Union-Oligopoly Bargaining and Vertical Differentiation: Do Unions Affect Quality?

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Abstract

This paper investigates unionized oligopolistic markets with differentiated products and quality improvement-R&D investments. In endogenous union structures, we investigate the conditions under which firm-level unions may strategically collude, or not, and the impact of their decisions upon the firms' incentives to individually spend on R&D investments. We show that, separate firm-level unions are sustained in the equilibrium, where product quality and the level of R&D investments are relatively high. Moreover, we consider two instances of policy maker's intervention. In the first case, we assume that a benevolent policy maker proceeds to quality improvement-R&D, as a common public good, by undertaking the costs of those investments and providing for free the know-how to the industry. In the second case he finances a percentage of the cost of firm-specific R&D investments. In both cases he finances those costs by indirect taxation on market products. We conclude that all market participant surpluses are higher (and consequently so is Social Welfare), when the R&D – quality improvement is a public good, even if this leads to indirect taxation on market products.

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1. Introduction

An approach of labor market analysis, regarding the perfect competitive rule, is the existence of unions as a means to ensure higher wages for its members. The institution of unions is not surprising, given the predominance of them in most advanced industrial economies (especially in northern Europe). There are several papers, theoretical and empirical, that are aimed to interpret the unions' effects on labor and product markets. The analysis focuses mainly on union structures (*centralized / decentralized*), their objective function (*wages* or/and *employment*) and their strategic environment (*monopoly unions, efficient bargain, Nash equilibrium*), within a closed or open economy with various institutional arrangements.

The institution of the unions was introduced relatively recently on the agenda of orthodox economics. The present paper focuses on unionized oligopolistic markets with differentiated products and quality improvement-R&D investments. The entire analysis explores the impact of unions' decisions on their structure i.e. decentralized and centralized wage-setting regimes on market outcomes, chiefly product quality improvement. Notice that both union structures and R&D investments, hence product' quality, are endogenously determined by market participants.

An approach to incorporate R&D into unionized oligopolies was realized by Emmanuelle Bacchiega (2007). Assuming that product quality depends on highly-skilled workers employed and firms entering into negotiations only with those workers, he concludes that if the bargaining power of those workers is relatively high (low), then firms prefer to produce low (high) quality products and the Social Welfare decreases with the bargaining power of highly-skilled workers. While, Symeonidis (2003) investigates duopolistic markets with differentiated products and R&D

investments – quality improvement, and focuses on the comparative analysis of firms' mode of competition, Bertrand and Cournot.

Recently and like our paper on unionized oligopolistic markets with differentiated products, Manasakis and Petrakis (2009) investigate the impact of union structures and externalities of R&D (R&D spillovers) on firms' incentives, not only for R&D investments, but also for Research Joint Venture (RJV) formation. Unlike us, the authors assume that R&D investments refer to reduction of production costs and they do not endogenize the union structures into their analysis. In contrast, in our research one of our findings demonstrates that if the spillover rate is low and firms do not form RJV, the R&D investments are always higher (lower) under a centralized (decentralized) system of wage-setting.

Empirical research by Menezes-Fillo and Van Reenen (2003), conclude that there is a strong negative impact of unions on R&D investment in South Africa, however there is not a clear conclusion about Europe. The above conclusion is further supported by a brief survey of Jorg Lingens (2009). He uses real data and focuses on the correlation between the unionization of a country and the level of R&D investments. The survey included data from15 European countries, United States and Japan. He tried to present graphically the total R&D investments (as a percentage of GDP) and unions' bargaining coverage. Taking into consideration all countries, he shows a clear negative correlation between investment on R&D and union negotiations over wages (w-bargaining). However, he agrees with Menezes-Fillo and Van Reenen (2003) about Europe, that there is not a clear correlation between investment on R&D and the degree of unionism in Europe.

Our paper studies unionized oligopolistic markets with differentiated products and firms' R&D investments on product quality improvement. We endogenize the union structures, i.e. the decentralized and the centralized wage-setting regimes, and investigate the impact of their decision on market outcomes/participant surpluses. We extend our research by developing two alternative market policies, where the role of the social planner is inserted and endogenize the selection of market structure in our model. In the first case, we assume that a benevolent policy maker proceeds to quality improvement-R&D, as a common public good, by undertaking the costs of those investments and providing for free the know-how to the industry. In the second case he finances a percentage of the expenditures of firm-specific R&D investments. In both cases he finances those costs by indirect taxation on market products. We conclude that union collusive play decreases product quality and output level under each of the proposed market structures (including where the social planner is absent). Additionally, our findings show the market structure in where the R&D – quality improvement is a public good, not only emerges in equilibrium, but also promotes important industry elements s, such as output level, wages and product quality, and all market participant surpluses (and consequently Social Welfare), even if this policy leads to indirect taxation on market products.

The rest of the paper is structured as follows. In Section 2 we present our unionized oligopoly model. In Section 3 - 5, we analyze separately the cases of market structure in where the social planner is inactive/absent, proceeds to R&D investments and partially funds the firms' R&D investments, respectively. Subsequently in Section 6, our model endogenizes the choice of market structure and demonstrates the one which emerges in equilibrium, while in Section 7 we proceed to the comparative analysis of each market structure outcomes/participant surpluses. Our findings are summarized in Section 8.

2. The Model

Consider a unionized product market where two technologically identical firms, denoted by $i \neq j = 1{,}2$, produce differentiated goods and investigate in R&D – quality improvement. Each firm faces an inverse linear demand function, which is derived by consumer utility from consumption under the restriction of their income. Following Häckner (2000), the represented consumer utility function[1] is the following:

$$u_c = (1 + hx_i)q_{ic} + (1 + hx_j)q_{jc} - \frac{1}{2}\left(q_{ic}^2 + q_{jc}^2 + 2\gamma q_{ic}q_{jc}\right) + m \qquad (1)$$

Where q_{ic}, q_{jc} and m respectively are the quantities of good i, good j and the competitive numeraire sector, consumed by the represented consumer and $\gamma \in (0,1)$ denotes the degree of substitutability among the goods $i \neq j = 1{,}2$: As $\gamma \to 1$ the firms' products become more close substitutes. Moreover, x_i denotes the quality of products which arises from firms' expenditures on R&D, and $h \in (0,1)$ is the consumer evaluation of the product quality: As $h \to 0$ the consumers become completely indifferent about product quality.

Taking into consideration the represented consumer's utility function [given in (1)] and its income limitation, we get the inverse linear demand function that firms' face, which is:

$$p_i(q_i, q_j) = 1 - q_i - \gamma q_j + hx_i \qquad (2)$$

Where, p_i, q_i respectively are the price and output of the firm $i \neq j = 1{,}2$.

For simplicity, we assume that the production technology exhibits constant returns to scale, and requires only labor input to produce the good[2]. Labor productivity equals

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[1] For simplicity, we assumed that both a and b are equal to one.

[2] This is equivalent to a two-factor Leontief technology in which the amount of capital is fixed in the short run and it is large enough not to induce zero marginal product of labor.

one, for both firms, namely one unit of labor is needed to produce one unit of product, that is:

$$\mathrm{L_i} = \mathrm{q_i} \tag{3}$$

Where L_i and q_i respectively represent employment and quantity of the firm i $(\neq j = 1,2)$.[3]

The firm's unit transformation cost of labor into product equals the wage rate, denoted by w_i. Hence, the profit function of firm i is defined by:

$$\Pi_\iota = (p_i - w_i)q_i - \frac{{x_i}^2}{2} \tag{4}$$

Where the ${x_i}^2/2$ denotes the firm i's expenditures on R&D in order to improve its own product quality.

The labor market is unionized: Workers are organized into two separate firm-specific unions. Hence, each firm enters into negotiations over (only) wages, exclusively with its own union (decentralized *Right-to-Manage* bargaining[4]). Moreover, we assume that unions are identical, endowed with monopoly bargaining power during the negotiations with their own firms and may compete or collude by independently adjusting their own wages. Hence, each union effectively acts as a firm-specific monopoly union, setting the wage, with the firm in turn choosing firm specific-employment. The union i's objective is to maximize the sum of its members' rents, given by the following equation:

$$u_i(w_i, L_i) = w_i L_i \tag{5}$$

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[3] We are aware of the limitations of our analysis in assuming specific functional forms and constant returns to scale. However, the use of more general forms would jeopardize the clarity of our findings, without significantly changing their qualitative character.

[4] Right-to-manage literature was initially developed by the British school during the 1980s (Nickell). It implies that the union-firm negotiations agenda includes only the wage rate, which is determined according to a typical Nash Bargaining Maximization.

Where, w_i is firm i's wage rate, provided that union membership is fixed and all members are (or the union leadership treats them as being) identical [see, e.g. Oswald (1982), Pencavel (1991), Booth, (1995)].

In addition, we insert the role of a benevolent policy maker in our model, who aims to maximize Social Welfare by endogenously deciding whether to intervene (and how) or not in the market structure. We consider two instances of policy maker's intervention. In the first case, we assume that the policy maker proceeds to quality improvement-R&D, as a common public good, by undertaking the costs of those investments and providing the know-how to the industry for free. Thus, his cost function is defined by the following equation:

$$TC_1^{PM} = \frac{x^2}{2} \tag{6}$$

Where $x^2/2$ denotes the expenditures on R&D in order to improve the industry's product quality.

In the second case he finances a percentage of the cost of firm-specific R&D investments and his cost function is defined by:

$$TC_1^{PM} = (1-f)\frac{x_i^2 + x_j^2}{2} \tag{7}$$

Where the ${x_i}^2/2$ and f denote the firm i's expenditures on R&D and the presentence of its financial participation in these expenditures, respectively. Consequently, the factor $1-f$ presents the presentence of policy maker's financing on firms' expenditures on R&D.

In both cases the policy maker finances these costs by indirect taxation on market products. In particular, we assume that he finances the investment on R&D exclusively by indirect consumption taxation on the final product [$TC \leq TR$ (Balance

Budget[5])]. Accordingly, his revenue function is defined by the following equation and applies to both cases:

$$TR^{PM} = tQ \tag{8}$$

Where t and Q denote the collected tax per unit of product and the sum of the firms' output level, respectively.

From the perspective of consumers, the consumption tax is an additional cost on the purchase price of industry's products, as it is presented in the following equation:

$$p_i^C = p_i + t \tag{9}$$

Where p_i^C denotes consumer price of products, which is the sum of the product price received by producers (denoted by factor p_i) and the consumption tax collected by the Social Planner (denoted by factor t).

Taking into consideration (9), we get the new inverse linear demand function that firms' face, which is:

$$p_i(q_i, q_j) = 1 - q_i - \gamma q_j + hx - t \tag{10}$$

In the above context, we propose three games, one for each potential action of the social planner, as follows:

1. Under the hypothesis that the social planner decides not to intervene in the market structure, our envisaged four-stage game unfolds as follows:
    - ❖ At the 1st stage, both unions simultaneously and independently decide whether to collude or to compete in the stage of w-negotiations with their firms.
    - ❖ At the 2nd stage, firms simultaneously and independently determine the optimal level of their R&D investments, by evaluating on the one hand the

[5] A government balance budget refers to a budget in which total revenues are equal or greater to total expenditures (no budget deficit). In our case, the balance budget has to do exclusively with our oligopoly industry.

increase of their revenues, through increasing their product demand because of their product quality improvement, and on the other hand the cost of these investments.

- At the 3rd stage, if (at the first stage) one or both unions have independently decided to play collusively, they simultaneously and independently set their wages for their own firms so that each maximizes the joint member rents or maximizes its own member rents. If, however, both unions have (at the first stage) independently decided to play competitively they both set their own wages in order for each one to maximize its own member rents.
- At the 4th stage, each firm simultaneously and independently compete with its rival by adjusting its own quantities, in order to maximize their own profits.

2. Assuming that the social planner decides to intervene in the market structure by proceeding to quality improvement-R&D and providing the know-how to the industry for free, our envisaged four-stage game unfolds as follows:
   - At the 1st stage, the social planner determines the optimal level in terms of Social Welfare of R&D investments and indirect taxation on industry products.
   - At the 2nd stage, both unions simultaneously and independently decide whether to collude or to compete in the stage of w-negotiations with their firms.
   - The 3rd stage and the 4th stage of the present game remain the same with the previously proposed one.
3. Now suppose that the social planner decides to intervene in the market structure by financing a percentage of the cost of firm-specific R&D investments, thus our envisaged five-stage game unfolds as follows:

- At the 1st stage, the social planner determines the optimal level in terms of Social Welfare of financing a percentage of the cost of firm-specific R&D investments and the indirect taxation on industry products.
- The 2nd, 3rd, 4th and 5th stages of the present game are nothing more or less than an image of the first proposed game.

3. 1st case: Absence of policy maker in market structure

Like in standard game-theoretic analysis, using backwards induction, we propose a candidate equilibrium and subsequently validate (or reject) it, by checking for all possible unilateral deviations on the part of the agent(s) who consider such a deviation. Due to symmetry, in our model three candidate equilibria arise, at the first stage of the game: In Subsection 3.1 the candidate equilibrium is the one where union collusive play takes place in w-negotiations with their firms (e.g., unions independently set the wages that maximize the joint rents) and the possible deviation, on the part of any union, is to adjust its own wages in order to maximize its own rents given that the other union sticks to collusive play. In Subsection 3.2, the candidate equilibrium is union competition and the possible deviation, on the part of any union, is to set its own wages in order to maximize the joint rents, given that the other union still behaves as a competitor. In Subsection 3.3, the candidate equilibrium is the one where one union acts collusively, while its rival union acts competitively, and the possible deviations arise by unilaterally switching each union's strategy to its rival's one.

3.1. Competitive Play (*m*)

Assume that at the first stage of the game each union aims to maximize its own rents by independently setting its wages at the stage of negotiations with their specific firm (hence, its employment level).

At the last stage of the game, both firms independently choose their own quantities (thus their own employment levels) in order to maximize their own profits. Hence, according to (2) and (4), the firm's i's objective is:

$$max_{q_i}\left[\Pi_i\left\{= q_i(1-\gamma q_j - w_i + hx_i) - \frac{{x_i}^2}{2}\right\}\right] \tag{11}$$

The first order condition (*f.o.c.*) of (11) provides the reaction function of firm i:

$$R_i(q_j) = (1-\gamma q_j - w_i + hx_i)/2 \tag{12}$$

Notice that each firms' output level decreases further with its rivals output level, the higher the substitutability of the products is.

Taking the reaction functions of both firms and solving the system of equations, we get the optimal output/employment rules in the candidate equilibrium:

$$q_i(w_i, w_j) = \frac{2-\gamma-2w_i+\gamma w_j+2hx_i-\gamma hx_j}{(2-\gamma)(2+\gamma)} \tag{13}$$

It is easily observable that firm i's output level is negatively affected by union i's wage rate and rival firm's R&D investment but it is positively affected by union j's wage rates and its R&D investment.

At the third stage, each union i chooses the firm-specific wage (w_i) in order to maximize its own rents [given in (5)], taking as given the outcomes of the production game [given in (33)].

$$max_{w_{im}}[u_i\{= w_{im}q_i\}] \tag{14}$$

From the *f.o.c*$_s$ of that maximization we may then derive the unions' $i \neq j = 1{,}2$, wage reaction functions which are as follows:

$$w_{im}(w_{jm}) = (2 - \gamma + \gamma w_{jm} + 2hx_{im} - \gamma hx_{jm})/4 \qquad (15)$$

Observe that wages are strategic complements for the unions, since: $dw_i/dw_j = \gamma/4 > 0 \ \ \forall\, \gamma \in (0{,}1)$

Solving system (15) we get the wage outcome (s) in the candidate equilibrium:

$$w_{im}^{*} = \frac{(2-\gamma)(4+\gamma) + hx_i(8-\gamma^2) - 2\gamma hx_j}{(4-\gamma)(4+\gamma)} \qquad (16)$$

Note that, $dw_{ic}/dx_{ic} = \big(h(8-\gamma^2)\big)/\big((4-\gamma)(4+\gamma)\big) > 0$, which means firm i by increasing its R&D investments (its product quality) and therefore its product and labor demand, creates an extra union cost – in terms of a higher wage set by its union of workers. The increment in union i's wages would be higher, the higher the consumer evaluation of the product quality from R&D is $\left[d^2w_{im}/(dx_{im}dh) = (8-\gamma^2)/\big((4-\gamma)(4+\gamma)\big) > 0\right]$. Moreover, even if wages are strategic complements for the unions, if firm *j* increases its R&D investment and creates an increment in union j's wages, the wages of union i will be decreased. $[dw_{im}/dx_{jm} = -\,(2h\gamma)/\big((4-\gamma)(4+\gamma)\big) > 0]$. The explanation is that an increment of firm j's R&D investments, hence product j's quality, cases two opposite effects on union i's wages: A positive one, due to higher union j's wages and wages' complementarity, and a negative one which is dominated, due to shrinkage of union i's labor demand by increasing the product j's output level.

At the second stage firms simultaneously and independently determine the optimal level of their R&D investment in order to maximize their profits, given the optimal output/employment rules and the equilibrium wages in (13) and (16) respectively. The firms' maximization objective is derived by substituting (4) for (13) and (16):

$$max_{x_{im}}\left[\Pi_i\left\{= q_{im}\left(1-\gamma q_{jm}-w_{im}+hx_{im}\right)-\frac{{x_{im}}^2}{2}\right\}\right] \quad (17)$$

The *f.o.c$_s$* of (27) provides the reaction function of firm i to the investments in R&D:

$$R_{im}^{R\&D}(x_{jm})=\frac{8h(8-\gamma^2)\left((4+\gamma)(2-\gamma)-2\gamma hx_{jm}\right)}{(4+\gamma)^2(2-\gamma)^2(4-\gamma)^2(2+\gamma)^2-8h^2(8-\gamma^2)} \quad (18)$$

From the above firms' reaction function, we get that R&D investments are strategic substitutes.

