case of non-cooperative R&D investments and firm-level unions.

4.2 An Industry-wide Union

When firms form an RJV and invest cooperatively in R&D under a centralized regime, the last two stages of the game are as in Subsection 3.2 and employment levels and the uniform wage rate are given by (8) and (18). In the second stage, firms choose their R&D investments so as to maximize their joint profits:

$$\begin{aligned}\max_{x_i,x_j}(\pi_i+\pi_j) &= \frac{1}{144}\left[2\left(a-c-w_0\right)+x_i\left(7\delta-5\right)+x_j\left(7-5\delta\right)\right]^2 \\ &+\frac{1}{144}\left[2\left(a-c-w_0\right)+x_i\left(7-5\delta\right)+x_j\left(7\delta-5\right)\right]^2-x_i^2-x_j^2\end{aligned} \tag{29}$$

Taking the first order conditions and solving the system of equations, we get the (symmetric) equilibrium R&D investment for each firm:

$$x_c^C=\frac{\left(1+\delta\right)\left(a-c-w_0\right)}{35-2\delta-\delta^2} \tag{30}$$

Using (30), we get the equilibrium uniform wage rate, the employment levels and individual firms' profits, respectively:

$$w_c^C=w_0+\frac{18\left(a-c-w_0\right)}{35-2\delta-\delta^2} \tag{31}$$

$$L_c^C=\frac{6\left(a-c-w_0\right)}{35-2\delta-\delta^2} \tag{32}$$

$$\pi_c^C=\frac{\left(a-c-w_0\right)^2}{35-2\delta-\delta^2} \tag{33}$$

A similar reasoning as under the decentralized regime applies for the centralized wage-setting case. Since firms form an RJV, spillovers are internalized and moreover, there is no strategic R&D spending by the firms. This implies that the equilibrium outcome depends on the spillover rate in a qualitatively similar way to that of the decentralized unionization structure. In fact, all the intuitive arguments are as in Subsection 4.1, with the only exception that the

wage-level hold-up problem becomes more severe as δ increases (see Subsection 3.2). Nevertheless, the firms' joint profits again increase with δ for all $x_i = x_j$ (see (29)). The following Lemma summarizes:

Lemma 5 *When firms form an RJV and wage-setting is centralized, individual firm's R&D investment, effective R&D investment level, wage rates, overall cost reduction, employment and output levels, and firms' profits are increasing in the spillover rate δ.*

Note also that the impact of the workers' outside option on the equilibrium outcome is qualitatively similar to all the cases analyzed previously.

4.3 A Comparison

We next compare the equilibrium outcomes of the decentralized and the centralized wage-setting regimes when firms form an RJV and invest cooperatively in R&D. As we have seen in Subsection 3.3, as δ increases, the wage-level and the wage-differentiation hold-up problems become less severe under the decentralized regime. In contrast, under the centralized regime, the wage-level hold-up becomes more severe as δ increases, while the wage-differentiation hold-up is absent. An immediate consequence is that the individual firm's investment, as a function of the spillover rate, is less steep under centralized rather than under decentralized wage-setting, i.e. $0 < \partial x_c^C/\partial\delta < \partial x_c^D/\partial\delta$. Moreover, since an industry-wide union is able to extract higher rents than the two competing firm-level unions ($w_c^C > w_c^D$), R&D investments are lower under a centralized rather than under a decentralized regime, i.e. $x_c^C < x_c^D$ for all δ. As a result, we obtain the following:

Proposition 2 *R&D investments in the industry, overall cost reduction, employment and output levels, and firms' profits are always higher, while wages are always lower, under a decentralized rather than under a centralized regime.*

When firms form an RJV and decide jointly their R&D investments, it is only the mode of industry unionization that drives the results. In addition, the firms' incentives to invest in R&D are always lower in a unionized rather than in a non-unionized industry (from (5), (25)

and (30), one can see that $x_c^C < x_c^{nU}$ and $x_c^D < x_c^{nU}$ for all δ). Hence, in line with the hold-up argument, $x_c^C < x_c^D < x_c^{nU}$.

An immediate consequence is that overall cost reduction, employment and output levels are higher under decentralized rather than under centralized wage-setting. Firms' profits are higher too, because the positive effect due to lower overall cost reduction under the decentralized regime dominates the negative effect due to higher R&D costs.

Propositions 1 and 2 suggest that the effect of alternative unionization structures on R&D investments depends crucially on whether technological spillovers are internalized or not. In particular, for relatively low spillovers ($\delta < 0.565$), a more centralized unionization structure leads to higher R&D investments when spillovers are not internalized, while the opposite is true when firms form an RJV and internalize those spillovers. This finding is novel in the literature and is in contrast with the conventional wisdom which predicts a negative correlation between union centralization and R&D investment level.