Solving the system of *f.o.c$_s$* of that maximization, we get the (candidate) equilibrium R&D investments:

$$x_{im}^*=\frac{8h(8-\gamma^2)}{(4+\gamma)(2-\gamma)(4-\gamma)^2(2+\gamma)^2-8h^2(8-\gamma^2)} \quad (19)$$

The firms' output/employment levels in the candidate equilibrium are then derived by substituting (19) and (16) for (13):

$$q_{im}^*=\frac{2(2-\gamma)(2+\gamma)(4-\gamma)(4+\gamma)}{(4+\gamma)(2-\gamma)(4-\gamma)^2(2+\gamma)^2-8h^2(8-\gamma^2)} \quad (20)$$

Moreover, we get that the firms' profits in the candidate equilibrium:

$$\Pi_{im}^*=\frac{4\left(\left(64-20s^2+s^4\right)^2-8h^2\left(8-s\right)^2\right)}{\left((4+\gamma)(2-\gamma)(4-\gamma)^2(2+\gamma)^2-8h^2(8-\gamma^2)\right)^2} \quad (21)$$

From Equations (16) and (5), we get the candidate equilibrium union wages and rents, respectively, as follows:

$$w_{im}^*=\frac{(4-\gamma)(4+\gamma)(2-\gamma)^2(2+\gamma)^2}{(4+\gamma)(2-\gamma)(4-\gamma)^2(2+\gamma)^2-8h^2(8-\gamma^2)} \quad (22)$$

$$u_{im}^*=\frac{2(4-\gamma)^2(4+\gamma)^2(2-\gamma)^3(2+\gamma)^3}{\left((4+\gamma)(2-\gamma)(4-\gamma)^2(2+\gamma)^2-8h^2(8-\gamma^2)\right)^2} \quad (23)$$

3.2. Collusive Play (*c*)

Assume next that, at the first stage of the game, both unions independently choose to behave collusively at the third stage, where they enter into negotiations over their wages with their own firms, in order to maximize the joint rents.

Thus, at the last stage of the game, we get the firms' reaction functions, and consequently the optimal output/employment rules in the candidate equilibrium in Equations (12) and (13).

Taking in to consideration (13) at the third stage, union i chooses w_i so as to maximize the sum of rents of its members and the competitor firm's union members:

$$max_{w_i}\left[u_i + u_j\{= w_i q_i + w_j q_j\}\right] \tag{24}$$

From the $f.o.c_s$ of (24) we subsequently derive the union i's wage reaction function:

$$w_{ic}(w_{jc}) = (2 - \gamma + 2\gamma w_{jc} + 2hx_{ic} - \gamma hx_j)/4 \tag{25}$$

As in the previous section, note that $dw_{ic}/dw_{jc} = \gamma/2 > 0 \ \forall\, s, \varphi \in (0,1)$, hence, wages are strategic complements on the part of unions. Solving the system (25) we get the (candidate) equilibrium wages:

$$w_{ic}^{*} = (1 + hx_{ic})/2 \tag{26}$$

Observe that $dw_{ic}/dx_{ic} = h/2 > 0$, i.e. the higher the quality of products, the higher is the wage set by the union. The magnitude of this wage increment is higher, when the consumer evaluation of the product quality from R&D is higher $[d^2 w_{ic}/(dx_{ic}dh) = 1/2 > 0]$.

At the second stage, firms simultaneously and independently determine the optimal level of their R&D investment in order to maximize their profits [given by substituting (4) for (13) and (26)]:

$$max_{x_{ic}}\left[\Pi_i\left\{= q_{ic}\left(1-\gamma q_{jc}-w_{ic}+hx_{ic}\right)-\frac{{x_{ic}}^2}{2}\right\}\right] \tag{27}$$

The *f.o.c$_s$* of (27) provides the reaction function of firm i to investments on R&D:

$$R_{ic}^{R\&D}(x_{jc}) = \frac{h\left(2-\gamma\left(1+hx_j\right)\right)}{(2(2-h)-\gamma^2)(2(2+h)-\gamma^2)} \tag{28}$$

Solving the system of (28) we get the (candidate) equilibrium R&D investments:

$$x_{ic}^* = \frac{h}{(2-\gamma)(2+\gamma)^2-h^2} \tag{29}$$

The firms' output/employment levels in the candidate equilibrium are then derived by substituting (26) and (29) for (13):

$$q_{ic}^* = \frac{(2-\gamma)(2+\gamma)}{2\left((2-\gamma)(2+\gamma)^2-h^2\right)} \tag{30}$$

Moreover, we get the firms' profits in the candidate equilibrium:

$$\Pi_{ic}^* = \frac{(2-\gamma)^2(2+\gamma)^2-2h^2}{4\left((2-\gamma)(2+\gamma)^2-h^2\right)^2} \tag{31}$$

From Equations (26) and (5), we get the candidate equilibrium union wages and rents, respectively, as follows:

$$w_{ic}^* = \frac{(2-\gamma)(2+\gamma)^2}{2\left((2-\gamma)(2+\gamma)^2-h^2\right)} \tag{32}$$

$$u_{ic}^* = \frac{(2-\gamma)^2(2+\gamma)^3}{4\left((2-\gamma)(2+\gamma)^2-h^2\right)^2} \tag{33}$$

3.3. Mix of Strategies (d_j)

The candidate equilibrium here is the one where one union (e.g. union j) adjusts its own wage competitively, while its rival's (e.g. union i's) strategy is to adjust its own wages in order to maximize joint rents.

Thus, at the last stage of the game where firms compete by adjusting simultaneously and independently their quantity in order to maximize their profits, we get the optimal output/employment rules in the candidate equilibrium in (13).

According to this Mix of Strategies configuration, at the third stage we must consider the *f.o.c*$_s$ of the pair (24) and (15) separately. Thus, respectively considering the union reaction functions (25) and (16), and solving that system, we get the following optimal wages in the candidate equilibrium:

$$w_{id_j}^{*}=\frac{(2-\gamma)(2+\gamma)(1+hx_i)}{8-\gamma^2} \tag{34}$$

$$w_{jd_j}^{*}=\frac{(2-\gamma)(4+\gamma)+hx_j(8-\gamma^2)-2\gamma hx_i}{2(8-\gamma^2)} \tag{35}$$

Now at the second stage where firms simultaneously and independently determine the optimal level of their R&D investment, we get the (candidate) equilibrium R&D investments by solving the system of *f.o.c*$_s$ of maximization of their profits [given by substituting (4) for (13), (34) and (35)]:

$$x_{id_j}^{*}=\frac{h((2+\gamma)(8-\gamma^2)(2-\gamma)^2-8h^2)}{(8-\gamma^2)(4-\gamma^2)^3+4h^2(32-12\gamma^2+\gamma^4)-8h^4} \tag{36}$$

$$x_{jd_j}^{*}=\frac{2h((2+\gamma)(4+\gamma)(2-\gamma)^2-4h^2)}{(8-\gamma^2)(4-\gamma^2)^3+4h^2(32-12\gamma^2+\gamma^4)-8h^4} \tag{37}$$

Substituting in turn (34), (35), (36) and (37) for (13) for each firm, respectively, we obtain the following firm-specific output/employment levels in the candidate equilibrium:

$$q_{id_j}^{*}=\frac{(4-\gamma^2)((2+\gamma)(8-\gamma^2)(2-\gamma)^2-8h^2)}{2\big((8-\gamma^2)(4-\gamma^2)^3+4h^2(32-12\gamma^2+\gamma^4)-8h^4\big)} \tag{38}$$

$$q_{jd_j}^{*}=\frac{(4-\gamma^2)((2+\gamma)(4+\gamma)(2-\gamma)^2-4h^2)}{(8-\gamma^2)(4-\gamma^2)^3+4h^2(32-12\gamma^2+\gamma^4)-8h^4} \tag{39}$$

Moreover, we get that the firms' profits in the candidate equilibrium:

$$\Pi_{id_j}^{*}=\frac{\left((4-\gamma^{2})-2h^{2}\right)((2+\gamma)(8-\gamma^{2})(2-\gamma)^{2}-8h^{2})^{2}}{4\left((8-\gamma^{2})(4-\gamma^{2})^{3}+4h^{2}(32-12\gamma^{2}+\gamma^{4})-8h^{4}\right)^{2}} \quad (40)$$

$$\Pi_{jd_j}^{*}=\frac{\left((4-\gamma^{2})-2h^{2}\right)((2+\gamma)(4+\gamma)(2-\gamma)^{2}-4h^{2})^{2}}{\left((8-\gamma^{2})(4-\gamma^{2})^{3}+4h^{2}(32-12\gamma^{2}+\gamma^{4})-8h^{4}\right)^{2}} \quad (41)$$

From Equations (34), (35) and (5), we get the candidate equilibrium union wages and rents, respectively, as follows:

$$w_{id_j}^{*}=\frac{(2-\gamma)^{2}(2+\gamma)^{3}((2+\gamma)(2-\gamma)^{2}-h^{2})}{(8-\gamma^{2})(4-\gamma^{2})^{3}+4h^{2}(32-12\gamma^{2}+\gamma^{4})-8h^{4}} \quad (42)$$

$$w_{jd_j}^{*}=\frac{(2-\gamma)^{2}(2+\gamma)^{2}((2+\gamma)(4+\gamma)(2-\gamma)^{2}-4h^{2})}{2\left((8-\gamma^{2})(4-\gamma^{2})^{3}+4h^{2}(32-12\gamma^{2}+\gamma^{4})-8h^{4}\right)} \quad (43)$$

$$u_{id_j}^{*}=\frac{(2-\gamma)^{3}(2+\gamma)^{4}((2+\gamma)(2-\gamma)^{2}-h^{2})((2+\gamma)(2-\gamma)^{2}(8-\gamma^{2})-8h^{2})}{2\left((8-\gamma^{2})(4-\gamma^{2})^{3}+4h^{2}(32-12\gamma^{2}+\gamma^{4})-8h^{4}\right)^{2}} \quad (44)$$

$$u_{jd_j}^{*}=\frac{(4-\gamma^{2})^{3}((2+\gamma)(4+\gamma)(2-\gamma)^{2}-4h^{2})^{2}}{2\left((8-\gamma^{2})(4-\gamma^{2})^{3}+4h^{2}(32-12\gamma^{2}+\gamma^{4})-8h^{4}\right)^{2}} \quad (45)$$

3.4. Equilibrium Analysis: Endogenous Selection of Union Structures

We now turn to the first stage of the game and investigate the unions' incentive to play collusively in our static framework by setting wages at the stage of w-negotiations that maximize the joint rents. Given our findings in 3.1.– 3.3., at the first stage the unions deal with the following matrix game, in which the payoffs of each union when both unions simultaneously and independently decide to collude or to compete at the stage of w-negotiations (3rd stage) with their specific firm is presented:

		Union i: *Collusion*	Union i: *Competition*
Union j	*Collusion*	$\{u_{ic}^{*}, u_{jc}^{*}\}$	$\{u_{id_i}^{*}, u_{jd_i}^{*}\}$
	Competition	$\{u_{id_j}^{*}, u_{jd_j}^{*}\}$	$\{u_{im}^{*}, u_{im}^{*}\}$

Table 1: The Matrix Game that unions deal with at the first stage of the game.

Due to symmetry, $\left(u^*_{id_j}, u^*_{jd_j}\right) = \left(u^*_{jd_i}, u^*_{id_i}\right)$ is applied and thus the number of candidate equilibria is reduced to three.

Collusive play is an equilibrium institution only if no union has incentive to unilaterally deviate in order to maximize its own revenue by adjusting independently its own wages. In particular, each union has incentives to deviate and earn higher revenue by decreasing its demanded wages at the stage of w-bargaining, enough to achieve the optimal firm's labor demand. To grasp it, let union i deviate from collusive play in order to maximize its own revenue by reducing its wages, assuming that union j sticks to collusion. The reduction of its wages causes two positive effects on its employment due to firm i's reaction to the lower labor cost; firstly, from the increment of the firm's demanded employment level and, secondly, from the release of the firm's economic resources to be invested in R&D investments that increase its product's quality and therefore the consumers' demanded quantity, hence employment level. Notice that, union i's deviation leads indirectly to reduction of union j's revenue, because of complimentary wage and product substitution. Consequently, it is deduced that union collusive play is not in Nash Equilibrium because there is lack of stability. For the same reasons, neither the mix of strategies emerge in equilibrium. The union that remains in collusion has incentive to switch its strategy to competition, like its rival, by reducing its wages too. So according to the above, union competition eventually emerges in equilibrium. Our relevant findings are summarized in Proposition 1.

Proposition 1: *Under the assumption of the absence of a policy maker in market structure, union competitive play eventually emerges in Nash equilibrium.*

[Proof: See Appendix (A.1)]

3.5. Consumer Evaluation of R&D's Quality and Product Substitutability: Unions Effects (utility)

In this section, we proceed to the analysis of the effects of our critical structural parameters, namely h and γ, on unions' utility (wages and labor).

It is generally accepted that union collusion achieves Pareto improving equilibrium, as it internalizes the negative externalities that are created from union competition and gives unions the opportunity to further increase their wages, hence their revenue. Thus, it could be a reasonable conclusion that Nash equilibrium achieved at the first stage is not Pareto optimal, as a transition from Nash equilibrium to a secure collusion increases the utility of both unions. However, in our model the above conclusion is not universal and does not apply for each case.

In particular, if consumer evaluation of product quality is high enough $(h \to 1)$ and the firms' products tends to be independent $(\gamma \to 0)$, then the transition of the unions from collusion to competition is not only in Nash Equilibrium but also Pareto improving.

To grasp it, assume first the standard/ad-hoc – collusive versus competitive – hypotheses in both of which R&D is absent $(x_i = 0)$, i.e. consumer evaluation of the product quality equals to zero $(h = 0)$. As the products are independent $(\gamma = 0)$, the two firms' products are targeted at completely different markets and thus each firm produces the quantity of a monopolist $[\mathrm{q_i} = \mathrm{q_M}]$. While, as the products tend to be close substitutes $(\gamma \to 1)$, the two firms' products are targeted at exactly the same market and consequently their total quantity is lower than that of two monopolists $[q_i < q_M]$. From the perspective of unions, the aforementioned product quantities are translated into units of labor demand. Therefore, and in accordance with the above, as $\gamma = 0$ the unions (no matter collusively or competitively) enjoy the maximum point of their revenue $[u_{im} = u_{ic}]$, while as $\gamma \rightarrow 1$ their revenue is reduced. Union collusion in turn means more inflexible labor supply; so as $\gamma \rightarrow 1$, union revenues under collusive play is reduced less than under competitive play, i.e. $\frac{\vartheta u_{im}}{\vartheta \gamma} < \frac{\vartheta u_{ic}}{\vartheta \gamma} < 0$ and $\frac{\partial (u_{ic} - u_{im})}{\partial \gamma} > 0$.

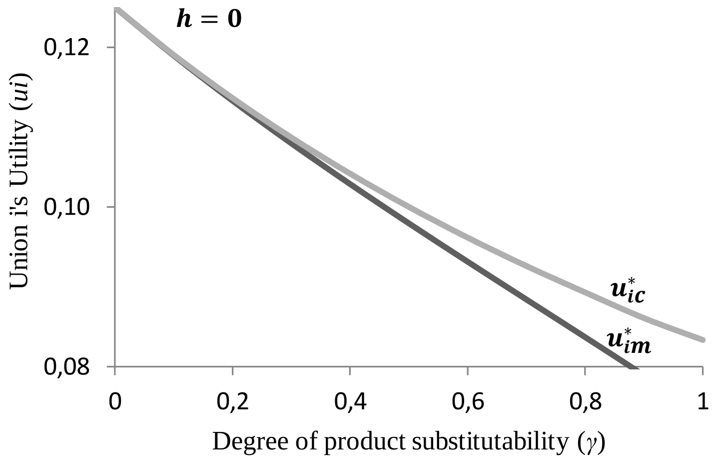


Figure 1: The utility of union i under collusion and competition, given that $h = 0$.

We will now investigate the impact of consumer evaluation of product quality (h) on union utility. According to (1), it is easy to check that consumer demand is increasing with factor h. The increase in demand is even higher the higher the level of investments on R&D is. Therefore, an increase in factor h strengthens the firms' incentives for R&D investments, which in turn increases consumer demand, hence labor demand. Thus, as factor $h \rightarrow 1$, the union utility increases , especially under collusive play (more inelastic labor supply) than under competitive play, i.e. $\frac{\vartheta u_{im}}{\vartheta h} > \frac{\vartheta u_{ic}}{\vartheta h} > 0$ and $\frac{\partial (u_{ic} - u_{im})}{\partial h} < 0$.

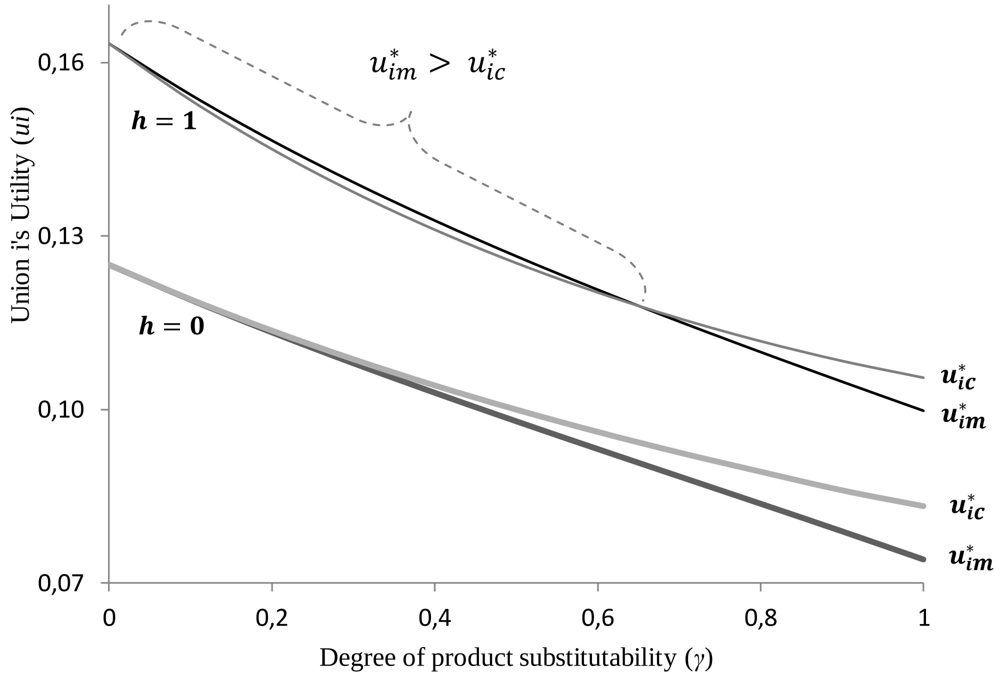


Figure 2: The upper and lower bound of the u^N_{im} and u^N_{ic} values.

In conclusion, it is proved that a high level of consumer evaluation of the products ($h \to 1$) and a low level of product substitutability ($\gamma \to 0$) affects negatively the ($u_{ic} - u_{im}$) differential. In contrast to conventional wisdom, those effects may be such that the unions' utility differential among competition and collusion can be reversed, i.e. $u_{im} > u_{ic}$. The following Proposition summarizes the above results.

Proposition 2:

- *If $\boldsymbol{h > h_{u(c,m)}(\gamma)}$, then Union Rents under Competition are always higher than under Collusion, i.e. $\boldsymbol{u^N_{im} > u^N_{ic}}$. Thus, a transfer from collusive to competitive play not only emerges in Nash Equilibrium, but is also Pareto improving for unions.*
- *Otherwise, the well-known in equation of $\boldsymbol{u^N_{ic} > u^N_{im}}$, where unions deal with the well-known paradox of Prisoners' dilemma applies.*

[Proof: See Appendix (A.2)]

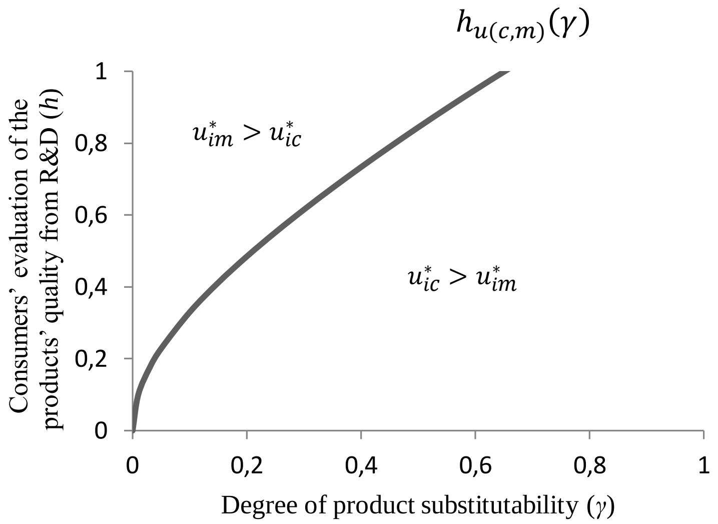


Figure 3: The $h_{u(c,m)}(\gamma)$ *critical value*

3.6. The Impact of Union Structures on Market Output and Product Quality

Given our findings in Subsections 3.1.-3.2., let us now analyze the impact of union structures, i.e. decentralized and centralized wage-setting regimes, on equilibrium outcomes, especially on output level and product quality improvement, hence R&D investments. Through this investigation, we will be able to mainly interpret the complicated way that unions' decisions affect market participants.

Regarding union structure and wages, a union collusion that takes place within an industry gives them the opportunity to increase their wages $[\boldsymbol{w_{ic}} > \boldsymbol{w_{im}}]$, hence limit their labor supply, in order to increase their rents. However, an increase of union wages causes two negative effects on firms' decisions, through their profit maximizing behavior: the reduction of their R&D investments $[\partial x_i/\vartheta w_i < 0]$, in order to compensate the higher labor cost and the limitation of their labor demand $[\partial q_i/\vartheta w_i < 0]$, hence their employment level and their product output. The following Proposition summarizes our findings:

Proposition 3: *The output level (union employment) and R&D investments (product quality) are always higher under a decentralized wage-setting regime than under a centralized one, i.e.* $\boldsymbol{q_{im}} > \boldsymbol{q_{ic}}$ *and* $\boldsymbol{x_{im}} > \boldsymbol{x_{ic}}$. *The opposite applies for union wages, i.e.* $\boldsymbol{w_{ic}} > \boldsymbol{w_{im}}$.

[Proof: See Appendix (A.4)

Proposition 4: *The elasticity of output level on union wages is negative and defined by* $\boldsymbol{\varepsilon_{qw}} = -\frac{\boldsymbol{w}}{\boldsymbol{1-w}} \in (\boldsymbol{-1}, \boldsymbol{0})$ *and union wages are obviously positive but lower than* $\boldsymbol{1/2}$, *i.e.* $\boldsymbol{w} \in (\boldsymbol{0}, \boldsymbol{1/2})$.

[Proof: See Appendix (A.5)]

Diagrammatically, the elasticity of output level on union wages is presented in the following figure:

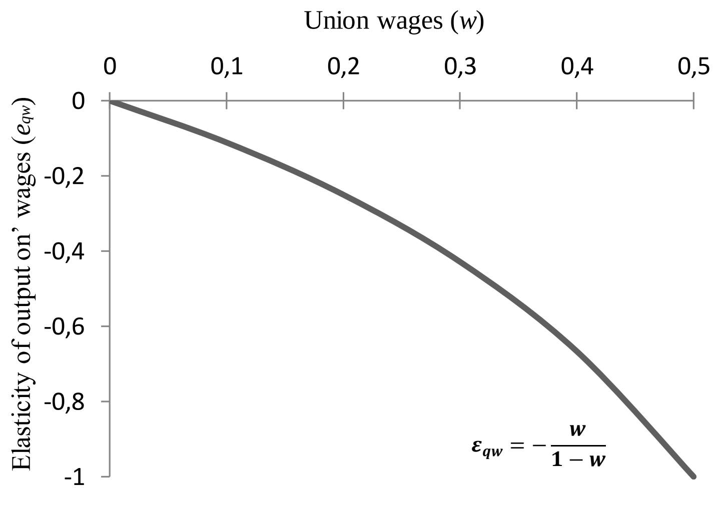


Figure 4: The elasticity of output level on union wages.

This implies that an increase in union wages of one unit decreases the equilibrium output level at less than one unit. In other words, an increase in wage level leads to a comparatively lower decrease in output level.

3.7. Welfare Analysis

The present section refers to the comparative analysis of the emerging equilibria (s, m and mos) in terms of social welfare. Social Welfare is defined to be the sum of Consumer Surplus (*CS*), Producer Surplus (*PS*) and Union Rents (*UR*), as follows:

$$SW_s = CS_s + PS_s + UR_s \;\; ; \;\; s = c, m, mos \tag{46}$$

Where$c$, m and mos respectively denote collusive, competitive, and mix of strategies, equilibria. The elements of the above equation are defined by:

$$CS_s = \sum_{k=i,j}[(1 + hx_{ks} - p_{ks})q_{ks}] - \frac{1}{2}\left({q_{is}}^2 + {q_{js}}^2 + 2\gamma q_{is}q_{js}\right) \tag{47}$$

$$PS_s = \sum_{k=i,j}[\Pi_{ks}] = \sum_{k=i,j}[(p_{ks} - w_{ks})q_{ks}] \tag{48}$$

$$UR_s = \sum_{k=i,j}[u_{ks}^N] = \sum_{k=i,j}[w_{ks}q_{ks}] \tag{49}$$

The total Consumer and Producer Surplus under collusion and competition proves to be [Proof: See Appendix (A.3)]:

$$CS_{c,m} = \frac{1+\gamma}{4}{Q_{c,m}}^2 \tag{50}$$

$$PS_{c,m} = \frac{{Q_{c,m}}^2}{2} - x_{i(j)c,m}^2 \tag{51}$$

Our findings from the comparative evaluation of (46), (47), (48) and (49), across s, are summarized in Proposition 5, Proposition 6 and Proposition 7.

Proposition 5: *Consumer and Producer Surpluses under Competition are always higher than those under a Mix of Strategies configuration, the latter being always higher than those under Collusion, i.e.* $\boldsymbol{CS_m} > \boldsymbol{CS_{mos}} > \boldsymbol{CS_c}$ *and* $\boldsymbol{PS_m} > \boldsymbol{PS_{mos}} > \boldsymbol{PS_c}$.

[Proof: See Appendix (A.4)]

Proposition 6:

a) *If* $\boldsymbol{h} > \boldsymbol{h_{UR(m,mos)}(\gamma)}$*, then Union Rents under Competition are higher than under a Mix of Strategies configuration, the latter being higher under Collusion, i.e.* $\boldsymbol{UR_m} > \boldsymbol{UR_{mos}} > \boldsymbol{UR_c}$.

b) *If* $\boldsymbol{h_{u(m,mos)}(\gamma)} > h > \boldsymbol{h_{u(c,mos)}(\gamma)}$*, then Union Rents under Mix of Strategies are always higher than under Collusion and Competition configuration, i.e.* $\boldsymbol{UR_{mos}} > \boldsymbol{UR_c}, \boldsymbol{UR_m}$.

In particular, if $\boldsymbol{h_{u(m,mos)}(\gamma)} > \boldsymbol{h_{u(c,m)}(\gamma)}$*, then.* $\boldsymbol{UR_{mos}} > \boldsymbol{UR_m} > \boldsymbol{UR_c}$*, while if* $\boldsymbol{h_{u(c,m)}(\gamma)} > \boldsymbol{h_{u(c,mos)}(\gamma)}$*, then.* $\boldsymbol{UR_{mos}} > \boldsymbol{UR_c} > \boldsymbol{UR_m}$

c) *If* $\boldsymbol{h} < \boldsymbol{h_{u(c,mos)}(\gamma)}$*, then Unio Rents under Collusion is always higher than under Competition, while under a Mix of Strategies it lays in-between, i.e.* $\boldsymbol{UR_c} > \boldsymbol{UR_{mos}} > \boldsymbol{UR_m}$.

Where, $h_{u(m,mos)}(\boldsymbol{\gamma}) > h_{u(c,m)}(\boldsymbol{\gamma}) > h_{u(c,mos)}(\boldsymbol{\gamma})\ \forall\ \gamma \in [0,1]$

[Proof: See Appendix (A.5)]

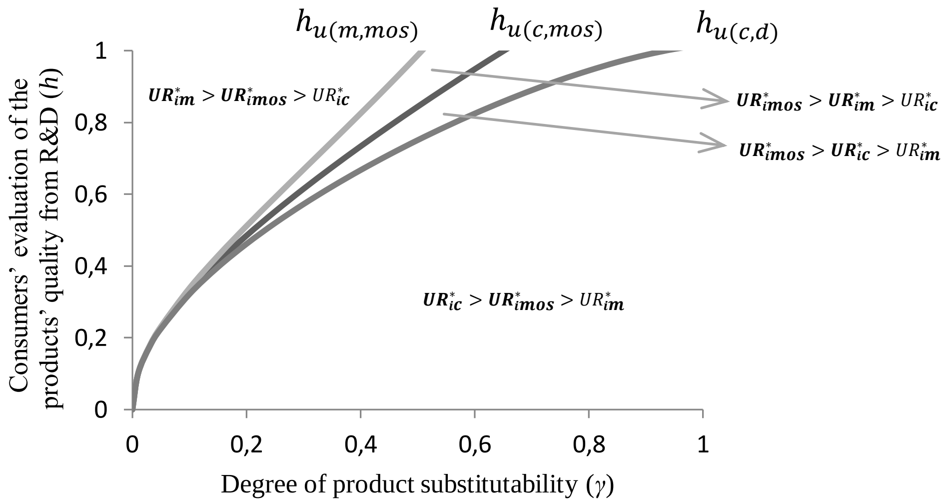


Figure 5: The h(γ) critical values for – c, m, mos, – Union Rents comparisons

Proposition 7: *Social Welfare under Competition is always higher than under Collusion, while under a Mix of Strategies it lies in-between, i.e.* $\boldsymbol{SW_m} > \boldsymbol{SW_{mos}} > \boldsymbol{SW_c}$.

[Proof: See Appendix (A.6)]

4. 2nd case: Policy maker proceeds to R&D investments

In this section, we assume that the social planner decides to intervene in the market structure by proceeding to quality improvement-R&D exclusively, as a public good, and thereafter providing the know-how to the industry for free, i.e. the firms do not invest in R&D and their profit function is defined by:

$$\Pi_i = (p_i - w_i)q_i \tag{52}$$

Moreover, we consider that the social planner finances the investment in R&D by setting indirect taxation on market products, under the industry's condition of a balanced budget.

Taking the same path with the previous section, in the following Subsections 4.1.-4.3., we propose all the candidate equilibria and then check their validation (or rejection) by analyzing all possible unilateral deviations on the part of the agent(s).

4.1 Competitive Play (*m*)

Let unions adopt competitive play at the second stage of the game, i.e. set independently their wages at the stage of w-bargaining with their firms.

At the last stage of the game, both firms independently determine their optimal output level. According to (10) and (52), their new objective is:

$$max_{q_i}\left[\Pi_i\left\{= q_i\left(1 - \gamma q_j - w_i + hx - t\right)\right\}\right] \tag{53}$$

Where x denotes the quality of products which come from the policy maker's expenditures on R&D.

We get the reaction function of firm i from the first order condition (*f.o.c.*) of (53):

$$R_i(q_j) = \left(1 - \gamma q_j - w_i + hx - t\right)/2 \tag{54}$$

Solving the system of both firms' reaction functions in (54), we get the optimal output/employment rules in the candidate equilibrium:

$$q_i\left(w_i, w_j\right) = \frac{(2-\gamma)(1+hx-t) - 2w_i + \gamma w_j}{(2-\gamma)(2+\gamma)} \tag{55}$$

Notice that the industry's output level increases with product quality improvement and decreases with the level of per product unit tax.

At the third stage, unions independently determine the wage (w_i) that maximizes its rents. Taking as given the outcomes of the production game [given in (55)] and getting the *f.o.c*$_s$ of their revenues' objective [given in (14)], we find the wage reaction functions which are as follows:

$$w_{im}\left(w_{jm}\right) = \left((2-\gamma)(1+hx-t) + \gamma w_{jm}\right)/4 \tag{56}$$

Solving now the system in (56), we get the wage outcome (s) in the candidate equilibrium:

$$w_{im}^{*} = \frac{(2-\gamma)(1+hx-t)}{4-\gamma} \tag{57}$$

Note that $w_{im}^{*} > 0$, if and only if $1 + hx - t > 0$. Consequently, under the present proposed market case, the oligopoly market exists, only if the following condition is satisfied:

$$t < 1 + hx \tag{58}$$

Taking into consideration the equations (5) and (57), we get the union i's rent in the candidate equilibrium:

$$u_{im}^{*} = \frac{2(2-\gamma)(2+hx-t)^2}{(2+\gamma)(4-\gamma)^2} \tag{59}$$

Substituting now (57) for (55), we get the optimal output/employment:

$$q_{im}^{*} = \frac{2(1 + hx - t)}{(2 + \gamma)(4 - \gamma)} \tag{60}$$

4.2 Collusive Play (c)

Suppose next that unions decides to play collusively at the second stage, and thus at the third stage set the wages as to maximize the sum of rents of its members and the competitor firm's union members.

At the last stage of the game, where firms' Cournot competition is taking place, we get firms' reaction functions and optimal output level, hence employment, in the candidate equilibrium by Equations (54) and (55), respectively.

At the third stage, we derive the union i's wage reaction function, by substituting union i's objective function [given in (24)] for the optimal output rules in (55) and taking the *f.o.c$_s$*, as follows:

$$w_{ic}(w_{jc}) = \left((2 - \gamma)(1 + hx - t) + 2\gamma w_{jc}\right)/4 \tag{61}$$

Solving now the system in (61) we get the candidate equilibrium wages:

$$w_{ic}^{*} = (1 + hx - t)/2 \tag{62}$$

Taking into consideration equations (5) and (62), we get the union i's rent in the candidate equilibrium:

$$u_{ic}^{*} = \frac{(1 + hx - t)^2}{4(2 + \gamma)} \tag{63}$$

Substituting now (62) for (55), we get the optimal output/employment:

$$q_{ic}^{*} = \frac{1 + hx - t}{2(2 + \gamma)} \tag{64}$$

4.3 Mix of Strategies (d_j)

Under the assumption of union mix of strategies candidate equilibrium, we let union j to be the one which plays competitively and union i to be the one which plays collusively. Thus, at the last stage of the game, where firms' Cournot completion takes place, we get the optimal output/employment in (55).