5 Firms' Incentives to Form an RJV

We now turn to the first stage of the game and investigate the firms' incentives to form an RJV under alternative unionization structures. First of all, we reconfirm for a unionized industry the finding obtained for a non-unionized one (see Lemma 1(iii)). That is, whenever the formation of an RJV is *costless*, firms have *always* incentives to form an RJV, independently whether the unionization structure is centralized or decentralized. Indeed, from (16), (28), (23) and (33), it can easily be checked that $\pi_c^D \geq \pi_{nc}^D$ and $\pi_c^C \geq \pi_{nc}^C$ for all δ (with strict inequality for all, but one, values of δ). The intuition is straightforward. By forming an RJV, firms are able to coordinate their R&D expenditure decisions in the second stage and thus attain two goals. First, they internalize the spillovers, avoiding any free-riding behavior; and second, they are better equipped to face the unions' hold up in the subsequent stage. This is, of course, independent of the degree of technological spillovers or the level of wage setting in the industry.

Interestingly enough, the range of spillover rates for which R&D investments are higher under an RJV rather than under non-cooperative R&D investments depends crucially on the unionization structure. In fact, from (13) and (25), it can be checked that $x_c^D > x_{nc}^D$ for all

$\delta > \delta_D \equiv 0.286$; while from (20) and (30), $x_c^C > x_{nc}^C$ for all $\delta > \delta_C \equiv 0.714$. When firm-level unions set the wage rates, R&D investments are higher under an RJV provided that the spillover rate is not too low. Observe that this holds for a wider range of parameter values rather than in a non-unionized industry where the critical value of the spillover rate is $\delta_{nU} = 0.5$. On the other hand, when an industry-wide union sets a uniform wage rate, an RJV promotes R&D investments for a smaller spectrum of parameter values, i.e. only if δ is large enough. If e.g. $\delta = 0.4$, an RJV will promote R&D investments only under a decentralized wage-setting, but not in a non-unionized industry or under a centralized wage-setting regime. The reasoning is as follows. As explained above, the rate of reduction of a firm's R&D investment with δ is smaller under firm-level rather than under industry-wide union wage-setting whenever firms invest non-cooperatively in R&D. In contrast, under an RJV, the rate of increase of a firm's R&D investment with δ is larger in the former rather than in the latter case. Also, when there are no spillovers ($\delta = 0$), the individual firm's R&D effort differential between non-cooperative R&D investments and an RJV is larger under a centralized than under a decentralized regime, i.e. $x_{nc}^C(0) - x_c^C(0) > x_{nc}^D(0) - x_c^D(0)$. This is an immediate consequence of the fact that, in contrast to the firm-level wage-setting case, there is no wage-differentiation hold up when an industry-wide union sets the wage rate (see Haucap and Wey, 2004). On the contrary, in the full spillovers case, we have $x_c^C(1) - x_{nc}^C(1) < x_c^D(1) - x_{nc}^D(1)$, i.e. the individual firm's R&D effort differential between an RJV and non-cooperative R&D investments is larger under a decentralized rather than under a centralized regime. This is due to the fact that, when $\delta = 1$, the wage-level hold up is the most severe under an industry-wide union, while both the wage-level and the wage-differentiation hold up problems are the least severe under firm-level unions. Finally, it can be checked that wages, overall cost reduction, employment and output levels follow the same pattern as the investment levels. Indeed, they turn out to be higher under an RJV rather than under non-cooperative R&D investments for a wider range of spillover rates in the decentralized regime as compared to the centralized one.

The following Proposition summarizes:

Proposition 3 *(i) If the formation of an RJV is costless, firms have always incentives to form an RJV, independently of the unionization structure.*

(ii) R&D investments, wages, and employment and output levels are higher under an RJV

rather than under non-cooperative R&D spending if and only if $\delta > \delta_D \equiv 0.286$ ($\delta > \delta_C \equiv 0.714$) *in the decentralized (centralized) wage-setting regime.*

In reality, however, the formation of an RJV often involves administration and coordination costs that are substantial for the participating firms. It is thus worth identifying the circumstances under which firms have stronger incentives to form an RJV, as well as investigate the role of the unionization structure for the magnitude of these incentives. Define $M^D = \pi_c^D - \pi_{nc}^D$ and $M^C = \pi_c^C - \pi_{nc}^D$, where M^D and M^C measure the magnitude of an individual firm's incentive to participate in an RJV under respectively firm-level unions and an industry-wide union.

In Figure 1 M^D and M^C have been plotted as functions of the spillover rate δ (where w.l.o.g. $a - c - w_0$ has been normalized to 1). The following observations are in order. First, the magnitude of the firms' incentives to form an RJV is non-monotone in the spillover rate under neither unionization structure. In particular, just like in the non-union case, it obtains its highest value for zero or full spillovers and is null for some intermediate value of δ. Second, the latter value differs across unionization structures; it is relatively low ($\delta_D = 0.286$) under decentralized wage-setting and relatively high ($\delta_C = 0.714$) under the centralized one, while it is in between in the non-union case ($\delta = 0.5$, see Lemma 1(iii)). Third, the strongest RJV incentives are observed when spillovers are zero under an industry-wide union, while, just like in the non-union case, they obtain their highest value when spillovers are full under firm-level unions. Last, but not least, the firms' incentives to form an RJV are stronger under the centralized rather than under the decentralized regime whenever spillovers are sufficiently low, i.e. $\delta < \delta_M = 0.534$; and vice versa.