Consequently, at the third stage we get the optimal wages in the candidate equilibrium by solving the system of union reaction function in (61) and (56), respectively, as follows:

$$w_{id_j}^{*} = \frac{(2-\gamma)(2+\gamma)(1+hx-t)}{8-\gamma^2} \tag{65}$$

$$w_{jd_j}^{*} = \frac{(2-\gamma)(4+\gamma)(1+hx-t)}{2(8-\gamma^2)} \tag{66}$$

Taking into consideration equations (5), (65) and (66), we get the union rents in the candidate equilibrium:

$$u_{id_j}^{*} = \frac{(2-\gamma)(1+hx-t)^2}{2(8-\gamma^2)} \tag{67}$$

$$u_{jd_j}^{*} = \frac{(2-\gamma)(4+\gamma)^2(1+hx-t)^2}{2(2+\gamma)(8-\gamma^2)^2} \tag{68}$$

Substituting now (65) and (66) for (55), respectively, we get the optimal firm output/employment:

$$q_{id_j}^{*} = \frac{1+hx-t}{2(2+\gamma)} \tag{69}$$

$$q_{jd_j}^{*} = \frac{(4+\gamma)(1+hx-t)}{(2+\gamma)(8-\gamma^2)} \tag{70}$$

4.4 Second Stage: Endogenous Selection of Union Structures

Turn now to the second stage of the game, where unions are asked to decide simultaneously and independently their strategy, collusive or competitive play, at the stage of w-negotiations (3rd stage) with their specific firm. The unions deal with the matrix game presented in Subsection 3.4., except that payoffs of each union are given by Subsections 4.1-4.3.

Like in the previous market structure case, the union collusion and mix of strategies do not emerge in Nash equilibrium, whereas even a union has incentive to deviate. Union competition is the only candidate equilibrium where no union has incentive to switch its strategy to collusive play, thus it is the only one emerging in Nash equilibrium. The intuition behind this is that the collusive play is weak / unstable, as a deviation from it gives the deviated union the advantage of wage reduction and consequently the increment of its labor demand that maximize its own rents, given that the rival union sticks to collusion. The mix of strategies is also an unstable candidate equilibrium, as the union, which plays collusively, has incentive to switch its strategy to competition in order to increase its rents by reducing its wage too.

Proposition 8: *Under the presence of a policy maker that proceeds to R&D investments, union competitive play eventually emerges in Nash equilibrium, even if union collusive play is Pareto improving candidate equilibrium. The unions deal with the well-known paradox of Prisoners' dilemma.*

[Proof: See Appendix (A.7)]

4.5 First Stage: R&D investments and product taxation

Given our findings in Subsections 4.1-4.4, at this stage the social planner aims to determine the optimal level of R&D investments for product quality improvement and indirect taxation on market products that maximize Social Welfare. Therefore, the social planner's objective is:

$$SW = CS + PS + UR + TR_1^{PM} - TC_1^{PM} \tag{71}$$

We assumed that he finances the R&D investments exclusively by indirect consumption taxation on the final product (Balance Budget):

$$TC_1^{PM} = TR_1^{PM} \tag{72}$$

So, the simplified formula of the social planner's objective is:

$$SW = CS + PS + UR \tag{73}$$

Where Consumer Surplus (CS) is the sum of consumer utility minus the cost of products purchased at the equilibrium price [given the (1) and (9)]:

$$CS = (1 + hx_i)q_i + (1 + hx_j)q_j - \frac{1}{2}\left(q_i{}^2 + q_j{}^2 + 2\gamma q_i q_j\right) - (p_i + t)q_i - (p_j + t)q_j \tag{74}$$

Under the assumption that firms do not proceed to R&D investments in this case i.e. $x_{i(j)} = 0$, Producer Surplus is the sum of firms' profits [given the (4)]:

$$PS = \sum_{k=i,j} \left((p_k - w_k)q_k\right) \tag{75}$$

The mathematical expression of Union Rents is defined by:

$$UR = \sum_{k=i,j} (w_k q_k) \tag{76}$$

As mentioned, the social planner sets indirect taxes on final products in order to finance the investments to improve product quality in the industry. Taking into consideration that indirect taxes lead to distortions in the market, the determination of the optimal tax is complicated. The R&D investment, hence taxes, should be such that the increase of social welfare by improving the quality of products exceeds the reduction by imposing indirect taxes on the market. Thus, given the impact of taxation, the social welfare maximization problem of the policy maker gives us the optimal combination of taxes and R&D investment, as it is presented in Proposition 9.

Proposition 9: *Under union competition, the optimal levels of Policy Maker's R&D investments and taxation policy are* $\boldsymbol{x_1^* = \frac{4h}{(2+\gamma)(4-\gamma)-2h^2} \in (0, 0.6)}$ *and* $\boldsymbol{t_1^* = \frac{2h^2}{(2+\gamma)(4-\gamma)-2h^2} \in (0, 0.3)}$, *respectively.*

[Proof: See Appendix (A.8)]

According to Proposition 7, we get the optimal solution of (t_1^*, x_1^*), which is:

$$x_1^* = \frac{4h}{(2+\gamma)(4-\gamma)-2h^2} \in (0,0.6) \tag{77}$$

$$t_1^* = \frac{2h^2}{(2+\gamma)(4-\gamma)-2h^2} \in (0,0.3) \tag{78}$$

Under the optimal solution of (t_1^*, x_1^*), the Social Welfare in equilibrium is defined by:

$$SW = \frac{4\big(7+\gamma(1-\gamma)\big)}{\big((2+\gamma)(4-\gamma)+2h^2\big)^2} \tag{79}$$

Substituting now the optimal levels of (t_1^*, x_1^*) for (57) and (60), we get the optimal union i's wages and firm i's output level, respectively, in the equilibrium:

$$w_{im}^* = \frac{4-\gamma^2}{(2+\gamma)(4-\gamma)-2h^2} \tag{80}$$

$$q_{im}^{*} = \frac{2}{(2+\gamma)(4-\gamma)-2h^2} \tag{81}$$

We can get now Consumer Surplus (*CS*), Producer Surplus (*PS*) and Union Rents (*UR*), from Equations (74), (75) and (76), respectively, by taking into consideration the optimal levels of (t_1^*, x_1^*), (80) and (81):

$$CS = \frac{4(1+\gamma)}{\left((2+\gamma)(4-\gamma)+2h^2\right)^2} \tag{82}$$

$$PS = \frac{8}{\left((2+\gamma)(4-\gamma)+2h^2\right)^2} \tag{83}$$

$$UR = \frac{4(2-\gamma)(2+\gamma)}{\left((2+\gamma)(4-\gamma)+2h^2\right)^2} \tag{84}$$

5. 3rd case: Policy maker funds partially firms' R&D investments

In this section, we investigate the case of a market structure where the policy maker intervenes by financing a percentage of the expenditures of firm-specific R&D investments, i.e. firms proceed to investments in R&D, whose costs is partially financed by the social planner. Thus firm i's profit function is defined by:

$$\Pi_\iota = (p_i - w_i)q_i - f\frac{x_i^2}{2} \tag{85}$$

Where $f \in (0,1)$ denotes the presentence of its financial participation on this expenditures.

As in the previous section, under the industry's condition of a balanced budget, the social planner imposes indirect taxation on market products, in order to finances firms' investment on R&D.

In the following Subsections 5.1.-5.3., we proceed to the validation (or rejection) check of all candidate equilibria by analyzing all possible unilateral deviations on the part of the agent(s).

5.1 Competitive Play (m)

Assume that both unions decide to play competitively at the second stage of the game by setting independently their wages in the negotiations with their specific firm.

Thus, at the last stage of the game, where firms' Cournot competition takes place, firms' aim to maximize their profits by deciding the optimal output level. Thus, firms' objective is the following [given (10) and (85)]:

$$max_{q_i}\left[\Pi_i\left\{= q_i\left(1-\gamma q_j - w_i + hx_i - t\right) - f\frac{x_i^2}{2}\right\}\right] \tag{86}$$

From the *f.o.c.*'s of (86), we get the reaction function of firm i:

$$R_i(q_j) = \left(1-\gamma q_j - w_i + hx_i - t\right)/2 \tag{87}$$

Solving now the system of both firms' reaction functions from (87), we get the optimal output level in the candidate equilibrium:

$$q_i\left(w_i, w_j\right) = \frac{(2-\gamma)(1-t) - 2w_i + \gamma w_j + 2hx_i - \gamma hx_j}{(2-\gamma)(2+\gamma)} \tag{88}$$

At the fourth stage of the game, each union decides its firm-specific wage rate. Taking under consideration the unions' objective in (14) and deriving the union wage reaction functions [by taking the *f.o.c.*'s of (14), given t (88)], we get that:

$$w_i\left(w_j\right) = \left((2-\gamma)(1-t) + \gamma w_j + 2hx_i - \gamma hx_j\right)/4 \tag{89}$$

Solving now the system of both union wage reaction functions from (89), we get the optimal wage rate in the candidate equilibrium, as follows:

$$w_{im}^{*}=\frac{(2-\gamma)(4+\gamma)(1-t)+(8-\gamma^2)hx_i-2\gamma hx_j}{(4-\gamma)(4+\gamma)} \quad (90)$$

Now at the third stage, firms simultaneously and independently determine the optimal level of their R&D investment in order to maximize their profits. Thus, their objective is:

$$max_{x_i}\left[\Pi_i\left\{=q_i\big(1-\gamma q_j-w_i+hx_i-t\big)-f\frac{x_i^2}{2}\right\}\right] \quad (91)$$

Solving the system of *f.o.c*$_s$ of that maximization for both firms, we get the (candidate) equilibrium R&D investments:

$$x_{im}^{*}=(1-t)\frac{8h(8-\gamma^2)}{f(4+\gamma)(2-\gamma)(4-\gamma)^2(2+\gamma)^2-8h^2(8-\gamma^2)} \quad (92)$$

Notice that:

$$x_{im}^{*}>0\Leftrightarrow\begin{cases}f>\dfrac{8h^2(8-\gamma^2)}{f(4+\gamma)(2-\gamma)(4-\gamma)^2(2+\gamma)^2-8h^2(8-\gamma^2)}\in(0,0.138)\\ t<1\end{cases} \quad (93)$$

Consequently, under the present proposed market case, the oligopoly market exists, only if condition (93) is satisfied.

According to (5), (90) and (92), union i's rent in the candidate equilibrium is the following:

$$u_{im}^{*}=f^2(1-t)^2\frac{2(4+\gamma)^2(4-\gamma)^2(2+\gamma)^3(2-\gamma)^3}{\big(f(4+\gamma)(2-\gamma)(4-\gamma)^2(2+\gamma)^2-8h^2(8-\gamma^2)\big)^2} \quad (94)$$

5.2 Collusive Play (c)

Take now as given that unions decide to play collusively at the second stage and consequently at the fourth stage they set those wages to maximize their joint rents.

Taking the optimal output rule, hence employment, at the last stage of the game in (88), at the fourth stage we derive the union i's wage reaction function by taking the *f.o.c$_s$* of union i's objective function by (24) [given in (88)], as follows:

$$w_{ic}(w_{jc}) = \big((2-\gamma)(1-t) + 2\gamma w_{jc} + 2hx_{ic} - \gamma h x_{jc}\big)/4 \tag{95}$$

Solving now the system in (95) we get the candidate equilibrium wages:

$$w_{ic}^{*} = (1 + hx_{ic} - t)/2 \tag{96}$$

Getting in at the third stage, where firms simultaneously and independently determine the optimal level of their R&D investment, by solving the system of *f.o.c$_s$* of their profit maximization [given by substituting i (91) for (88) and (96)]:

$$x_{ic}^{*} = (1-t)\frac{h}{f(2-\gamma)(2+\gamma)^2 - h^2} \tag{97}$$

Notice that:

$$x_{ic}^{*} > 0 \Leftrightarrow \begin{cases} f > \dfrac{h^2}{(2-\gamma)(2+\gamma)^2} \in (0{,}0.125) \\ t < 1 \end{cases} \tag{98}$$

Consequently, under the present proposed market case, the oligopoly market exists, only if condition (100) is satisfied.

We get the union i's rent in the candidate equilibrium by equations (5), (88) and (96):

$$u_{ic}^{*} = f^2(1-t)^2\frac{(2-\gamma)^2(2+\gamma)^3}{4(f(2-\gamma)(2+\gamma)^2 - h^2)^2} \tag{99}$$

5.3 Mix of Strategies ($\mathbf{d_j}$)

Under the assumption of the union mix of strategies candidate equilibrium, we let union j to be the one which plays competitively and union i to be the one which plays collusively. Thus, at the last stage of the game, where firms' Cournot completion takes place, we get the optimal output/employment by (88).

At the fourth stage we get the optimal wages in the candidate equilibrium by solving the system of union reaction function in (95) and (89), respectively, as follows:

$$w_{id_j}^* = \frac{(2-\gamma)(2+\gamma)(1+hx_i-t)}{8-\gamma^2} \tag{100}$$

$$w_{jd_j}^* = \frac{(2-\gamma)(4+\gamma)(1-t)+(8-\gamma^2)hx_j-2\gamma hx_i}{2(8-\gamma^2)} \tag{101}$$

At the third stage, firms choose the optimal level of their R&D investment, which is derived by solving the system of $f.o.c_s$ of their profit maximization [given by substituting (91) for (88) and (100) for firm i and (88) and (101) for firm j, respectively]:

$$x_{imos}^* = (1-t)\frac{h(f(2+\gamma)(2-\gamma)^2(8-\gamma^2)-8h^2)}{f^2(8-\gamma^2)(4-\gamma^2)^3-4h^2f(32-12\gamma^2+\gamma^4)+8h^4} \tag{102}$$

$$x_{jmos}^* = (1-t)\frac{h(f(2+\gamma)(2-\gamma)^2(4+\gamma)-4h^2)}{f^2(8-\gamma^2)(4-\gamma^2)^3-4h^2f(32-12\gamma^2+\gamma^4)+8h^4} \tag{103}$$

Notice that:

$$x_{imos}^* > 0 \Leftrightarrow \begin{cases} f > \dfrac{8h^2}{(2+\gamma)(2-\gamma)^2(8-\gamma^2)} \in (0,0.381) \\ t < 1 \end{cases} \tag{104}$$

$$x_{jmos}^* > 0 \Leftrightarrow \begin{cases} f > \dfrac{4h^2}{(2+\gamma)(2-\gamma)^2(4+\gamma)} \in (0,0.267) \\ t < 1 \end{cases} \tag{105}$$

Consequently, under the present proposed market case, the oligopoly market exists, only if conditions (104) and (105) are satisfied.

Taking into consideration equations (5), (100) and (101), we get the union rents in the candidate equilibrium:

$$u_{imos}^{*} = f^2(1-t)^2 \frac{(2-\gamma)^3(f(2+\gamma)(2-\gamma)^2(8-\gamma^2)-8h^2)(f(2+\gamma)(2-\gamma)^2-h^2)}{2(f^2(8-\gamma^2)(4-\gamma^2)^3-4h^2f(32-12\gamma^2+\gamma^4)+8h^4)^2} \quad (106)$$

$$u_{jmos}^{*} = f^2(1-t)^2 \frac{(2-\gamma)^3(2+\gamma)^3(f(2+\gamma)(2-\gamma)^2(4+\gamma)-4h^2)^2}{2(f^2(8-\gamma^2)(4-\gamma^2)^3-4h^2f(32-12\gamma^2+\gamma^4)+8h^4)^2} \quad (107)$$

5.4 Second Stage: Endogenous Selection of Union Structures

At the second stage of the game, unions decide simultaneously and independently to play collusively or competitively at the 4th stage of w-negotiations. The unions deal with the matrix game presented in Subsection 3.4., except that the payoffs of each union are given in Subsections 5.1-5.3.

Like in Subsections 3.4 and 4.4, the union competition is the only one which emerges in Nash Equilibrium, as no union has incentives to deviate by switching its strategy to collusive play.

Proposition 10: *Under the presence of a policy maker that funds partially firms' R&D investments, union competitive play eventually emerges in Nash equilibrium, even if union collusive play is Pareto improving candidate equilibrium. The unions deal with the well-known paradox of Prisoners' dilemma.*

[Proof: See Appendix (A.9)]

5.5 First Stage: R&D investments and product taxation

Taking into considerations our findings in Subsections 5.1-5.4, at this stage the social planner aims to determine the optimal level of funding rate of firms' R&D investments $(1-f)$ and indirect taxation on market products (t) that maximize Social Welfare. Thus, the social planner's objective is:

$$SW = CS + PS + UR + TR_2^{PM} - TC_2^{PM} \quad (108)$$

Where TR_2^{PM} and TC_2^{PM} are given by (**8**) and (**7**), respectively.

Like in the previous case of market structure, we suppose that the Social Planner funds the firms' R&D investments exclusively by indirect consumption taxation on the final product (Balance Budget):

$$TC_1^{PM} = TR_1^{PM} \tag{109}$$

So, the simplified formula of the social planner's objective is:

$$SW = CS + PS + UR \tag{110}$$

Where Consumer Surplus (CS) and Union Rents are given by (74) and (76), respectively, while Producer Surplus is defined by the following equation:

$$PS = \sum_{k=i,j} \left((p_k - w_k) q_k - f \frac{{x_i}^2}{2} \right) \tag{111}$$

Where ${x_i}^2/2$ denotes the total expenditures on R&D, while $f \frac{{x_i}^2}{2}$ presents the actual firm i's participation on those investments [the rest of the participation belongs to the Social Planner through its findings, i.e. $(1-f) \frac{{x_i}^2}{2}$].

Taking into consideration the indirect taxes' market distortions, the Social planner aims to determine the optimal combination of product taxes and funding rate of firms' R&D investments in order to maximize Social Welfare. The optimal solution of the social planner's maximizing problem is presented in Proposition 11.

Proposition 11: *Under union competition, the optimal levels of Policy Maker's funding rate in firms' R&D investments and taxation policy are* $\boldsymbol{f_1^*} \in (\mathbf{0.44}, \mathbf{0.56})$ *and* $\boldsymbol{t_1^*} \in (\mathbf{0}, \mathbf{0.11})$, *respectively. Where:*

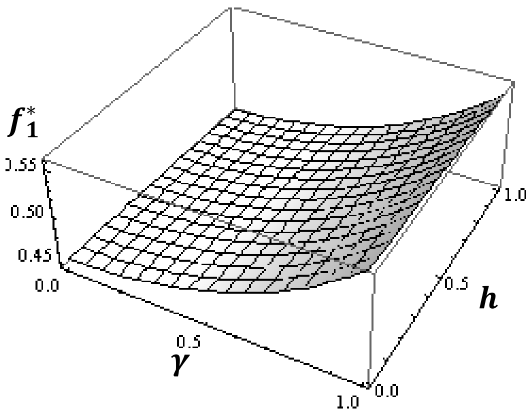
$$t_1 = \frac{(1-f)(8-\gamma^2)^2 16h^2}{f^2(2-\gamma)^2(4+\gamma)^2(2+\gamma)^3(4-\gamma)^3 - 8h^2(8-\gamma^2)\big(f(80-22\gamma^2+\gamma^4) - 2(8-\gamma^2)\big)} \tag{112}$$

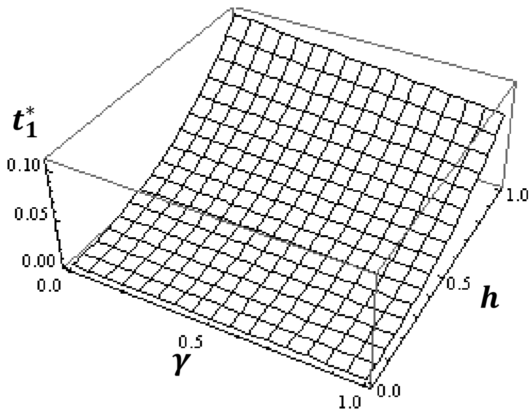
$$f_1^* \in (0.44, 0.56)^6 \tag{113}$$

[Proof: See Appendix (A.10)]

[6] The mathematical expression of f_1 is left out because of its wide extent. It is available by the authors upon request.

The 3D plots of the optimal Policy Maker's funding rate in firms' R&D investments and taxation policy, respectively, are presented below:



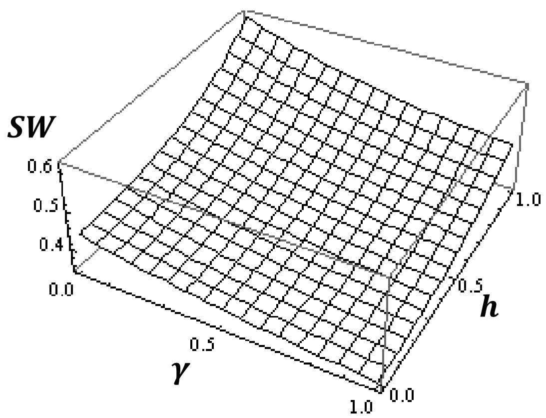


Under the optimal solution of (t_1^*, f_1^*), the Social Welfare in equilibrium is defined by:

$$SW = \frac{4f^3(64-20\gamma^2+\gamma^4)^2\left(f\left(7+\gamma(1-\gamma)\right)(64-20\gamma^2+\gamma^4)^2-(8-\gamma^2)^2 16h^2\right)}{\left(f^2(2-\gamma)^2(4+\gamma)^2(2+\gamma)^3(4-\gamma)^3-8h^2(8-\gamma^2)\left(f(80-22\gamma^2+\gamma^4)-2(8-\gamma^2)\right)\right)^2} \quad (114)$$

Where: $f = f_1^* \in (0.44, 0.56)$

Its 3D plot is presented below:



In addition, accordingly to the optimal solution of (t_1^*, f_1^*), (88), (90), (91) and (92) the output/employment levels and wages in Nash equilibrium are the following:

$$q_{im}^* = f(1-t)\frac{2(4+\gamma)(4-\gamma)(2+\gamma)(2-\gamma)}{f(4+\gamma)(2-\gamma)(4-\gamma)^2(2+\gamma)^2-8h^2(8-\gamma^2)} \quad (115)$$

$$w_{im}^* = f(1-t)\frac{(4+\gamma)(4-\gamma)(2+\gamma)^2(2-\gamma)^2}{f(4+\gamma)(2-\gamma)(4-\gamma)^2(2+\gamma)^2-8h^2(8-\gamma^2)} \quad (116)$$

$$x_{im}^{*} = (1-t)\frac{8h(8-\gamma^2)}{f(4+\gamma)(2-\gamma)(4-\gamma)^2(2+\gamma)^2 - 8h^2(8-\gamma^2)} \quad (117)$$

Where: $(t,f) = (t_1^*, f_1^*)$

Furthermore, by means of the optimal solution of (t_1^*, f_1^*), (116), (117), (121) and market participant surplus configurations from (74), (76) and (111), we obtain:

$$CS_m^* = f^2(1-t)^2\frac{4(1+\gamma)(64-20\gamma^2+\gamma^4)^2}{\left(f(4+\gamma)(2-\gamma)(4-\gamma)^2(2+\gamma)^2 - 8h^2(8-\gamma^2)\right)^2} \quad (118)$$

$$PS_m^* = f^2(1-t)^2\frac{8((64-20\gamma^2+\gamma^4)^2-(8-\gamma^2)^2 8h^2)}{\left(f(4+\gamma)(2-\gamma)(4-\gamma)^2(2+\gamma)^2 - 8h^2(8-\gamma^2)\right)^2} \quad (119)$$

$$UR_m^* = f^2(1-t)^2\frac{4(4+\gamma)^2(4-\gamma)^2(2+\gamma)^3(2-\gamma)^3}{\left(f(4+\gamma)(2-\gamma)(4-\gamma)^2(2+\gamma)^2 - 8h^2(8-\gamma^2)\right)^2} \quad (120)$$

Where: $(t,f) = (t_1^*, f_1^*)$

6. Endogenous Selection of Market Structures

In this Section, we insert an additional dimension to the social planner's role by endogenously deciding whether to intervene (and how) or not in the market structure. In fact, we insert an extra stage at the beginning of the game where the social planner decides which of the three economic policies will be adopted, as analyzed in Sections 3-5:

Section 3: 1st case: Absence of policy maker in market structure.
No intervention of policy maker in market's structure

Section 4: 2nd case: Policy maker proceeds to R&D investments.
Policy maker proceeds to quality improvement-R&D, as a common public good, by undertaking the costs of those investments and providing the know-how to the industry for free.

Section 5: 3rd case: Policy maker funds partially firms' R&D investments
Financing a percentage of the cost of firm-specific R&D investments

For convenience, we denote the above economic policies with indexes (a), (b) and (c), respectively in the order referred.

The selection depends on which one is the optimum in terms of Social Welfare; therefore, the social planner's maximization problem is the following:

$$\max_{\text{SW}} \{SW_a, SW_b, SW_c\} \tag{121}$$

Social welfare is higher when the social planner undertakes R&D [economic policy (b)], although this implies taxes that create distortions in the industry.

The interpretation is simple and is based on the following observations:

- in economic policy (a) and (c), each firm independently, invest in R&D to improve exclusively the quality of its own product,
- while in economic policy (b), the social planner invests in R&D on behalf of both firms by aiming to improve the quality of both products at once.

In conclusion, in economic policy (b) the market succeeds to save economic resources by investing in R&D, because those investments aim to improve the quality of both products of the present market. The following Proposition summarizes the above findings.

Proposition 12: *Social Welfare is higher when the social planner proceeds to R&D investment, than when it finances part of firms' ones. The market case, where the social planner is absent, gives comparatively the lowest Social Welfare, i.e.* $\boldsymbol{SW_b > SW_c > SW_a}$

7. Comparative Results

In the present section, we proceed to the comparative analysis of the three proposed markets structures / economic policies of the previous sections and investigate the potential superiority of the one which emerges eventually in equilibrium.

Our analysis targets to determine which of the three proposed markets structures gives comparatively higher outcomes for the main industry. Our findings, regarding the comparative evaluation of the main industry's outcomes, are summarized in the following Propositions.

Proposition 13: *Important industry elements, such as output level, wages and product quality improving, are always higher under the market structure where the social planner proceeds to R&D investment. The market case, where the social planner is absent, gives comparatively the lowest, i.e.*

$\boldsymbol{Q_b > Q_c > Q_a}$, $\boldsymbol{w_b > w_c > w_a}$ *and* $\boldsymbol{x_b > x_c > x_a}$.

[Proof: See Appendix (A.12)]

Proposition 14: *Consumer Surplus and Union Rents are always higher when the social planner proceeds to R&D investment, than when it finances part of firms' ones, the latter being always higher than when it is absent, i.e.* $\boldsymbol{CS_b > CS_c > CS_a}$ *and* $\boldsymbol{UR_b > UR_c > UR_a}$.

[Proof: See Appendix (A.13)]

Proposition 15: *The Producer Surplus is at its highest when the social planner proceeds to R&D investment, and at its lowest when it finances part of firms' ones. The market case, where the social planner is absent, lies in-between, i.e.* $\boldsymbol{PS_b > PS_a > PS_c}$

[Proof: See Appendix (A.14)]

Summarizing the above findings of the comparative analysis of the three proposed markets structures / economic policies, we show the superiority of the one which emerges eventually in equilibrium, by proving that under this market structure the social planner proceeds to R&D investment where:

- Social Welfare and its elements, Consumer Surplus, Producer Surplus, and Union rents, are comparatively higher and
- Important industry elements, such as output level, wages and product quality improving are also comparatively higher.

The main reason is that the specific market formation succeeds to save comparative economic resources by letting the social planner invests in R&D and thus improving the quality of both products at once.

8. Concluding Remarks

The present paper focuses mainly on unionized oligopolistic markets with differentiated products and R&D investments on product quality improvement. Its contribution in the "R&D investments in unionized oligopolies" literature is manifold, by not only investigating the correlation between quality improvement and union incentives for collusive play, but also by developing alternative market policies in the field of R&D, in order to promote Social Welfare. Additionally, we endogenize the selection of the policy which will be adopted for the present market by the Social Planner. The selection depends on which one is the optimum in terms of Social Welfare.

In particular, we develop two additional instances of policy maker's intervention. Firstly, we assume that a benevolent policy maker proceeds to quality improvement-R&D, as a common public good, by undertaking the costs of those investments and providing for free the know-how to the industry. Secondly, he finances a percentage of the cost of firm-specific R&D investments. The common assumption of both cases is that the policy maker finances the investments on R&D by indirect consumption taxation on final products, under the industry's condition of a balanced budget [$TC \leq TR$].

In the one-shot game, our analysis demonstrates that union collusion is weak / unstable and each union's dominant strategy is to act independently (competitively) under each social planner's policy (including the case where he is absent). The union competitive play increases the Social Welfare of the industry. Our remarkable findings arise from the endogenous selection of one of the three social planner's policies. Specifically, it suggests that the market structure in which the social planner proceeds to quality improvement-R&D, as a common public good, not only emerges in equilibrium by maximizing Social Welfare, but also promotes important industry elements, such as output level, wages and product quality improving, and all market participant surpluses, i.e. consumer, producer and union. The main reason is that the market, through that policy, succeeds to save economic resources by proceeding to R&D, as a common good, which improves the quality of both products at once.

Appendix

A.1 Proof of Proposition 1

At the first stage of the game, both unions simultaneously and independently decide whether to collude or to compete at the stage of w-negotiations (3^{rd} stage) with their specific firms. The unions deal with the following matrix game, in which the payoffs of each union in combination with the possible decisions of the unions are presented:

		Union i: *Collusion*	Union i: *Competition*
Union j	*Collusion*	(E1) $\{u_{ic}^*, u_{jc}^*\}$	(E2) $\{u_{id_i}^*, u_{jd_i}^*\}$
Union j	*Competition*	(E2) $\{u_{id_j}^*, u_{jd_j}^*\}$	(E3) $\{u_{im}^*, u_{im}^*\}$

Table 2: The Matrix Game that unions deal with at the first stage of the game.

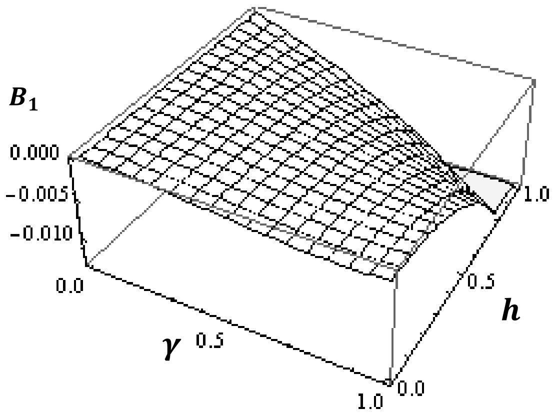
Due to symmetry, $\left(u_{id_j}^*, u_{jd_j}^*\right) = \left(u_{jd_i}^*, u_{id_i}^*\right)$ is applied and thus the number of candidate equilibria is reduced to three.

We demonstrate the Nash equilibrium by analyzing the candidate equilibria and their deviations. The possible deviation on the part of each union is to unilaterally switch its own strategy, given that its rival does not.

The first proposed candidate equilibrium (E1) is the one where union collusion is formed and the possible deviation, on the part of any union, is to adjust its own wages in order to maximize its own rents given that the other union sticks to collusive play. From equations (33) and (45) it is derived that:

$$u_{ic}^*(= u_{jc}^*) - u_{id_i}^*\left(= u_{jd_j}^*\right) = B_1 \tag{A1}$$

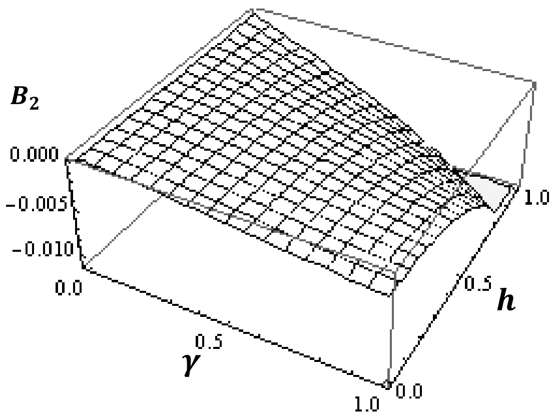
Each union has incentive to deviate and consequently union collusive play is not in Nash equilibrium. The 3D plot of factor B_1 is presented below.



The candidate equilibrium (E2) is the one where one union acts collusively (let it be union i), while the other acts competitively (let it be union j), and the possible deviations arise by unilaterally switching each union's strategy to its rival's one. Even if union i has no incentive to deviate [see (A1)], it is inferred that (E2) is also not in Nash equilibrium because union j has incentive to deviate by acting competitively. From equations (23) and (44) it is derived that:

$$u^*_{id_j}\left(= u^*_{jd_i}\right) - u^*_{im}(= u^*_{jm}) = B_2 \tag{A2}$$

The 3D plot of factor B_2 is presented below.



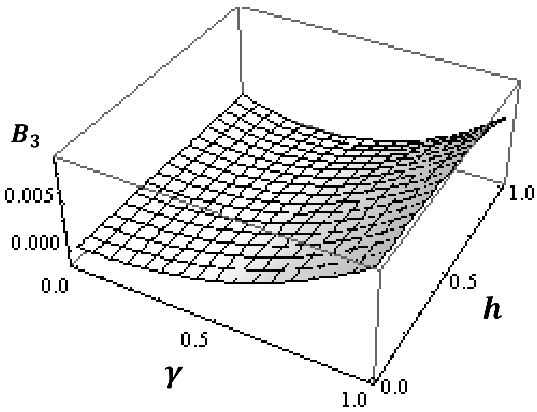
The last candidate equilibrium (E3) is the one where unions act competitively and the possible deviation, on the part of any union, is to adjust its own wages in order to maximize the collusive revenues. It is easy to check by (A1) and (A2) that this one is in Nash equilibrium, as no union has incentive to deviate.

A.2 Proof of Proposition 2

By means of (23) and (33), we obtain:

$$u_{ic}^{*}(=u_{jc}^{*})-u_{im}^{*}(=u_{jm}^{*})=B_3 \quad \text{(A3)}$$

Where, $B_3>0\ \forall\, h(\gamma)<h_{\boldsymbol{u}(c,d)}(\gamma)$[7] its 3D plot is the following:



Moreover, $h_{u(c,m)}(\gamma)\in(0,1)\ \forall\,\gamma\in(0,0.65), w_0\in(0,1)$ – with value field (0,1) and it is depicted in Figure 5 of the main text.