Interestingly enough, the magnitude of the firms' incentives to form an RJV depend not only on the spillover rate, but more importantly on the unionization structure. If, for instance, $\delta = 0.3$ and the RJV formation costs are equal to $0.001(a - c - w_0)^2$, firms have no incentives to form an RJV when they face firm-level unions, while they do so under an industry-wide union. Note that the opposite is true for $\delta = 0.8$ (see Figure 1).

The intuition goes as follows. An individual firm's incentives to participate in an RJV depend on two factors. The overall unit cost reduction effect and the R&D cost savings effect. When spillovers are low, the RJV formation leads to a relatively larger unit cost increase

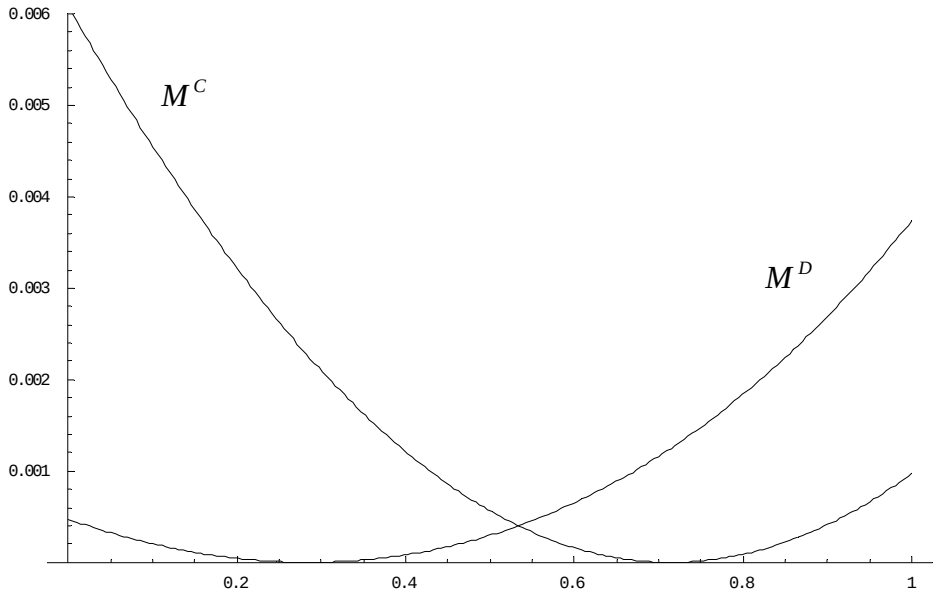

Figure 1: Incentives to form an RJV in case of firm-level unions (M^D) and an industry-wide union (M^C).

under the centralized rather than under the decentralized unionization structure. At the same time, it leads to relatively larger R&D cost savings in the former case rather than in the latter case. This positive R&D cost savings effect dominates the negative unit cost increase effect and firms have stronger incentives to form an RJV in the presence of an industry-wide union rather than under firm-level unions. In contrast, if spillovers are high, the RJV leads to a relatively higher unit cost reduction and a relatively larger increase in R&D expenditures under the decentralized rather than under the centralized regime. The latter negative effect is dominated by the former positive effect and thus the decentralized regime offers stronger incentives for firms to form an RJV when spillovers are high. An immediate consequence of the above discussion is that there exists an intermediate value of δ, $\delta_M = 0.534$, such that for all $\delta < \delta_M$ firms' have stronger incentives to form an RJV under a centralized than under a decentralized regime (and vice versa).

Our findings are summarized in the following Proposition:

Proposition 4 *Firms' incentives to form an RJV are non-monotone in the spillover rate*

and are strongest for zero spillovers under a centralized regime and for full spillovers under a decentralized regime. Moreover, firms have stronger incentives to form an RJV under centralized than under decentralized wage-setting whenever spillovers are low enough, i.e. $\delta < 0.534$*; otherwise, they have weaker incentives.*

6 Welfare analysis

In this Section we perform a welfare analysis and compare the regulator's incentives to encourage the formation of an RJV with the firms' incentives. Social welfare is defined as the sum of consumers' surplus, firms' profits and unions' rents, i.e.,

$$SW_j^k = \frac{1}{2}\left(Q_j^k\right)^2 + 2\pi_j^k + 2(w_j^k - w_0)L_j^k,\ j = nc, c,\ k = D, C \tag{34}$$

where $Q_j^k = 2q_j^k = 2L_j^k$ is the total industry output. Substituting the relevant expressions into (34), we obtain social welfare in the four cases under consideration:

$$SW_{nc}^D = \frac{2\left(21491 + 448\delta - 64\delta^2\right)(a - c - w_0)^2}{\left(377 - 20\delta + 8\delta^2\right)^2} \tag{35}$$

$$SW_{nc}^C = \frac{10\left(91 + 14\delta - 5\delta^2\right)(a - c - w_0)^2}{\left(65 - 2\delta + 5\delta^2\right)^2} \tag{36}$$

$$SW_c^D = \frac{2\left(835 - 32\delta - 16\delta^2\right)(a - c - w_0)^2}{\left(77 - 8\delta - 4\delta^2\right)^2} \tag{37}$$

$$SW_c^C = \frac{2\left(125 - 2\delta - \delta^2\right)(a - c - w_0)^2}{\left(35 - 2\delta - \delta^2\right)^2} \tag{38}$$