According to our findings, we conclude that:

$$u_{im}^{*}(=u_{jm}^{*})>u_{ic}^{*}(=u_{jc}^{*}) \qquad \forall\ h(\gamma)>h_{\boldsymbol{u}(c,m)}(\gamma) \quad \text{(A4)}$$

$$u_{ic}^{*}(=u_{jc}^{*})>u_{im}^{*}(=u_{jm}^{*}) \qquad \forall\ h(\gamma)<h_{\boldsymbol{u}(c,d)}(\gamma) \text{ or } \gamma>0.65 \quad \text{(A5)}$$

A.3 Proof of Equations (56) and (57)

(i) **Proof of Equation (56):**

By definition, the Consumer Surplus is the sum of consumer utility minus the cost of products purchased at the equilibrium price, hence in our model the mathematical expression of Consumer Surplus is the following [given in(1)]:

$$CS=(1+hx_i)q_i+(1+hx_j)q_j-\frac{1}{2}\left(q_i^{\,2}+q_j^{\,2}+2\gamma q_i q_j\right)-p_i q_i-p_j q_j \quad \text{(A6)}$$

Assuming the absolute symmetry of firms and their strategies, we get that:

[7] The mathematical expressions of B_3 and $h_{\boldsymbol{u}(c,d)}(\gamma)$ are left out, because it was complicated to be shaped as closed forms.

$$q_i = q_j = q \tag{A7}$$

$$p_i = p_j = p \tag{A8}$$

$$x_i = x_j = x \tag{A9}$$

$$w_i = w_j = w \tag{A10}$$

Moreover, substituting (A7), (A8), (A9) and (A10) for the demand function [given in (2)] and firms' reaction functions [given in (12)], we get that:

$$p = 1 - (1 + \gamma)q + hx \tag{A11}$$

$$q = \frac{(2 + \gamma)q - (1 - w)}{h} \tag{A12}$$

It is easy to check that taking (A11) and (A12) and substituting them for (A6), the Consumer Surplus is defined by:

$$CS = \frac{Q^2}{4} - (1 + \gamma) \tag{A13}$$

Where Q is the sum of the firms' output level.

(ii) **Proof of Equation (57):**

By definition the Producer Surplus is the sum of firms' profits, hence in our model the mathematical expression of Producer Surplus is the following [given in (4)]:

$$PS = \sum_{k=i,j} \left((p_k - w_k)q_k - \frac{{x_k}^2}{2} \right) \tag{A14}$$

Assuming the absolute symmetry of firms and their strategies, the Producer Surplus is also defined by [taking (A11) and (A12) and substituting them for (A14)]:

$$PS = \frac{Q^2}{2} - x^2 \tag{A15}$$

Where Q is the sum of the firms' output level.

A.4 Proof of Proposition 3

We now proceed to the comparative analysis of equilibrium outcomes, i.e. wages, output level and product quality improvement under each union structure, i.e. decentralized and centralized wage-setting regimes:

Assuming the absolute symmetry of unions and their strategies, we get that:

$$w_{is} = w_{js} = w_s \tag{A16}$$

$$q_{is} = q_{js} = q_s \tag{A17}$$

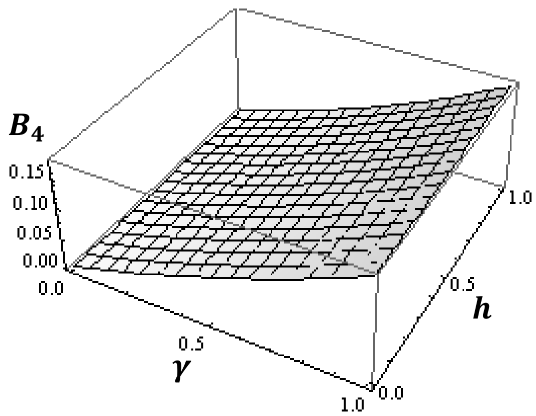
$$x_{is} = x_{js} = x_s \tag{A18}$$

Where $s = c, m$

Regarding wages, by means of (A16), (22) and (32), we obtain:

$$w_c - w_m = B_4 > 0 \qquad \forall\ h, \gamma \in (0,1) \tag{A19}$$

Where, $B_4 > 0\ \forall\ h, \gamma \in (0,1)$[8] and its 3D plot is respectively the below:



Summarizing the above results, we conclude that:

$$w_{ic}^* = w_{jc}^* = w_c^* > w_{im}^* = w_{jm}^* = w_m^* \tag{A20}$$

[8] The mathematical expression of B_{15} and B_{16} are left out because of their wide extent. They are available by the authors upon request.

To easily grasp the effects of wages on R&D investments and market output level, we get firms' reaction functions to R&D investments by taking the *f.o.c$_s$* of firm's profit maximization objective with respect to R&D investments in (17) given only the optimal output rule in equilibrium in (13), as follows:

$$R_i^{R\&D}(x_j) = \frac{4h\left(2-\gamma-2w_i+\gamma w_j - h\gamma\left(x_j\right)\right)}{(2-\gamma)^2(2+\gamma)^2-8h^2} \quad \text{(A21)}$$

By substituting (A16) for (A21) we obtain that the new formation of firms' reaction functions to R&D investments is the following:

$$R_i^{R\&D}(x_j) = \frac{4h\left(2-\gamma+(\gamma-2)w - h\gamma\left(x_j\right)\right)}{(2-\gamma)^2(2+\gamma)^2-8h^2} \quad \text{(A22)}$$

From the *f.o.c$_{.s}$* of (A22) we get the optimal R&D investment which is presented in the following equation:

$$x_i^* = \frac{4h(1-w)}{(2-\gamma)(2+\gamma)^2-4h^2} \quad \text{(A23)}$$

It is easily observable that R&D investment decreases with the labor unit cost:

$$\frac{\partial x_i^*}{\partial w} = -\frac{4h}{(2-\gamma)(2+\gamma)^2-4h^2} < 0 \quad \text{(A24)}$$

Combining our findings presented by equations (A20) and (A24) we conclude that:

$$x_{im}^* = x_{jm}^* = x_m^* > x_{ic}^* = x_{jc}^* = x_c^* \quad \text{(A25)}$$

By substituting now the optimal R&D investments in (A23) for the optimal output rule in equilibrium in (13), we get:

$$q_i^* = \frac{(2-\gamma)(2+\gamma)(1-w)}{(2-\gamma)(2+\gamma)^2-4h^2} \quad \text{(A26)}$$

Notice that the market output level decreases with the union wages:

$$\frac{\partial q_i^*}{\partial w} = -\frac{(2-\gamma)(2+\gamma)}{(2-\gamma)(2+\gamma)^2-4h^2} < 0 \quad \text{(A27)}$$

According to equations (A20) and (A27), we conclude that:

$$q_{im}^{*} = q_{jm}^{*} = q_{m}^{*} > q_{ic}^{*} = q_{jc}^{*} = q_{c}^{*} \tag{A28}$$

A.4. Proof of Proposition 4

Supposing the absolute symmetry of unions and their strategies, i.e. decentralized and centralized wage-setting regimes, we get that:

$$u_{is}^{*} = u_{js}^{*} = u_{s}^{*} \quad ; \quad s = c, m \tag{A29}$$

By definition, the unions set those wages that gives them positive utility:

$$w \ : \ u_{s}^{*} > 0 \tag{A30}$$

Thus, by substituting the optimal output rule [given in (A26)] into the union utility function [given in (5)], we get that:

$$u_{s}^{*} = w\frac{(2-\gamma)(2+\gamma)(1-2w)}{(2-\gamma)(2+\gamma)^{2} - 4h^{2}} > 0 \tag{A31}$$

Notice that the above in equation is satisfied if and only if the following applies:

$$0 < w_{s} < \frac{1}{2} \tag{A32}$$

The elasticity of product on union wages is the following:

$$\varepsilon_{qw} = \frac{\partial Q(w)}{\partial w_{s}}\frac{w_{s}}{Q(w)} \tag{A33}$$

Substituting now the optimal output rule in (A26) for the formula of elasticity of product on union wages in the game in (A33), we get:

$$\varepsilon_{qw} = -\frac{w_{s}}{1-w_{s}} \tag{A34}$$

Combining our findings presented by equations (A32) and (A34), we conclude that:

$$w_{s} \in \left(0, \frac{1}{2}\right) \tag{A35}$$

$$\varepsilon_{qw} = -\frac{w_{s}}{1-w_{s}} \in (-1,0) \tag{A36}$$

A.4. Proof of Proposition 5

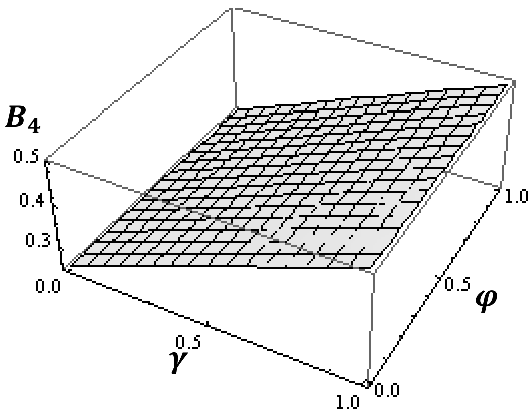
Recall that total Consumer Surplus under collusion and competition proves to be:

$$CS_{c,m} = \frac{1+\gamma}{4} {Q_{c,m}}^2 \tag{A37}$$

Furthermore, by means of (47), in the case of a Mix of Strategies configuration total Consumer Surplus proves to be:

$$CS_{mos} = B_4 {Q_{mos}}^2 \tag{A38}$$

Where, $B_4 > 0 \; \forall \; \gamma, \varphi \in (0,1)$[9] and its 3D plot is presented below.

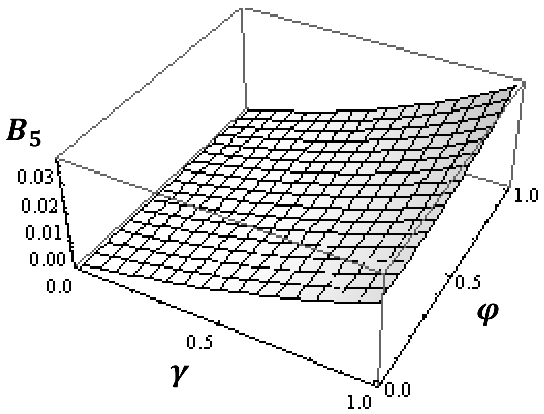


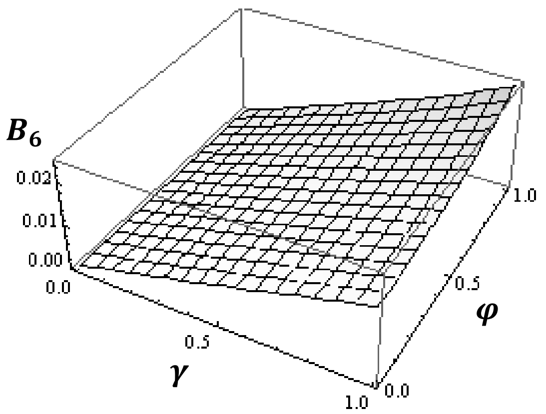
Using (A**37**) and (A**38**), it is then straightforward that, by virtue of Proposition 5:

$$CS^*_{mos} - CS^*_c = B_5 > 0 \qquad \forall \; h, \gamma \in (0,1) \tag{A39}$$

$$CS^*_m - CS^*_{mos} = B_6 > 0 \qquad \forall \; h, \gamma \in (0,1) \tag{A40}$$

Where, $B_5, B_6 > 0 \; \forall \; \gamma, \varphi \in (0,1)$[10] and their 3D plot are presented below.





[9] The mathematical expression of B_4 is left out because of its wide extent. It is available by the authors upon request.
[10] The mathematical expressions of B_5 and B_6 are left out because of their wide extent. They are available by the authors upon request.

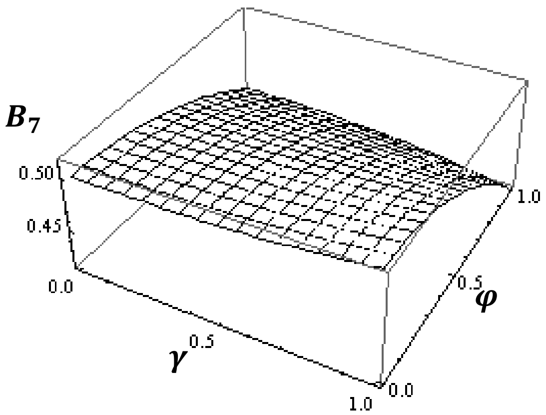
Turning now to total Producer Surplus and recalling its simplified expression under collusion and competition, we get:

$$PS_{c,m} = \frac{Q_{c,m}^2}{2} - x_{i(j)c,m}^2 \qquad \text{(A41)}$$

Furthermore, by means of (54), in the case of a Mix of Strategies configuration, total Producer Surplus proves to be:

$$PS_{mos} = B_7 {Q_{mos}}^2 \qquad \text{(A42)}$$

Where, $B_7 > 0 \; \forall \, \gamma, \varphi \in (0,1)$[11] and its 3D plot is presented below.

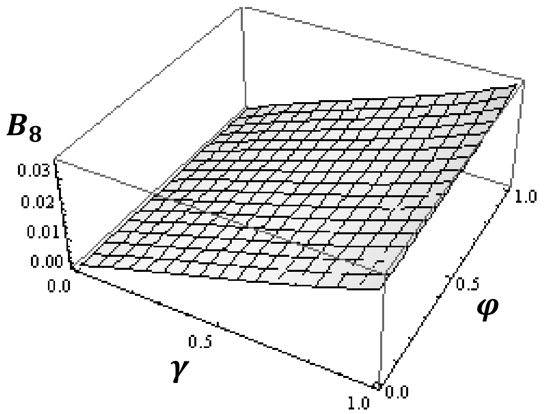


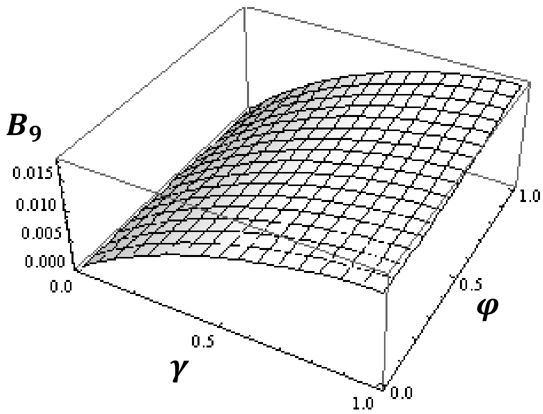
Using (A41) and (A42), it is straightforward then that, by virtue of Proposition 5:

$$PS_{mos}^* - PS_c^* = B_8 > 0 \qquad \forall \; h, \gamma \in (0,1) \qquad \text{(A43)}$$

$$PS_m^* - PS_{mos}^* = B_9 > 0 \qquad \forall \; h, \gamma \in (0,1) \qquad \text{(A44)}$$

Where, $B_8, B_9 > 0 \; \forall \, \gamma, h \in (0,1)$[12] and their 3D plot are presented below.





[11] The mathematical expression of B_7 is left out because of its wide extent. It is available by the authors upon request.

[12] The mathematical expressions of B_8 and B_9 are left out because of their wide extent. They are available by the authors upon request.

A.5. Proof of Proposition 6

Total Union Rents in the *m*, *c*, and *mos* equilibria are defined as:

$$UR_s = u_{is} + u_{js}, \quad \text{where } s = m, c, d \tag{A45}$$

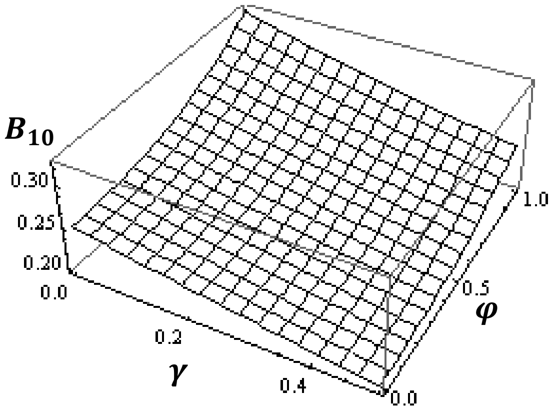
By means of (23), (33), (44) and (45) Union Rents under collusion, competition, and mix of strategies, is respectively given by:

$$UR_m^* = 2u_{im}^* = \frac{4(4+\gamma)^2(4-\gamma)^2(4-\gamma^2)^3}{((2-\gamma)(4+\gamma)(2+\gamma)^2(4-\gamma)^2 - 8h^2(8-\gamma^2))^2} \tag{A46}$$

$$UR_c^* = 2u_{ic}^* = \frac{(2-\gamma)^2(2+\gamma)^3}{2((2-\gamma)(2+\gamma)^2 - h^2)^2} \tag{A47}$$

$$UR_{mos}^* = \sum_{k=i,j} q_{kmos}^* = B_{10} > 0 \tag{A48}$$

Where, $B_{10} > 0 \; \forall \, \gamma, h \in (0,1)$[13] and its 3D plot is presented below.



It then proves that:

$$UR_m^* > UR_d^* \qquad \forall \; h(\gamma) > h_{u(c,m)}(\gamma) \tag{A49}$$

$$UR_m^* > UR_d^* \qquad \forall \; h(\gamma) > h_{u(m,mos)}(\gamma) \tag{A50}$$

$$UR_d^* > UR_c^* \qquad \forall \; h(\gamma) > h_{u(c,mos)}(\gamma) \tag{A51}$$

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[13] The mathematical expression of B_{10} is left out because of its wide extent. It is available by the authors upon request.