One can easily check that $SW_{nc}^D > SW_{nc}^C$ and $SW_c^D > SW_c^C$. Thus, a centralized wage-setting regime leads *always* to lower social welfare than a decentralized one, independently whether firms form, or not, an RJV. The intuition is straightforward. Firms' profits and consumers' surplus are always higher under a decentralized wage-setting regime. In contrast, the unions' rents are always higher under centralized wage-setting. The latter effect is dominated by the former and social welfare turns out to be higher under firm-level unions. It can further

be checked that welfare is always higher in the absence of unions rather than in any unionized industry.[14] Clearly, due to the unions' hold up, firms have weaker incentives to invest in cost-reducing R&D activities. At the same time, unionized firms face higher labor costs. Therefore, consumers' surplus and firms' profits are lower under the presence of unions. As the unions' rents cannot compensate for the losses in the consumer surplus and the firms' profits, welfare is lower in a unionized industry. The above suggest that policy makers should take measures to promote labor market flexibility such that wages reflect better the firms' productivity, e.g. via establishing a more decentralized wage-setting regime in R&D intensive industries.[15]

In a similar vein, unemployment benefits w_0 lead to lower social welfare in all cases, because by strengthening the unions' rent-extracting power, they deter R&D investments and reduce employment and output levels. An immediate policy implication is that a reduction of unemployment benefits is expected to increase cost-reducing R&D activities and thus enhance social welfare.[16]

An important question that arises in our setup is whether a regulator should encourage the formation of an RJV or not. From (35) and (37), it can be checked that $SW_c^D > SW_{nc}^D$ if and only if $\delta > \delta_D = 0.286$; also, from (36) and (38), we have $SW_c^C > SW_{nc}^C$ if and only if $\delta > \delta_C = 0.714$. This is a direct consequence of Proposition 3. Although firms' profits are always higher under an RJV rather than under non-cooperative investments, unions' rents and consumer surplus are higher but only if $\delta > \delta_D$ ($\delta > \delta_C$) under a decentralized (centralized) wage-setting regime. This is due to the fact that R&D investments, wages, and employment and output levels are then higher under an RJV rather than under non-cooperative R&D investments. The following Proposition summarizes.

Proposition 5 *Under firm-level unions, the regulator should encourage the formation of an RJV as long as the spillover rate is not too low (for all $\delta > \delta_D = 0.286$). In contrast, under an*

[14] In a non-unionized industry social welfare is the sum of consumers' surplus and firms' profits. Using the relevant expressions of Subsection 2.1, we obtain $SW_{nc}^{nU} = \frac{2(14+4\delta-\delta^2)(a-c-w_0)^2}{(7-\delta+\delta^2)^2}$ and $SW_c^{nU} = \frac{2(17-2\delta-\delta^2)(a-c-w_0)^2}{(8-2\delta-\delta^2)^2}$. It can then be checked that $SW_{nc}^{nU} > SW_{nc}^D > SW_{nc}^C$ and $SW_c^{nU} > SW_c^D > SW_c^C$.

[15] Haucap and Wey (2004) also suggest that the formation of industry-wide unions should not be allowed due to their monopolization effects.

[16] This is in line with Nickell et al., (2003) suggesting that "Among the wide range of policies and institutions that have the potential to shift the wage curve upwards and generate high unemployment are collective bargaining arrangements that lead to high wage settlements and minimum wages that are high relative to the average wage".

industry-wide union, the formation of an RJV should be encouraged only if the spillover rate is high enough (only if $\delta > \delta_C = 0.714$).

Note further that in the absence of unions, the formation of an RJV should be encouraged only if $\delta > \delta_{nU} = 0.5$.[17] A number of observations are in order. First, the range of spillover parameters for which the regulator should encourage the formation of an RJV is much wider under firm-level unions than under an industry-wide union, with the non-union case lying in between. Thus, the unionization structure of an industry may affect the regulator's decision to encourage the formation of an RJV in that industry. Second, the social and market incentives for the formation of an RJV are not always aligned. Indeed, they diverge significantly in the centralized wage-setting regime, since although firms have always incentives to form an RJV when its formation is costless, this is socially desirable only if spillovers are quite pronounced ($\delta > 0.714$). In contrast, under decentralized wage-setting, the social and market incentives quite often coincide (with the exception in case that spillovers are rather low, $\delta < 0.286$). Interestingly, the extent of alignment between social and market incentives for the formation of an RJV is not monotone in the degree of unionization. In particular, as we move from a non-unionized industry to a decentralized and then to a centralized wage-setting industry, the alignment of incentives initially increases and then decreases. Third, the design of technology and other policies for the encouragement/deterrence of RJVs should make a careful account of all the characteristics of the industry under consideration, and in particular whether firms face a competitive labor market or their employees belong to firm-level unions or to an industry-wide union. Our analysis thus reinforces the argument according to which, labor market policies should be designed in coordination with other policies affecting wages, i.e., technology policy. This is in line with the recent OECD conclusions that "Interactions between collective bargaining and other policies affecting wages receive only cursory attention" (OECD, 2004, p. 128).

[17] It can be checked that $SW_c^{nU} > SW_{nc}^{nU}$ if and only if $\delta > \delta_{nU} = 0.5$ (see footnote above).

7 Extensions

In this section we consider a number of modifications of the basic model in order to discuss the robustness of our main results.

7.1 Bertrand Competition

In the basic model we have assumed that firms produce homogenous goods and compete in quantities. Consider now the case where the firms sell differentiated goods and compete in prices. Each firm i faces a standard linear demand, $q_i = [a(1-\gamma) - p_i + \gamma p_j]/(1-\gamma^2)$, where γ, $0 \leq \gamma < 1$, is the degree of product substitutability, with $\gamma = 0$ ($\gamma = 1$) corresponding to the case of independent (homogenous) goods. Keeping all other modeling specifications fixed, we reconfirm for the Bertrand competition case all our main results.[18] In particular, we show that firms have always incentives to form an RJV, independently of the unionization structure as long as the RJV formation is costless. Further, that there exist critical values of the spillover rate $\delta_D(\gamma)$ and $\delta_C(\gamma)$, respectively for the decentralized and the centralized unionization structure, such that for all $\delta > \delta_r(\gamma)$, $r = D, C$, firms' R&D investments, wages, employment and output levels and social welfare are higher under an RJV than under non-cooperative R&D investments. It also holds that $\delta_D(\gamma) < \delta_C(\gamma)$ for all γ, and that $\delta_D(\gamma)$ and $\delta_C(\gamma)$ are increasing in the degree of product substitutability (with $\delta_D(0) = 0 < \delta_C(0) = 0.333$ and $\lim_{\gamma \to 1} \delta_D(1) = \lim_{\gamma \to 1} \delta_C(1) = 1$). The intuition for the latter result is as follows. The more homogeneous the goods are, the fiercer is the competition between firms, and the larger should thus be the internalized spillovers under an RJV in order R&D investments, wages, employment and output levels and social welfare to be higher under an RJV than under non-cooperative R&D investments. Finally, the intuitive arguments in the Bertrand case are in line with the respective ones in the Cournot case.

7.2 Right-to-Manage

In the basic model we have assumed that unions have all the power to set wages. In reality however, unions and firms often negotiate over their wages, before firms choose their employ-

[18] The detailed analysis for the Bertrand case is available from the authors upon request.

ment and output levels (Right-to-Manage model). It is then natural to ask whether our main results still hold when firms have bargaining power in the wage determination stage. Let β and $(1-\beta)$, $0 \leq \beta \leq 1$, be respectively the bargaining power of the union(s) and the firms during the wage determination stage. That is, both firms have equal bargaining power; moreover, the industry-wide union's power in the centralized negotiations case is equal to a firm-level union's power under decentralized wage negotiations. To solve for the equilibrium wage rates, we employ the Nash equilibrium between two simultaneous firm-union generalized Nash Bargaining games under firm-level unions. While under an industry-wide union, the negotiated wage is the solution to the generalized Nash Bargaining game where the central union negotiates with the firms' federation (whose objective is to maximize the overall industry's profits) over the uniform wage rate.[19]

In the Right-to-Manage model we have reconfirmed our main results.[20] In particular, we show that again firms have always incentives to form an RJV, independently whether wage-negotiations are centralized or decentralized, provided that the formation of the RJV is costless. Secondly, that there exist critical values of the spillover rate $\delta_D(\beta)$ and $\delta_C(\beta)$, respectively for the decentralized and the centralized wage negotiations case, such that for all $\delta > \delta_r(\beta)$, $r = D, C$, firms' R&D investments, wages, employment and output levels and social welfare are higher under an RJV than under non-cooperative R&D investments. Thirdly, we find that $\delta_D(\beta) < \delta_C(\beta)$ for all β, and that $\delta_D(\beta)$ is decreasing, while $\delta_C(\beta)$ is increasing, in the union(s) power. Intuitively, beginning from the benchmark case where wages are exogenous ($\delta = 0.5$), the critical spillover rate decreases (increases), as we move towards the polar case of two monopoly firm level unions (one monopoly industry-wide union). Finally, and as expected, $\delta_D(1) = 0.286 < \delta_C(1) = 0.714$, and $\delta_D(0) = 0.5 = \delta_C(0)$.