Regarding the validity of (A49), (A50) and (A51), it holds that $h_{u(c,m)}(\gamma) \in (0,1)\ \forall\, \gamma \in (0,0.65)$, $h_{u(m,mos)}(\gamma) \in (0,1)\ \forall\, \gamma \in (0,0.51)$ and $h_{u(c,mos)}(\gamma) \in (0,1)\ \forall\, \gamma \in (0,0.93)$.[14]

Hence, as shown in *Figure 5* (see main text) depicting the $h_{u(c,m)}(\gamma)$, $h_{u(m,mos)}(\gamma)$ and $h_{u(c,mos)}(\gamma)$ critical schedules, $h_{u(m,mos)}(\gamma) > h_{u(c,m)}(\gamma) > h_{u(c,mos)}(\gamma)$ $\forall\, \gamma \in [0,1]$, with $\frac{\partial h_{u(m,mos)}}{\partial \gamma}, \frac{\partial h_{u(c,m)}}{\partial \gamma}, \frac{\partial h_{u(c,mos)}}{\partial \gamma} > 0$

Summarizing the above results, we conclude that:

$$UR_c^* > UR_{mos}^* > UR_m^* \qquad \forall\, h \in \left(0, h_{u(c,mos)}\right) \text{ or } \gamma \in (0.93,1) \qquad \text{(A52)}$$

$$UR_{mos}^* > UR_c^* > UR_m^* \qquad \forall\, h \in \left(h_{u(c,mos)}, h_{u(c,m)}\right) \qquad \text{(A53)}$$

$$UR_{mos}^* > UR_m^* > UR_c^* \qquad \forall\, h \in \left(h_{u(c,m)}, h_{u(m,mos)}\right) \qquad \text{(A54)}$$

$$UR_m^* > UR_{mos}^* > UR_c^* \qquad \forall\, h \in \left(h_{u(m,mos)}, 1\right) \qquad \text{(A55)}$$

A.6. Proof of Proposition 7

Social Welfare, in the *c*, *m*, and *mos* equilibria, is defined as follows:

$$SW_s = CS_s + PS_s + UR_s, \qquad \text{where } s = c, m, d \qquad \text{(A56)}$$

Thus, respectively substituting the CS_s, PS_s, UR_s elements for (A52), by virtue of (A37), (A38), (A41), (A42), (A46), (A47) and (A48), we get that:

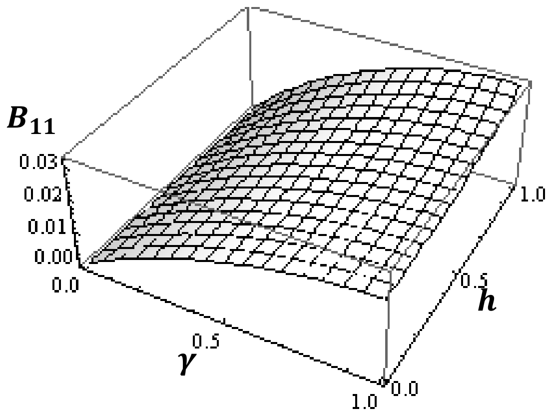
$$SW_m^* - SW_{mos}^* = B_{11} > 0 \qquad \forall\ h, \gamma \in (0,1) \qquad \text{(A57)}$$

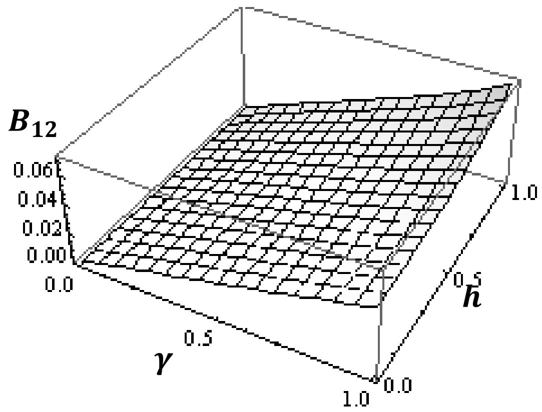
$$SW_{mos}^* - SW_c^* = B_{12} > 0 \qquad \forall\ h, \gamma \in (0,1) \qquad \text{(A58)}$$

Where, B_{11}, $B_{12} > 0\ \forall\ h, \gamma \in (0,1)$[15] and their 3D plots are respectively the following:

[14] The mathematical expressions of $h_{u(c,m)}(\gamma)$, $h_{u(m,d)}(\gamma)$ and $h_{u(c,d)}(\gamma)$ are left out because of their wide extent. They are available by the authors upon request.

[15] The mathematical expression of B_{11} and B_{12} are left out because of their wide extent. They are available by the authors upon request.





A.7. Proof of Proposition 8

At the second stage of the game, both unions simultaneously and independently decide the strategy that will follow in 3rd stage. The unions deal with the matrix game presented in Appendix A.1, except that payoffs of each union are given by equations (59), (63), (67) and (68) in Subsections 4.1-4.3.

As proof of Proposition 1, we demonstrate the Nash equilibrium by proposing the candidate equilibria and checking their deviations, with the possible deviation on the part of each union being to switch its own strategy, given that its rival sticks to the first decision.

The first proposed candidate equilibrium (E1) is not in Nash equilibrium, as both unions have incentive to turn their strategy to competition. From equations (63) and (68) it is derived that:

$$u^*_{ic}(= u^*_{jc}) - u^*_{id_i}\left(= u^*_{jd_j}\right) = B_4(1 + hx - t)^2 < 0 \qquad \text{(A59)}$$

Where $B_{13} = -\frac{\gamma^2(4-\gamma(2+\gamma))}{4(2+\gamma)(8-\gamma^2)^2} < 0,\ \forall\ \ \gamma \in (0,1).$

The candidate equilibrium (E2) does also not emerge in Nash equilibrium, as the union plays collusively and has incentive to deviate by acting competitively. From equations (59) and (67), it is derived that:

$$u^*_{id_j}\left(= u^*_{jd_i}\right) - u^*_{im}(= u^*_{jm}) = B_5(1 + hx - t)^2 < 0 \qquad \text{(A60)}$$

Where $B_{14} = -\frac{1}{2}(2-\gamma)\frac{4(8-\gamma^2)-(2+\gamma)(4-\gamma)^2}{(8-\gamma^2)(2+\gamma)(4-\gamma)^2} < 0,\ \forall\ \ \gamma \in (0,1)$.

The last candidate equilibrium (E3) is in Nash equilibrium, as no union has incentive to deviate and it is proved by equations (A59) and (A60).

Notice that although union collusive play is not in Nash equilibrium, it is Pareto improving for the unions, as it is presented by the following in equation:

$$u_{ic}^{*}(= u_{jc}^{*}) - u_{im}^{*}(= u_{jm}^{*}) = B_{15}(1 + hx - t)^2 > 0 \tag{A61}$$

Where $B_{15} = \frac{\gamma}{4(2+\gamma)(4-\gamma)^2} > 0,\ \forall\ \ \gamma \in (0,1)$.

A.8. Proof of Proposition 9

The social planner aims to determine the optimal level of R&D investments for product quality improvement and indirect taxation on market products that maximize Social Welfare.

Under the assumption of a Balanced Budget policy by the social planner in the industry, we substitute the equations (6) and (8) for (72) and get that:

$$Q = \frac{x^2}{2t} \tag{A62}$$

Where Q is the sum of the firms' output level.

Given that union competitive play emerges in equilibrium, we get the optimal industry output level by the equations (55) and (57):

$$Q^{*} = \frac{4(1 + hx - t)}{(2+\gamma)(4-\gamma)} \tag{A63}$$

Taking now the optimal firms' output level [given in (A62)] and substituting it on the condition of a Balanced Budget [given in (A63)], we get the optimal combinations of R&D investments and product taxation:

$$t_1 = \frac{1}{4}\left(2 + 2hx - \sqrt{4 + 2x(4h + 2h^2x - (4-\gamma)(2+\gamma)x)}\right) \tag{A64}$$

$$t_2 = \frac{1}{4}\left(2 + 2hx + \sqrt{4 + 2x(4h + 2h^2x - (4-\gamma)(2+\gamma)x)}\right) \qquad \text{(A65)}$$

Therefore, the maximization problem of the social planner is to define the optimal R&D investments under the one of the two proposed taxation forms satisfying the Balanced Budget condition:

$$max_{x_i}[SW\{= CS + PS + UR\}] \qquad \text{(A66)}$$
$$s.t. \quad t = t_1, t_2$$

The above maximization problem gives the following solutions:

$$\begin{Bmatrix} t_1^* = \dfrac{2h^2}{(2+\gamma)(4-\gamma)+2h^2} \in (0{,}0.3) \\ x_1^* = \dfrac{4h}{(2+\gamma)(4-\gamma)+2h^2} \in (0{,}0.6) \end{Bmatrix} \qquad \text{(A67)}$$

$$\begin{Bmatrix} t_2^* = \dfrac{(2+\gamma)(4-\gamma)}{(2+\gamma)(4-\gamma)+2h^2} \in (1{,}1.3) \\ x_2^* = \dfrac{4h}{(2+\gamma)(4-\gamma)+2h^2} \in (0{,}0.6) \end{Bmatrix} \qquad \text{(A68)}$$

The solution (t_2^*, x_2^*) is rejected, because it does not satisfy the condition of oligopoly existence in (58). Thence, it arises that the accepted solution is (t_1^*, x_1^*) and the Social Welfare in equilibrium is defined by:

$$SW = \frac{4\big(7 + \gamma(1-\gamma)\big)}{\big((2+\gamma)(4-\gamma)+2h^2\big)^2} \qquad \text{(A69)}$$

A.9. Proof of Proposition 10

At the second stage of the game, both unions simultaneously and independently decide the strategy which will follow in 4th stage. The unions deal with the matrix game presented in Appendix A.1, except that payoffs of each union are given by equations (94), (99), (106) and (107) in Subsections 5.1-5.3.

We will demonstrate the Nash equilibrium by proposing the candidate equilibria and checking for all possible deviations, taking into consideration the limitations of minimum presentence of policy maker's financial participation in firms' R&D expenditures. Those limitations are derived from Equations (93), (98), (104) and (105), respectively, and they are presented below:

$$f > f_1 = \frac{8h^2(8-\gamma^2)}{f(4+\gamma)(2-\gamma)(4-\gamma)^2(2+\gamma)^2 - 8h^2(8-\gamma^2)} \in (0,0.138) \qquad \text{(A70)}$$

$$f > f_2 = \frac{h^2}{(2-\gamma)(2+\gamma)^2} \in (0,0.125) \qquad \text{(A71)}$$

$$f > f_3 = \frac{8h^2}{(2+\gamma)(2-\gamma)^2(8-\gamma^2)} \in (0,0.381) \qquad \text{(A72)}$$

$$f > f_4 = \frac{4h^2}{(2+\gamma)(2-\gamma)^2(4+\gamma)} \in (0,0.267) \qquad \text{(A73)}$$

Consequently, the proposed market structure gives positive R&D investments under all possible union strategic decisions when the following condition is satisfied:

$$f > \max\{f_1, f_2, f_3, f_4\} \qquad \text{(A74)}$$

It then proves that:

$$\max\{f_1, f_2, f_3, f_4\} = f_3 \left\{= \frac{8h^2}{(2+\gamma)(2-\gamma)^2(8-\gamma^2)} \in (0,0.381)\right\} \qquad \text{(A75)}$$

Taking into consideration the above condition, the first proposed candidate equilibrium (E1) is not in Nash equilibrium, because both unions have incentive to deviate from it, as it is derived from equations (99) and (107):

$$u_{ic}^*(= u_{jc}^*) - u_{id_i}^*\left(= u_{jd_j}^*\right) = \frac{1}{4}B_{16}f^2(1-t)^2 < 0 \qquad \text{(A76)}$$

Where $B_{16} < 0,\ \forall\ \gamma \in (0,1)$, $h \in (0,1)$ and $f \in \left(\frac{8h^2}{(2+\gamma)(8-\gamma^2)(2-\gamma)^2}, 1\right)$.

The candidate equilibrium (E2) does not also emerge in Nash equilibrium, as the union which plays collusively has incentive to deviate by acting competitively. From equations (94) and (106), it applies that:

$$u^*_{id_j}\left(=u^*_{jd_i}\right)-u^*_{im}\left(=u^*_{jm}\right)=\frac{1}{2}B_{17}f^2(1-t)^2<0 \tag{A77}$$

Where $B_{17}<0,\ \forall\ \ \gamma\in(0,1), h\in(0,1)$ and $f\in\left(\frac{8h^2}{(2+\gamma)(8-\gamma^2)(2-\gamma)^2},1\right)$.

The last candidate equilibrium (E3) is in Nash equilibrium, as no union has incentive to deviate and it is proved by equations (A76) and (A77).

Notice that although union collusive play is not in Nash equilibrium, it is Pareto improving for the unions, as presented by the following in equation:

$$u^*_{ic}\left(=u^*_{jc}\right)-u^*_{im}\left(=u^*_{jm}\right)=\frac{1}{4}B_{18}f^2(1-t)^2<0 \tag{A78}$$

Where $B_{18}<0,\ \forall\ \ \gamma\in(0,1), h\in(0,1)$ and $f\in\left(\frac{8h^2}{(2+\gamma)(8-\gamma^2)(2-\gamma)^2},1\right)$ [16].

A.10. Proof of Proposition 11

The social planner's maximization problem is to determine the optimal level of funding rate of firms' R&D investments and indirect taxation on market products that maximize Social Welfare.

Accordingly to a Balanced Budget policy of the social planner in the industry, we substitute equations (7) and (8) for (72) and get that:

$$Q=\frac{(1-f)\left(x_i^2+x_j^2\right)}{2t} \tag{A79}$$

Where Q is the sum of the firms' output level.

Getting the optimal industry output level and wage rate in Nash Equilibrium, i.e. union competitive institution [given in (88) and (90), respectively], we get the optimal industry output level as follows:

[16] The mathematical expressions of B_{16}, B_{17} and B_{18} are left out because of their wide extent. They are available by the authors upon request. Their plot are not presentable as are depended by three variables, γ, h and f. Their negative sign was found by using the Bolzano Theorem, i.e. (a) we found the $f_{critical}$s that $B=0$, (b) prove that $f_{critical}s<f_3$ and (c) get a random value of $f\in(f_3,1)$ and observe that $B<0$.

$$Q^* = \frac{4f(1-t)(2-\gamma)(2+\gamma)(4-\gamma)(4+\gamma)}{f(2-\gamma)(4+\gamma)(2+\gamma)^2(4-\gamma)^2 - 8h^2(8-\gamma^2)} \quad \text{(A80)}$$

Substituting (A80) for (A79), we can get the level of product taxation that satisfies the Balance Budget condition of the industry:

$$t_1 = \frac{(1-f)(8-\gamma^2)^2 16h^2}{f^2(2-\gamma)^2(4+\gamma)^2(2+\gamma)^3(4-\gamma)^3 - 8h^2(8-\gamma^2)\big(f(80-22\gamma^2+\gamma^4) - 2(8-\gamma^2)\big)} \quad \text{(A81)}$$

$$t_2 = 1 \quad \text{(A82)}$$

Therefore, the maximization problem of the social planner is to define the optimal R&D investments under one of two taxation forms:

$$max_{x_i}[SW\{= CS + PS + UR\}] \quad \text{(A83)}$$
$$s.t. \quad t = t_1, t_2$$

The above maximization problem gives the following solutions:

$$\left\{ \begin{array}{c} t_1^* = \frac{(1-f)(8-\gamma^2)^2 16h^2}{f^2(2-\gamma)^2(4+\gamma)^2(2+\gamma)^3(4-\gamma)^3 - 8h^2(8-\gamma^2)\big(f(80-22\gamma^2+\gamma^4) - 2(8-\gamma^2)\big)} \\ f_{1a}^* \in (0.44, 0.56), \quad f_{1b}^* \in (0, 0.38), \quad f_{1c}^* = 0 \text{ [17]} \end{array} \right\} \text{(A84)}$$

$$\left\{ \begin{array}{c} t_2^* = 1 \\ SW = 0 \end{array} \right\} \quad \text{(A85)}$$

The solutions f_{1b}^* and f_{1c}^* are rejected, as they do not satisfy the condition presented in (A75). In addition, the solution t_2^* is rejected, because it leads to null Social Welfare. Thence, it arises that the accepted solution is (t_1^*, f_{1a}^*)[18] and the Social Welfare in equilibrium is defined by:

$$SW = \frac{4f^3(64-20\gamma^2+\gamma^4)^2\big(f\big(7+\gamma(1-\gamma)\big)(64-20\gamma^2+\gamma^4)^2 - (8-\gamma^2)^2 16h^2\big)}{\Big(f^2(2-\gamma)^2(4+\gamma)^2(2+\gamma)^3(4-\gamma)^3 - 8h^2(8-\gamma^2)\big(f(80-22\gamma^2+\gamma^4) - 2(8-\gamma^2)\big)\Big)^2} \quad \text{(A86)}$$

Where: $f = f_1^* \in (0.44, 0.56)$

[17] The mathematical expressions of f_{1a} and f_{1b} are left out because of their wide extent. They are available by the authors upon request.

[18] For simplicity, hereafter the factor f_{1a}^* is called f_1^*.