An immediate consequence of the above is that it is the institutional level of wage determination (centralized vs. decentralized), and not the distribution of power between firms and unions, that drives our main results. This is a novel finding, because the existing literature does not consider R&D incentives under wage negotiations in alternative unionization

[19] Disagreement payoffs are assumed to be zero and w_0 for firms and union(s), respectively.

[20] The case of firm-level negotiations over wages was analytically solved, while results for the case of bargaining between a central union and the firms' federation were obtained with numerical simulations. Detailed analysis is available from the authors upon request.

structures (see footnote 20).

7.3 Coordinated Union

So far we have assumed that under centralized wage-setting, the industry-wide union sets a uniform wage rate for both firms. Following Hawcap and Wey (2004), we consider now the case where the industry-wide union makes simultaneous take-it-or-leave-it wage offers to the firms in order to maximize overall union's rents, $U(w_i, w_j, L_i, L_j) = (w_i - w_0) L_i(.) + (w_j - w_0) L_j(.)$. This is known in the literature as the *Coordinated* (Co) unionization structure.

Considering first the case in which firms invest non-cooperatively in R&D, we solve the four-stage game and compare its equilibrium outcome with those obtained under the decentralized and the centralized wage-setting regimes.[21] The following Proposition summarizes.

Proposition 6 *An individual firm's R&D investments, as well as employment and output levels, are lower under the coordinated than under both the decentralized and the centralized wage-setting regimes. Equilibrium wage rates, firms' profits and social welfare under the coordinated regime lie in between the decentralized and the centralized regime.*

Interestingly, and in contrast to the conventional hold-up argument, R&D investments under the coordinated regime are lower than equilibrium investments under the centralized regime. This is so because the *wage-level hold-up* is more severe under an industry-wide union that coordinates its wage demands than under a union that sets a uniform wage rate. In addition, in contrast to the centralized wage-setting regime where the wage-differentiation hold-up is absent, wage-differentiation hold-up is present under coordinated wage-setting.

Turning next to the case where firms form an RJV and invest cooperatively in R&D, it can be shown that the coordinated wage-setting regime leads to the same equilibrium outcomes as the centralized one. This is due to the linearity of the firms' labor demand functions, which are also symmetric as long as the two firms' R&D investments are equal under the RJV. In this case a wage discriminating industry-wide union will set the same wage rate for both firms, which will be equal to the uniform wage rate that would have been set by a (non-discriminating)

[21] See Appendix for the analysis of the coordinated union case. Further details are available from the authors upon request.

industry-wide union. Anticipating this, firms that form an RJV and avoid thus free-riding have the same incentives to spend on R&D independently whether an industry-wide union sets a uniform wage rate or two firm-specific wage rates. We further find that R&D investments, wages, employment and output levels are higher under an RJV than under non-cooperative R&D spending if and only if $\delta > \delta_{Co} \equiv 0.5$, with $\delta_D < \delta_{Co} = \delta_{nU} < \delta_C$. Surprisingly enough, the critical spillover rate under the coordinated case coincides with that under a non-unionized industry.

Finally, defining $M^{Co} = \pi_c^{Co} - \pi_{nc}^{Co}$ as an individual firm's incentive to participate in an RJV under a coordinated wage-setting regime, and comparing firms' incentives to form an RJV under the three alternative unionization structures, we obtain the following result:

Proposition 7 *(i) Firms have stronger incentives to form an RJV under coordinated than under decentralized wage-setting whenever $\delta < 0.379$; otherwise, they have weaker incentives.*

(ii) Firms have stronger incentives to form an RJV under coordinated than under centralized wage-setting whenever $\delta < 0.638$; otherwise, they have weaker incentives.

The intuitive arguments go along the lines of the analysis that compares the magnitude of an individual firm's incentives to participate in an RJV under firm-level unions and an industry-wide union.

8 Conclusions

In this paper we have investigated the effects of alternative unionization structures on firms' R&D investments, employment and output levels, firms' profits and welfare, by incorporating R&D spillovers and allowing firms to form Research Joint Ventures. In our setup, we have identified various circumstances under which a reversal of the "hold-up" argument is observed. In particular, union centralization is shown to create stronger R&D incentives than a decentralized unionization structure for all market sizes whenever spillovers are low enough. We have also shown that the magnitude of the firms' incentives to form an RJV is non-monotone in the spillover rate, independently whether firms are unionized or not, as well as independently of the mode of unionization. In fact, the formation of an RJV is more attractive for firms when spillovers are absent or when they are full, but this depends on the particular unionization

structure in the industry. As a consequence, the firms' benefits from an RJV depend crucially on both the severity of the spillovers and the mode of unionization. Therefore, the firms' incentives to form a costly RJV could differ substantially across industries. Finally, market and social incentives for the formation of an RJV often diverge, and in particular they are hardly aligned in the case of a centralized unionization structure. Our findings further suggest that policy measures that are intended to encourage RJVs should be carefully designed, taking into account all the features of the industry, namely its unionization structure, the severity of spillovers etc.

Our results could also provide some guidelines for future empirical research on the "R&D investments in unionized industries" literature which, as mentioned above, is so far inconclusive as regards the role of unions for firms' innovation activities. Empirical analyses should begin with a detailed study classifying industries according to their unionization structure, the severity of the spillovers as well as the organizational mode of R&D activities. A number of testable hypotheses emerges from our analysis. For instance, in industries with low R&D spillovers and non-cooperative R&D spending, a testable hypothesis is that R&D investments under an industry-wide union are larger than the respective ones under firm-level unions. A second testable hypothesis is that the probability of firms to participate in an RJV depends on the level at which wages are set for industries with similar spillover rates. A third testable hypothesis is that in industries with low spillovers, the probability of firms' participation in RJVs is higher under centralized than under decentralized unionization; and vice versa for high spillovers.

In our analysis we have assumed that spillovers are exogenously given. There is however a recent line of research where spillovers are treated as endogenous, that is, firms optimally choose the extent to which their technological achievements will spill over to their rivals (see e.g. Poyago-Theotoky, 1999; Gil-Moltó et al., 2005; Piga and Poyago-Theotoky, 2005). An interesting direction for further research would be to endogenize spillovers for both the cases of non-cooperative R&D spending and an RJV and investigate the role of alternative unionization structures for the firms' incentives to spend on R&D as well as to form RJVs.

9 Appendix

The Coordinated Union case: We first consider non-cooperative R&D investments. Output and employment levels are then given by (8). In the third stage, the industry-wide union chooses w_1 and w_2 so as to maximize its overall rents:

$$\max_{w_i, w_j} U = \sum_{i,j=1,2,i\neq j} \frac{1}{3}(w_i - w_0)\left[(a-c) - 2w_i + w_j + x_i(2-\delta) + x_j(2\delta - 1)\right] \tag{39}$$

>From the first order conditions of (39), the firm i's wage rate is:

$$w_i(x_i, x_j) = \frac{1}{2}(a - c + w_0 + x_i + \delta x_j) \tag{40}$$

As expected, w_i increases with the workers' outside option w_0, as well as with the firm i's R&D effort x_i. The latter reflects the *wage-level hold-up*, with $\frac{\partial w_i^{Co}}{\partial x_i} = \frac{1}{2}$, independent of the spillover rate δ. Note also that w_i increases with the rival firm's R&D effort x_j. Moreover, one can check from (40) that $\Delta w = w_i - w_j = \frac{1-\delta}{2}(x_i - x_j)$. This reflects the *wage-differentiation hold-up,* with $\frac{\partial \Delta w^{Co}}{\partial x_i} = \frac{1-\delta}{2}$; i.e. it becomes less pronounced as δ increases.

In the second stage, firms simultaneously invest in R&D, each maximizing its profits, which after substituting (40) into (7) are given by:

$$\max_{x_i} \pi_i = \frac{1}{36}\left[a - c - w_0 + x_i(2-\delta) + x_j(2\delta - 1)\right] - x_i^2 \tag{41}$$

>From the first order conditions of (41) and symmetry, the equilibrium R&D investment is:

$$x_{nc}^{Co} = \frac{(2-\delta)(a-c-w_0)}{34 - \delta + \delta^2} \tag{42}$$

Using (42), we get respectively each firm's equilibrium wage rate, employment level, and profits:

$$w_{nc}^{Co} = w_0 + \frac{18(a-c)}{34 - \delta + \delta^2} \tag{43}$$

$$L_{nc}^{Co} = \frac{6(a-c-w_0)}{34 - \delta + \delta^2} \tag{44}$$

$$\pi_{nc}^{Co} = \frac{(32 + 4\delta - \delta^2)(a - c - w_0)^2}{\left(34 - \delta + \delta^2\right)^2} \tag{45}$$

Interestingly, when an industry-wide union coordinates its wage demands w_1 and w_2, the relation between the effective R&D investment $e_{nc}^{Co} = (1 + \delta)x_{nc}^{Co}$ and the spillover rate is an inverted U-shaped, with its maximum attained at $\delta = 0.5$. The intuition behind this result goes along the lines of the centralized wage-setting case. It can also be shown that the rate of reduction of an individual firm's R&D effort as the spillover rate δ increases lies in between the respective rates under the centralized and the decentralized regime, i.e. $\mid \partial x_{nc}^{D}/\partial\delta \mid < \mid \partial x_{nc}^{Co}/\partial\delta \mid < \mid \partial x_{nc}^{C}/\partial\delta \mid$. The equilibrium wage rates, the overall cost reduction $(e_{nc}^{Co} - w_{nc}^{Co})$, and the employment and output levels follow the same pattern as the effective R&D investment level. Nevertheless, firms' profits are always increasing in the spillover rate δ.