A.11. Proof of Proposition 12

The social planner's maximization problem is to determine which of the three economic policies, as analyzed in Sections 3 – 5, maximize Social Welfare:

- Absence of policy maker
- Policy maker proceeds to R&D investments
- Policy maker funds partially firms' R&D investments

The above economic policies give the followings outcomes in terms of Social Welfare, respectively:

$$SW_a = \frac{4\left(\left(7+\gamma(1-\gamma)\right)(64-20\gamma^2+\gamma^4)^2 1-16h^2(8-\gamma^2)^2\right)}{((2-\gamma)(4+\gamma)(2+\gamma)^2(4-\gamma)^2-8h^2(8-\gamma^2))^2} \quad \text{(A87)}$$

$$SW_b = \frac{4\left(7+\gamma(1-\gamma)\right)}{\left((2+\gamma)(4-\gamma)+2h^2\right)^2} \quad \text{(A88)}$$

$$SW_c = \frac{4f^3(64-20\gamma^2+\gamma^4)^2\left(f\left(7+\gamma(1-\gamma)\right)(64-20\gamma^2+\gamma^4)^2-(8-\gamma^2)^2 16h^2\right)}{\left(f^2(2-\gamma)^2(4+\gamma)^2(2+\gamma)^3(4-\gamma)^3-8h^2(8-\gamma^2)\left(f(80-22\gamma^2+\gamma^4)-2(8-\gamma^2)\right)\right)^2} \quad \text{(A89)}$$

Where: $f = f_1^* \in (0.44, 0.56)$

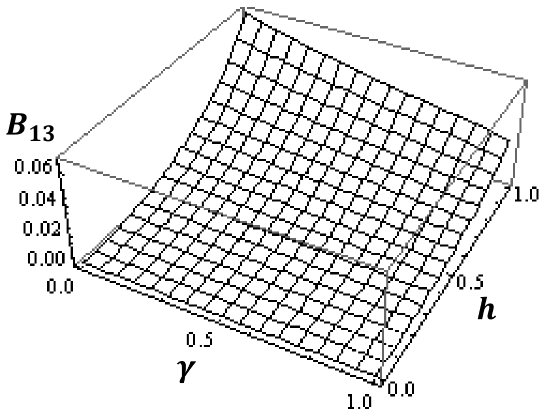
It then proves that:

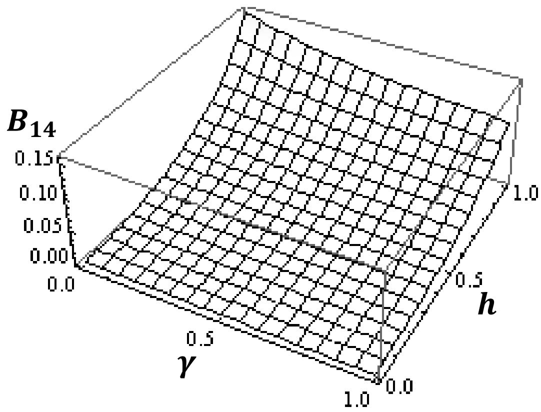
$$SW_c - SW_a = B_{13} > 0 \qquad \forall\ h,\gamma \in (0,1) \quad \text{(A90)}$$

$$SW_b - SW_c = B_{14} > 0 \qquad \forall\ h,\gamma \in (0,1) \quad \text{(A91)}$$

Where, B_{13}, $B_{14} > 0\ \forall\ h,\gamma \in (0,1)$[19] and their 3D plots are respectively the following:

[19] The mathematical expression of B_{13} and B_{14} are left out because of their wide extent. They are available by the authors upon request.





Summarizing the above results, we conclude that:

$$SW_b > SW_c > SW_a \qquad \forall\ h,\gamma \in (0,1) \qquad \text{(A92)}$$

A.12. Proof of Proposition 13

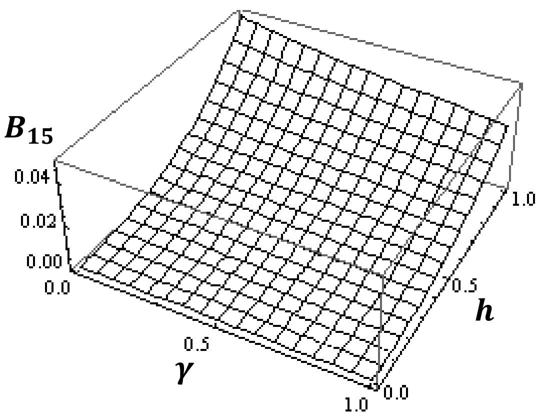
We now proceed to the comparative analysis of important industry elements, such as output level, wages and product quality improving under each of the three proposed market structures in the present paper.

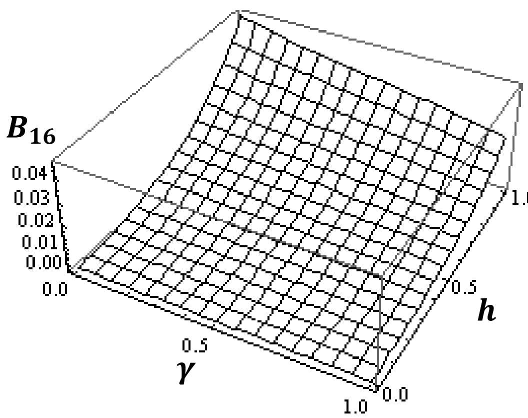
- Regarding market output level, by means of (20), (81) and (115), we obtain:

$$Q_c - Q_a = B_{15} > 0 \qquad \forall\ h,\gamma \in (0,1) \qquad \text{(A93)}$$

$$Q_b - Q_c = B_{16} > 0 \qquad \forall\ h,\gamma \in (0,1) \qquad \text{(A94)}$$

Where, B_{15}, $B_{16} > 0\ \forall\ h,\gamma \in (0,1)$[20] and their 3D plots are respectively the following:





[20] The mathematical expression of B_{15} and B_{16} are left out because of their wide extent. They are available by the authors upon request.

Summarizing the above results, we conclude that:

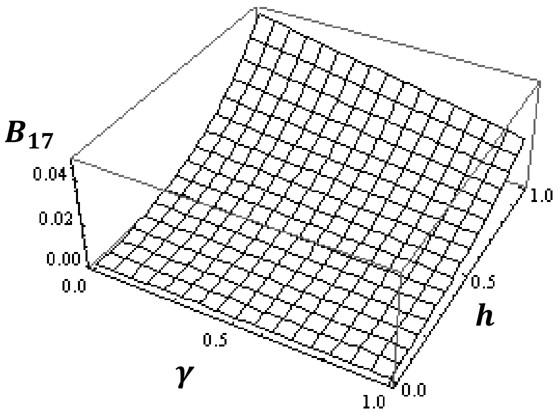
$$Q_b > Q_c > Q_a \qquad \forall\ h,\gamma \in (0,1) \qquad \text{(A95)}$$

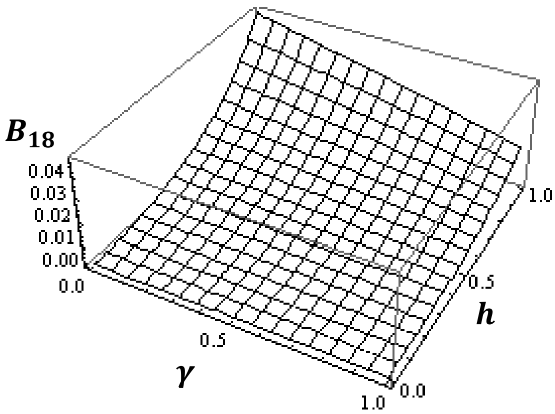
- Regarding union wages, by means of (22), (80) and (116), we obtain:

$$w_c - w_a = B_{17} > 0 \qquad \forall\ h,\gamma \in (0,1) \qquad \text{(A96)}$$

$$w_b - w_c = B_{18} > 0 \qquad \forall\ h,\gamma \in (0,1) \qquad \text{(A97)}$$

Where, B_{17}, $B_{18} > 0\ \forall\ h,\gamma \in (0,1)$[21] and their 3D plots are respectively the following:





Summarizing the above results, we conclude that:

$$w_b > w_c > w_a \qquad \forall\ h,\gamma \in (0,1) \qquad \text{(A98)}$$

- Regarding product quality improving from R&D, by means of (19), (77) and (117), we obtain:

$$x_c - x_a = B_{19} > 0 \qquad \forall\ h,\gamma \in (0,1) \qquad \text{(A99)}$$

$$x_b - x_c = B_{20} > 0 \qquad \forall\ h,\gamma \in (0,1) \qquad \text{(A100)}$$

Where, B_{19}, $B_{20} > 0\ \forall\ h,\gamma \in (0,1)$[22] and their 3D plots are respectively the following:

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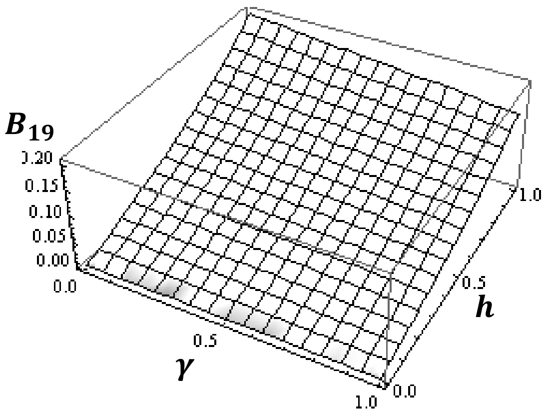
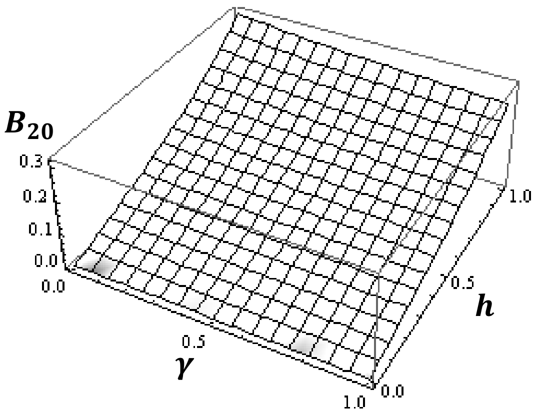
[21] The mathematical expression of B_{17} and B_{18} are left out because of their wide extent. They are available by the authors upon request.





Summarizing the above results, we conclude that:

$$x_b > x_c > x_a \qquad \forall\ h,\gamma \in (0,1) \qquad \text{(A101)}$$

A.13. Proof of Proposition 14

Let us now proceed to the comparative analysis of Consumer Surplus (*CS*) and Union Rents (*UR*) under each of the three proposed market structures in the present paper.

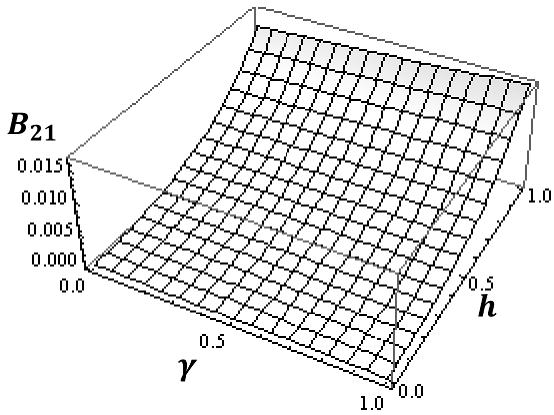
- Regarding Consumer Surplus, by means of (50), (82) and (118), we obtain:

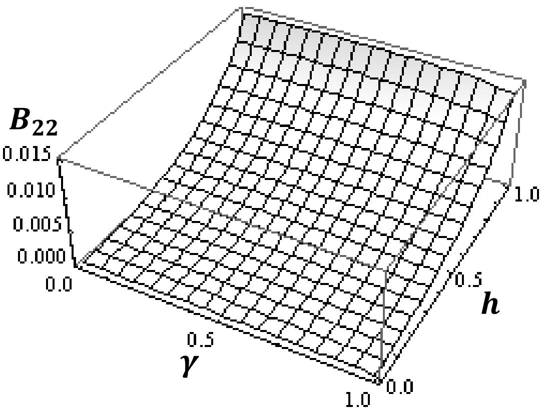
$$CS_c - CS_a = B_{21} > 0 \qquad \forall\ h,\gamma \in (0,1) \qquad \text{(A102)}$$

$$CS_b - CS_c = B_{22} > 0 \qquad \forall\ h,\gamma \in (0,1) \qquad \text{(A103)}$$

Where, B_{21}, $B_{22} > 0\ \forall\ h,\gamma \in (0,1)$[23] and their 3D plots are respectively the following:

[22] The mathematical expression of B_{21} and B_{20} are left out because of their wide extent. They are available by the authors upon request.
[23] The mathematical expression of B_{21} and B_{22} are left out because of their wide extent. They are available by the authors upon request.





Summarizing the above results, we conclude that:

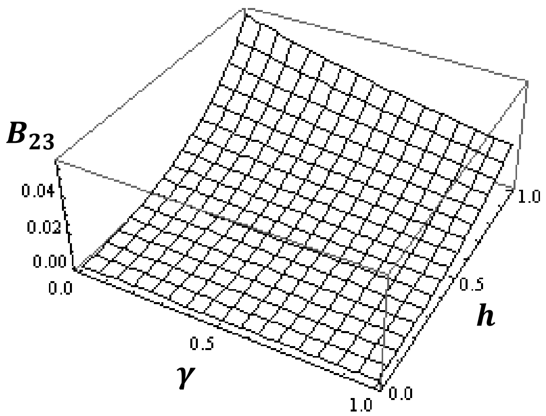
$$CS_b > CS_c > CS_a \qquad \forall \ h, \gamma \in (0,1) \qquad \text{(A104)}$$

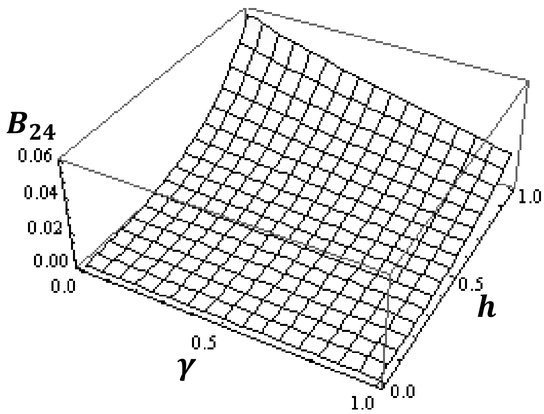
- Regarding Union Rents, by means of (49), (84) and (120), we obtain:

$$UR_c - UR_a = \ B_{23} > 0 \qquad \forall \ h, \gamma \in (0,1) \qquad \text{(A105)}$$

$$UR_b - UR_c = B_{24} > 0 \qquad \forall \ h, \gamma \in (0,1) \qquad \text{(A106)}$$

Where, B_{23}, $B_{24} > 0 \ \forall \ h, \gamma \in (0,1)$[24] and their 3D plots are respectively the following:





Summarizing the above results, we conclude that:

$$UR_b > UR_c > UR_a \qquad \forall \ h, \gamma \in (0,1) \qquad \text{(A107)}$$

[24] The mathematical expression of B_{23} and B_{24} are left out because of their wide extent. They are available by the authors upon request.

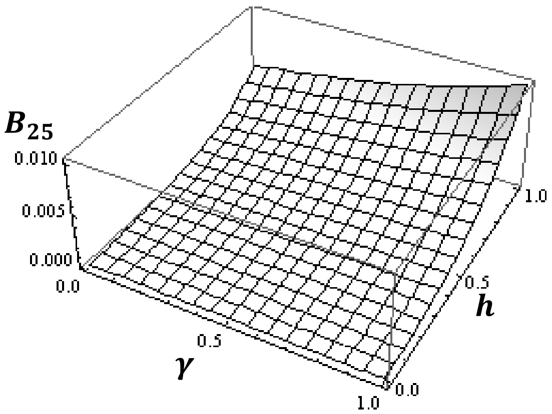
A.14. Proof of Proposition 15

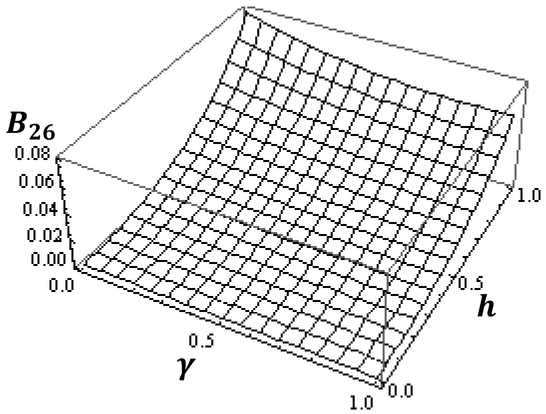
By means of (51), (83) and (119), a comparative analysis of Producer Surplus under each of the three proposed market structures, give the following results:

$$PS_a - PS_c = B_{25} > 0 \qquad \forall\ h, \gamma \in (0,1) \qquad \text{(A108)}$$

$$PS_b - PS_a = B_{26} > 0 \qquad \forall\ h, \gamma \in (0,1) \qquad \text{(A109)}$$

Where, $B_{25}, B_{26} > 0\ \forall\ h, \gamma \in (0,1)$[25] and their 3D plots are respectively the following:





Summarizing the above findings, we conclude that:

$$PS_b > PS_a > PS_c \qquad \forall\ h, \gamma \in (0,1) \qquad \text{(A110)}$$

[25] The mathematical expression of B_{25} and B_{26} are left out because of their wide extent. They are available by the authors upon request.

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