On the other hand, when firms form an RJV and invest cooperatively, it turns out that the equilibrium outcome is the same independently whether the industry-wide union sets a uniform wage rate w or it coordinates its wage demands w_1 and w_2 (and is given by Eqns. (30) - (33)). In fact, the industry-wide union's wage demand for each firm is equal to the equilibrium uniform wage rate under the centralized wage-setting regime. As a result, firms have the same incentives to invest in R&D in the coordinated and the centralized wage-setting regime.

Finally, one can easily check that in the coordinated wage-setting regime, equilibrium R&D investments, wage rates, and employment and output levels are higher under an RJV than under non-cooperative R&D spending if and only if $\delta > \delta_{Co} \equiv 0.5$. ■

References

[1] Benfratello, L. and A. Sembenelli (2002), "Research joint ventures and firm-level performance", *Research Policy,* 31, 493-507.

[2] Bernstein, J. and M. Nadiri (1989), "R&D and intra-industry spillovers: an empirical application of dynamic duality", *Review of Economic Studies,* 56, 249-269.

[3] Calabuig, V. and M. Gonzalez-Maestre (2002), "Union structure and incentives for innovation", *European Journal of Political Economy,* 18, 177-192.

[4] Caloghirou, Y., S. Ioannides, and N.S. Vonortas (2003), "Research Joint Ventures", *Journal of Economic Surveys,* 17, 541-570.

[5] Coe, D. and E. Helpman (1988), "International R&D spillovers", *European Economic Review,* 39, 854-888.

[6] d'Aspremont, C. and A. Jacquemin (1988), "Cooperative and non-cooperative R&D in duopoly with spillovers", *American Economic Review,* 78, 1133-1137.

[7] Flanagan, R.J. (1999), "Macroeconomic performance and collective bargaining: an international perspective", *Journal of Economic Literature,* 37, 1150–1175.

[8] Frantzen, D. (2000), "Innovation, international technological diffusion and the changing influence of R&D on productivity", *Cambridge Journal of Economics,* 24, 193-210.

[9] Gil Moltó, M. J., N. Georgantzis, and V. Orts (2005), "Cooperative R&D with endogenous technology differentiation," *Journal of Economics and Management Strategy*, 14, 461-476.

[10] Grout, P.A. (1984), "Investment and wages in the absence of binding contracts: a Nash bargaining approach", *Econometrica,* 52, 449-460.

[11] Haucap, J. and C. Wey (2004), "Unionisation structures and innovation incentives", *Economic Journal,* 114, 149–165.

[12] Hagedoorn, J. and H. van Kranenburg (2003), "Growth patterns in R&D partnerships: an exploratory statistical study", *International Journal of Industrial Organization,* 21, 517–531.

[13] Hartog, J. and J. Theeuwes (1992), *Labour market contracts and institutions: a cross national comparison*, Amsterdam: North-Holland.

[14] Hirsch, B.T. (2004), "What Do Unions Do for Economic Performance?", *Journal of Labor Research,* 25, 415-455.

[15] Mauleon, A., J. Sempere-Monerris, and V. J. Vannetelbosch (2005), "R&D networks among unionized firms", Fondazione Eni Enrico Mattei, Nota di Lavoro, 49.2005.

[16] Menezes-Filho, N. and J. Van Reenen (2003), "Unions and innovation: A survey of the theory and empirical evidence", CEPR Discussion Paper no. 3792, CEPR: London.

[17] Nickell, S., L. Nunziata, W. Ochel, and G. Quintini (2003), "The Beveridge Curve, Unemployment and Wages in the OECD from the 1960s to the 1990s", in P. Aghion, R. Frydman, J. Stiglitz and M.Woodford (eds.), *Knowledge, Information and Expectations in Modern Macroeconomics: In Honor of Edmund S. Phelps*, Princeton University Press, Princeton.

[18] OECD (2004), "Employment Outlook", Paris.

[19] Petrakis, E. and M. Vlassis (2004), "Endogenous wage-bargaining institutions in oligopolistic industries", *Economic Theory,* 24, 55–73.

[20] Piga, C. and J. Poyago-Theotoky (2005), "Endogenous R&D spillovers and location choice," *Regional Science and Urban Economics*, 35, 127-139.

[21] Poyago-Theotoky, J. (1999), "A note on endogenous spillovers in a non-tournament R&D duopoly," *Review of Industrial Organization*, 15, 253-262.

[22] Tauman, Y. and Y. Weiss (1987), "Labor unions and the adoption of new technology", *Journal of Labor Economics,* 5, 477-501.

[23] Ulph, A. and D. Ulph (1994), "Labour markets and innovation: ex-post bargaining", *European Economic Review,* 38, 195-210.

[24] Ulph, A. and D. Ulph (1998), "Labour markets, bargaining and innovation", *European Economic Review,* 42, 931-939.

[25] Vonortas, N.S. (1997), "Research joint ventures in the United States", *Research Policy,* 26, 577-595.